IEEE Standard for Ethernet

SECTION FIVE

This section includes Clause 56 through Clause 77 and Annex 57A through Annex 76A.

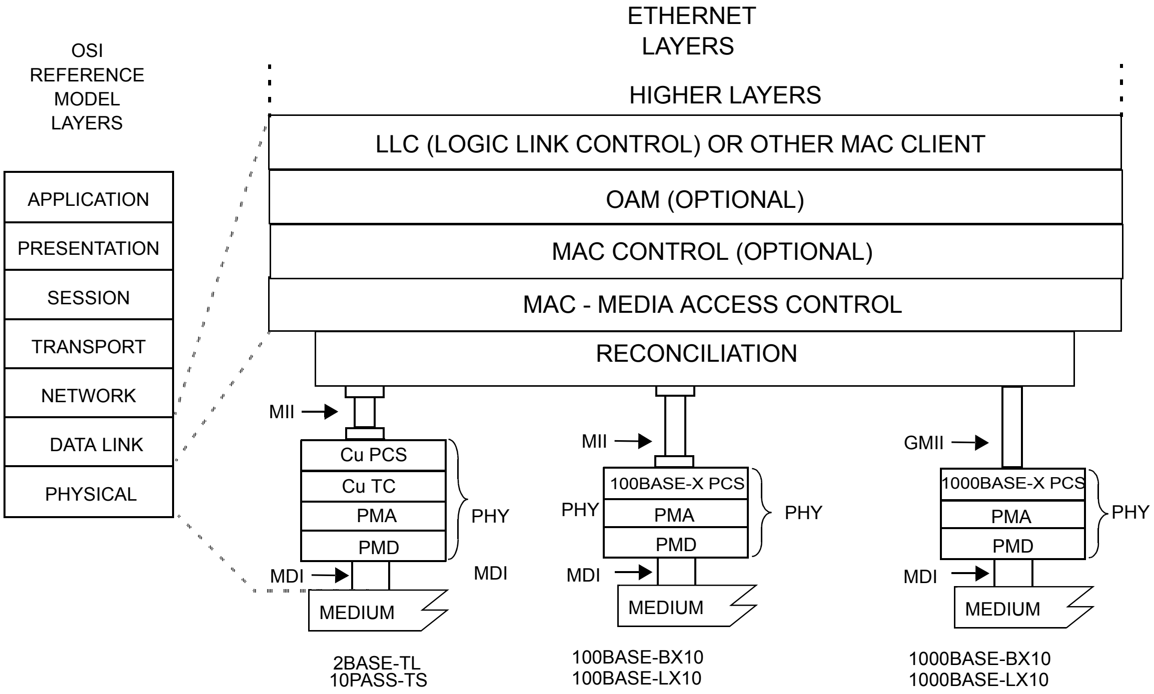
Contents

64. Multipoint MAC Control 290

56. Introduction to Ethernet for subscriber access networks

56.1 Overview

Ethernet for subscriber access networks, also referred to as “Ethernet in the First Mile,” or EFM, combines a minimal set of extensions to the IEEE 802.3 Media Access Control (MAC) and MAC Control sublayers with a family of Physical Layers. These Physical Layers include optical fiber and voice grade copper cable Physical Medium Dependent sublayers (PMDs) for point-to-point (P2P) connections in subscriber access networks. EFM also introduces the concept of Ethernet Passive Optical Networks (EPONs), in which a point-to-multipoint (P2MP) network topology is implemented with passive optical splitters, along with extensions to the MAC Control sublayer and Reconciliation sublayer as well as optical fiber PMDs to support this topology. In addition, a mechanism for network Operations, Administration, and Maintenance (OAM) is included to facilitate network operation and troubleshooting. 100BASE-LX10 extends the reach of 100BASE-X to achieve 10 km over conventional single-mode two-fiber cabling. The relationships between these EFM elements and the ISO/IEC Open System Interconnection (OSI) reference model are shown in Figure 56–1 for point-to-point topologies, Figure 56–2 for 1G-EPON topologies, Figure 56–3 for 10/10G-EPON topologies, and Figure 56–4 for 10/1G-EPON topologies.



GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
MII = MEDIA INDEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION, AND MAINTENANCE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 56–1—Architectural positioning of EFM: P2P Topologies

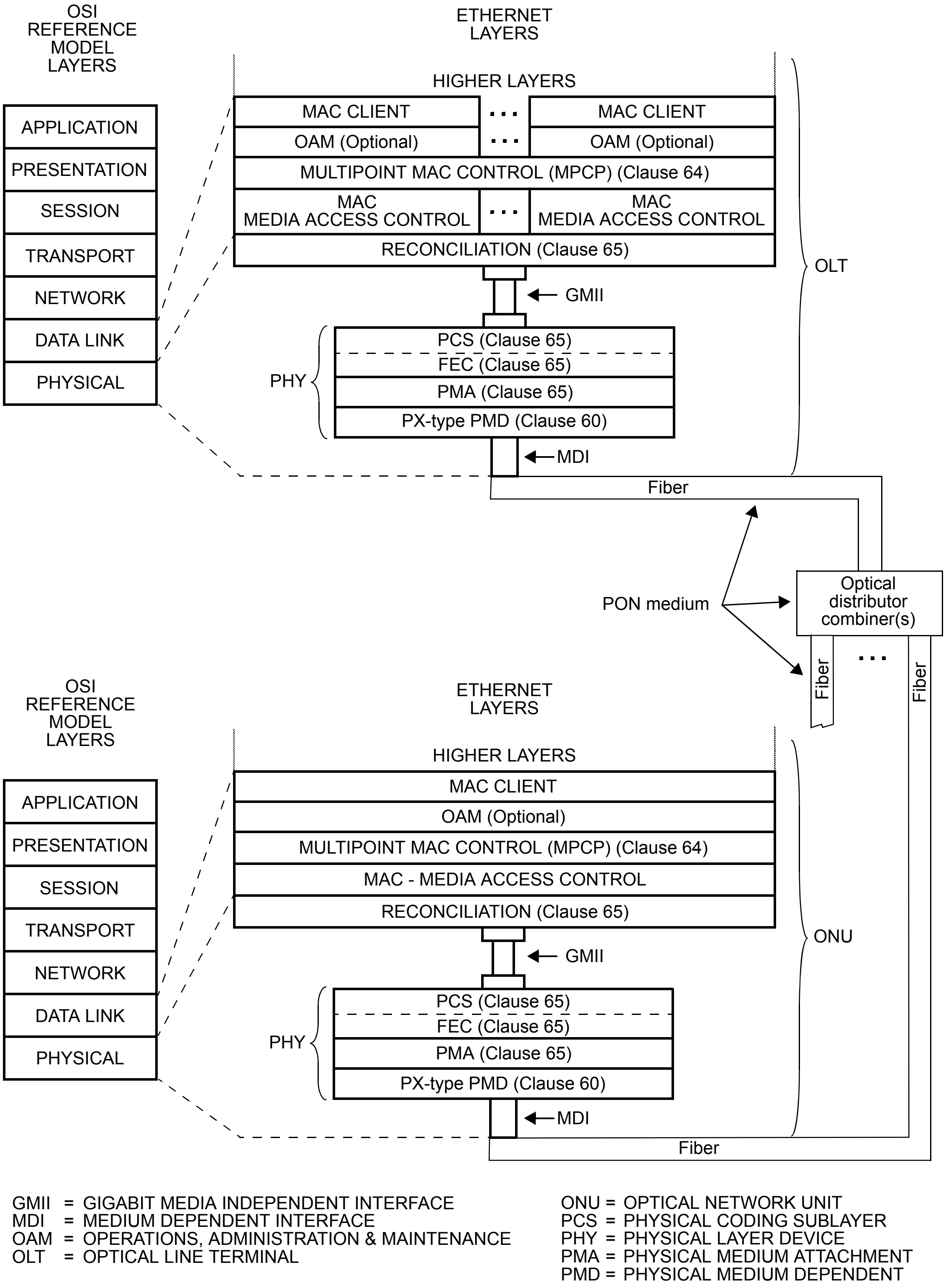
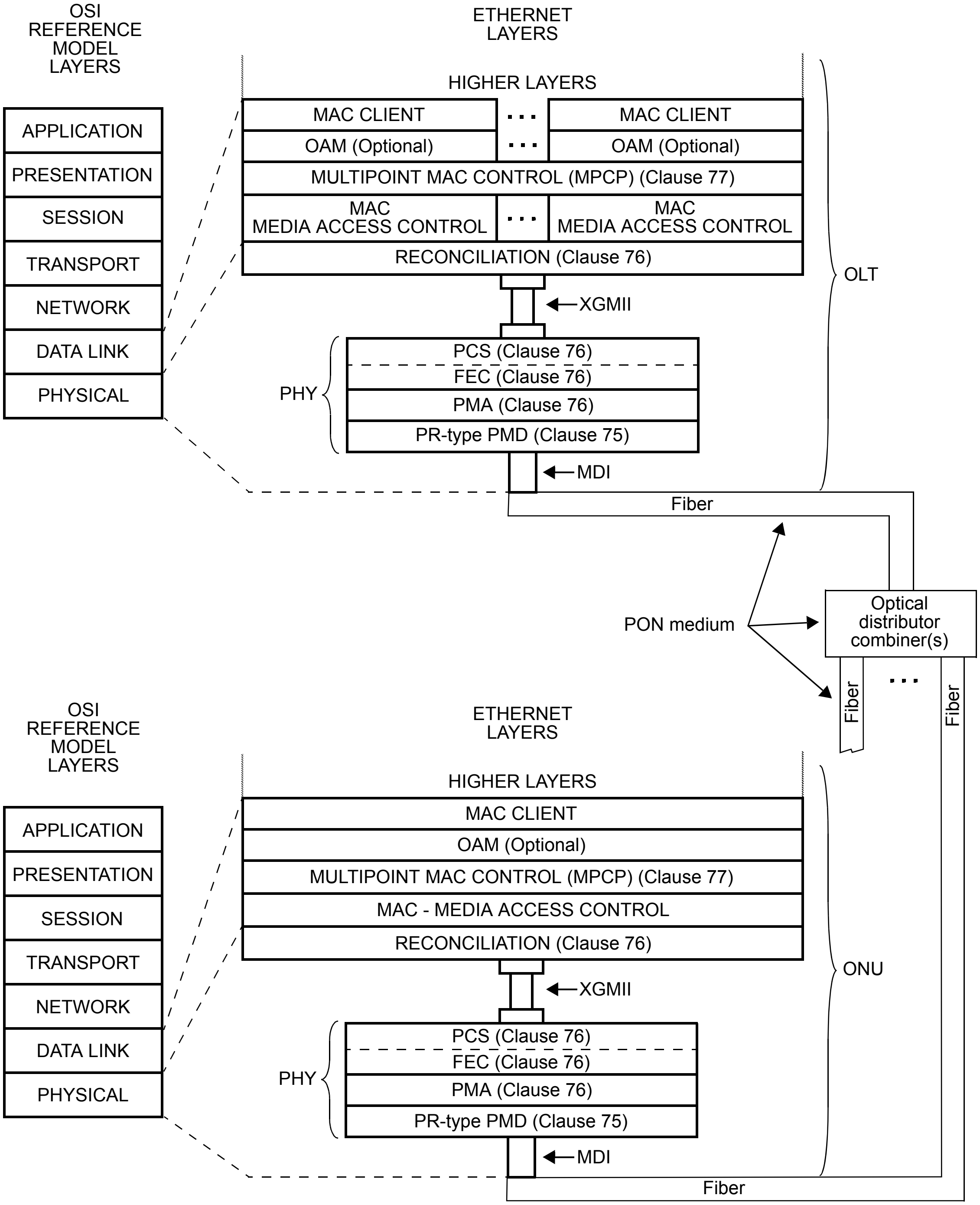


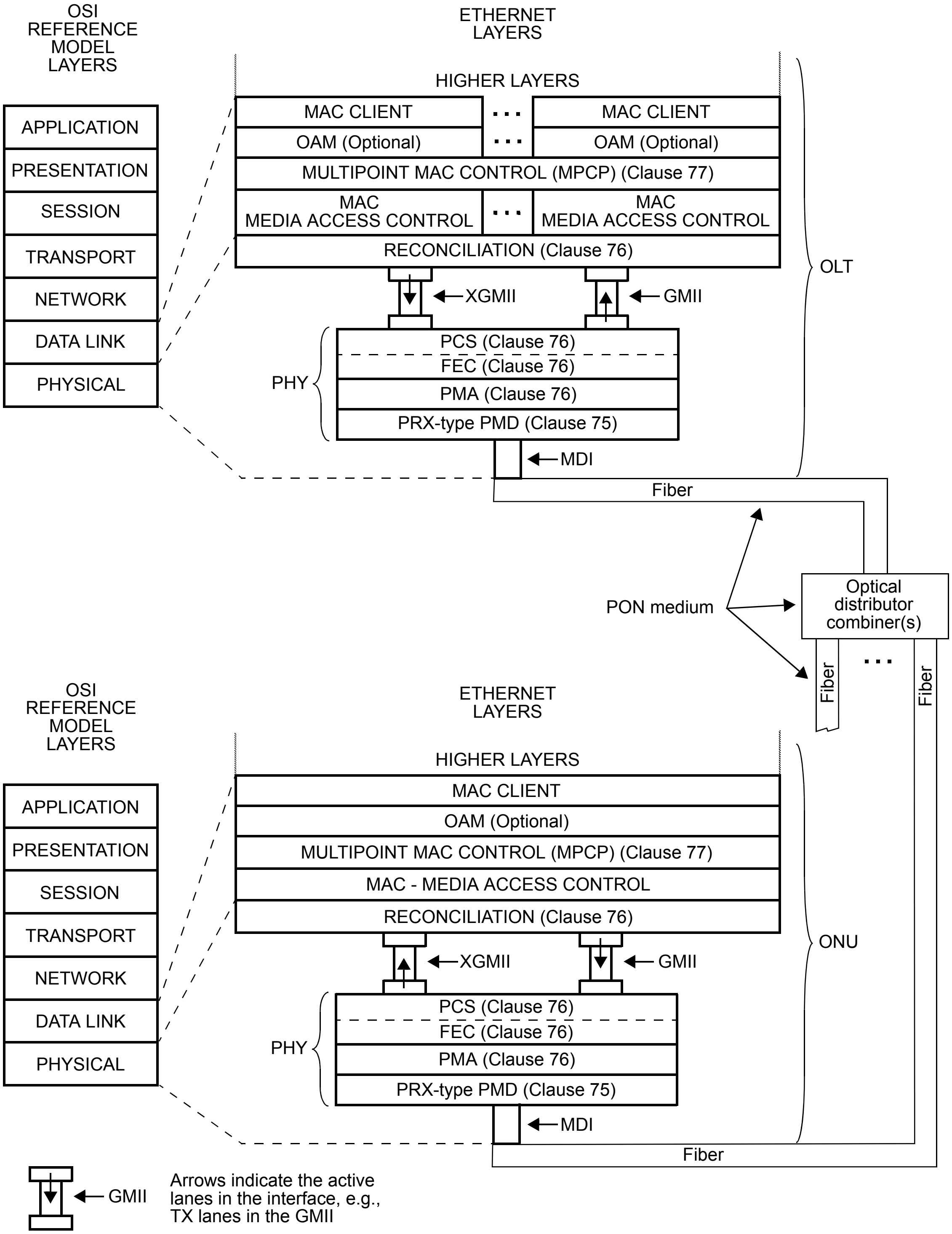
**Figure 56–2—Architectural positioning of EFM:
P2MP 1G-EPON architecture (1 Gb/s downstream, 1 Gb/s upstream)**



XGMII= 10 GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION & MAINTENANCE
OLT = OPTICAL LINE TERMINAL

ONU = OPTICAL NETWORK UNIT
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 56–3—Architectural positioning of EFM: P2MP 10/10G–EPON architecture (10 Gb/s downstream, 10 Gb/s upstream)



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PMD = PHYSICAL MEDIUM DEPENDENT

Figure 56–4—Architectural positioning of EFM: P2MP 10/1G–EPON architecture (10 Gb/s downstream, 1 Gb/s upstream)

An important characteristic of EFM is that only full duplex links are supported. A simplified full duplex MAC is defined in Annex 4A for use in EFM networks. P2MP applications must use this simplified full duplex MAC. EFM Copper applications may use either this simplified full duplex MAC or the Clause 4 MAC operating in half duplex mode as described in 61.1.4.1.2. All other EFM P2P applications may use either this simplified full duplex MAC or the Clause 4 MAC operating in full duplex mode.

The EFM architecture is extended in Clause 75 and Clause 76 by the addition of 10G–EPON. 10G–EPON includes the 10/10G-EPON (10 Gb/s downstream and 10 Gb/s upstream) as well as 10/1G-EPON (10 Gb/s downstream and 1 Gb/s upstream) PONs.

56.1.1 Summary of P2P sublayers

EFM P2P supports operation at several different bit rates, depending on the characteristics of the underlying medium. In the case of point-to-point optical fiber media, bit rates of 100 Mb/s and 1000 Mb/s are supported, using the 100BASE-X and 1000BASE-X Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayers defined in 66.1 and 66.2, respectively. In the case of point-to-point copper, EFM supports a variety of bit rates, depending on the span and the signal-to-noise ratio (SNR) characteristics of the medium as described in Clause 61 through Clause 63. 2BASE-TL supports a nominal bit rate of 2 Mb/s at a nominal reach of 2700 meters.[1] 10PASS-TS supports a nominal bit rate of 10 Mb/s at a nominal reach of 750 meters.[2]

56.1.2 Summary of P2MP sublayers

For P2MP optical fiber topologies, EFM supports two systems:

a) PON with a nominal bit rate of 1000 Mb/s in both downstream and upstream directions (1G-EPON), shared amongst the population of Optical Network Units (ONUs) attached to the P2MP topology. The P2MP PHYs use the 1000BASE-PX Physical Coding Sublayer (PCS), the Physical Medium Attachment (PMA) sublayer defined in Clause 65 and an optional forward error correction (FEC) function defined in Clause 65.
b) PON with a nominal bit rate of 10 Gb/s in both the downstream and upstream directions (10/10G-EPON) as well as PON with a nominal bit rate of 10 Gb/s in the downstream direction and 1 Gb/s in the upstream direction (10/1G-EPON), shared amongst the population of ONUs attached to the P2MP topology. The P2MP PHYs for the 10/10G-EPON use the 10GBASE-PR PCS and PMA (see Clause 75). The P2MP PHYs for 10/1G-EPON use the 10GBASE-PRX PCS and PMA (see Clause 76). EPONs using a nominal 10 Gb/s bit rate use a mandatory FEC function defined in Clause 76 in any direction running at the 10 Gb/s bit rate.

56.1.2.1 Multipoint MAC Control Protocol (MPCP)

The Multipoint MAC Control Protocol (MPCP) for 1G-EPON uses messages, state diagrams, and timers, as defined in Clause 64, to control access to a P2MP topology, while Clause 77 defines the messages, state diagrams, and timers required to control access to a P2MP topology in 10G-EPON. The issues related to coexistence of 1G-EPON and 10G-EPON on the same fiber plant are described in 77.4.

Every P2MP topology consists of one Optical Line Terminal (OLT) plus one or more ONUs, as shown in Figure 56–2, Figure 56–3, and Figure 56–4, for 1G-EPON, 10/10G-EPON and 10/1G-EPON, respectively. One of several instances of the MPCP in the OLT communicates with the instance of the MPCP in the ONU. A pair of MPCPs that communicate between the OLT and ONU are a distinct and associated pair.

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[1] Refer to Annex 63B for a more detailed discussion of bit rates and reach.

[2] Refer to Annex 62B for a more detailed discussion of bit rates and reach.

56.1.2.2 Reconciliation Sublayer (RS) and media independent interfaces

The Clause 22 RS and MII, Clause 35 RS and GMII, and Clause 46 RS and XGMII are all employed for the same purpose in EFM, that being the interconnection between the MAC sublayer and the PHY sublayers. Extensions to the Clause 35 RS for P2MP topologies are described in Clause 65, while the RS for 10G-EPON P2MP topologies is described in Clause 76.

The combination of MPCP and the extension of the Reconciliation Sublayer (RS) for P2P Emulation allows an underlying P2MP network to appear as a collection of point-to-point links to the higher protocol layers (at and above the MAC Client).

The MPCP achieves this by providing a Logical Link Identification (LLID) in each packet by replacing two octets of the preamble.

This is described in Clause 65 for EPON and in Clause 76 for 10G-EPON. EFM Copper links use the MII of Clause 22 operating at 100 Mb/s. This is described in 61.1.4.1.2.

56.1.3 Physical Layer signaling systems

EFM extends the family of 100BASE-X Physical Layer signaling systems to include 100BASE-LX10 (long wavelength), plus the combination of the 100BASE-BX10-D (Bidirectional long wavelength Downstream) and the 100BASE-BX10-U (Bidirectional long wavelength Upstream), as defined in Clause 58. All of these systems employ the 100BASE-X PCS and PMA as defined in Clause 66.

EFM also extends the family of 1000BASE-X Physical Layer signaling systems to include 1000BASE-LX10 (long wavelength), plus the combination of the 1000BASE-BX10-D (Bidirectional long wavelength Downstream) and the 1000BASE-BX10-U (Bidirectional long wavelength Upstream), as defined in Clause 59. All of these systems employ the 1000BASE-X PCS and PMA as defined in Clause 66. 1000BASE-LX10 is interoperable with 1000BASE-LX on single-mode and multimode fiber, and offers greater reach than 1000BASE-LX on single-mode fiber.

For P2MP topologies, EFM introduces a family of Physical Layer signaling systems that are derived from 1000BASE-X, but which include extensions to the RS, PCS and PMA, along with an optional forward error correction (FEC) capability, as defined in Clause 65. The family of P2MP Physical Layer signaling systems includes the combination of 1000BASE-PX10-D (Passive Optical Network Downstream 10 km), plus 1000BASE-PX10-U (PON Upstream 10 km), the combination of 1000BASE-PX20-D (PON Downstream 20 km) plus 1000BASE-PX20-U (PON Upstream 20 km), the combination of 1000BASE-PX30-D (PON Downstream 20 km) plus 1000BASE-PX30-U (PON Upstream 20 km), and the combination of 1000BASE-PX40-D (PON Downstream 20 km) plus 1000BASE-PX40-U (PON Upstream 20 km), as defined in Clause 60.

Additionally, EFM introduces a family of Physical Layer signaling systems which are derived from 10GBASE–R, but which include RS, PCS and PMA sublayers adapted for 10G-EPON, along with a mandatory FEC capability, as defined in Clause 76. All of these systems employ the PMD defined in Clause 75. The family of P2MP Physical Layer signaling systems utilizes 10GBASE-R signaling for the downstream direction while supporting both 10GBASE-R and 1000BASE-X upstream signaling in the following series of PMD combinations:

a) 10GBASE–PR–D1 and 10GBASE–PR–U1, creating a PR10 power budget, with 10 Gb/s downstream and 10 Gb/s upstream data rates, supporting a reach of at least 10 km and a split ratio of at least 1:16.
b) 10GBASE–PR–D2 and 10GBASE–PR–U1, creating a PR20 power budget, with 10 Gb/s downstream and 10 Gb/s upstream data rates, supporting a reach of at least 20 km and a split ratio of at least 1:16 or the reach of at least 10 km and the split ratio of at least 1:32.

c) 10GBASE–PR–D3 and 10GBASE–PR–U3, creating a PR30 power budget, with 10 Gb/s downstream and 10 Gb/s upstream data rates, supporting a reach of at least 20 km and a split ratio of at least 1:32.
d) 10GBASE–PR–D4 and 10GBASE–PR–U4, creating a PR40 power budget, with 10 Gb/s downstream and 10 Gb/s upstream data rates, supporting a reach of at least 20 km and a split ratio of at least 1:64.
e) 10/1GBASE–PRX–D1 and 10/1GBASE–PRX–U1, creating a PRX10 power budget, with 10 Gb/s downstream and 1 Gb/s upstream data rates, supporting a reach of at least 10 km and a split ratio of at least 1:16.
f) 10/1GBASE–PRX–D2 and 10/1GBASE–PRX–U2, creating a PRX20 power budget, with 10 Gb/s downstream and 1 Gb/s upstream data rates, supporting a reach of at least 20 km and a split ratio of at least 1:16.
g) 10/1GBASE–PRX–D3 and 10/1GBASE–PRX–U3, creating a PRX30 power budget, with 10 Gb/s downstream and 1 Gb/s upstream data rates, supporting a reach of at least 20 km and a split ratio of at least 1:32.
h) 10/1GBASE–PRX–D4 and 10/1GBASE–PRX–U4, creating a PRX40 power budget, with 10 Gb/s downstream and 1 Gb/s upstream data rates, supporting a reach of at least 20 km and a split ratio of at least 1:64.

All 10G-EPON PMDs are defined in Clause 75.

For copper cabling, EFM introduces a family of Physical Layer signaling systems. There are two distinct signaling systems specified for copper cabling. Both of them share a set of common functions and interfaces as described in Clause 61. Clause 61 also includes an optional specification that supports combined operation on multiple copper pairs, affording greater data rate capability for a given link span. Underlying these functions, two Physical Layer signaling system specific PMAs and PMDs are described in Clause 62 and Clause 63. Non-loaded cable is a requirement of the signaling methods employed.

For high-speed applications, the 10PASS-TS signaling system is defined in Clause 62. 10PASS-TS relies on a technique referred to as Frequency Division Duplexing (FDD) to accomplish full duplex communication on a single wire pair. 10PASS-TS is a passband signaling system derived from the Very high-speed Digital Subscriber Line (VDSL) standard defined in American National Standard T1.424, using Multiple Carrier Modulation (MCM, also referred to as Discrete Multi-Tone or DMT). This PHY supports a nominal full duplex data rate of 10 Mb/s, hence the identifier 10PASS-TS. For the 10PASS-TS PHY, two subtypes are defined: 10PASS-TS-O and 10PASS-TS-R. A connection can be established only between a 10PASS-TS-O PHY on one end of the voice-grade copper line, and a 10PASS-TS-R PHY on the other end. In public networks, a 10PASS-TS-O PHY is used at a central office (CO), a cabinet, or other centralized distribution point; a 10PASS-TS-R PHY is used at the subscriber premises. In private networks, the network administrator will designate one end of each link as the network end. A PHY implementation may be equipped to support both subtypes and provide means to be configured as a 10PASS-TS-O or a 10PASS-TS-R.

For long distance applications, the 2BASE-TL signaling system is defined in Clause 63. 2BASE-TL is a baseband signaling system derived from the Single-Pair High-Speed Digital Subscriber Line (SHDSL) standards defined by ITU-T. The 2BASE-TL PMD supports a nominal full duplex data rate of approximately 2 Mb/s. As is the case with the 10PASS-TS PHY, the 2BASE-TL PHY consists of two subtypes: 2BASE-TL-O (network end) and 2BASE-TL-R (subscriber end).

System considerations for Ethernet subscriber access networks are described in Clause 67.

Specifications unique to the operation of each Physical Layer device are shown in Table 56–1.

Table 56–2 specifies the correlation between nomenclature and clauses for P2P systems, while Table 56–3 specifies the correlation between nomenclature and clauses for P2MP systems. A complete implementation conforming to one or more nomenclatures meets the requirements of the corresponding clauses.

Table 56–1—Summary of EFM Physical Layer signaling systems

Name	Location	Rate[a]	Nominal reach (km)	Medium	Clause
100BASE-LX10	ONU/OLT[b]	100 Mb/s	10	Two single-mode fibers	58
100BASE-BX10-D	OLT	100 Mb/s	10	One single-mode fiber	58
100BASE-BX10-U	ONU				
1000BASE-LX10	ONU/OLT[b]	1000 Mb/s	10 0.55	Two single-mode fibers Two multimode fibers	59
1000BASE-BX10-D	OLT	1000 Mb/s	10	One single-mode fiber	59
1000BASE-BX10-U	ONU				
1000BASE-PX10-D	OLT	1000 Mb/s	10	One single-mode fiber PON	60
1000BASE-PX10-U	ONU				
1000BASE-PX20-D	OLT	1000 Mb/s	20	One single-mode fiber PON	60
1000BASE-PX20-U	ONU				
1000BASE-PX30-D	OLT	1000 Mb/s	20	One single-mode fiber PON	60
1000BASE-PX30-U	ONU				
1000BASE-PX40-D	OLT	1000 Mb/s	20	One single-mode fiber PON	60
1000BASE-PX40-U	ONU				
10/1GBASE-PRX-D1	OLT	10 Gb/s (tx) 1000 Mb/s (rx)	10	One single-mode fiber PON	75
10/1GBASE-PRX-U1	ONU	1000 Mb/s (tx) 10 Gb/s (rx)			
10/1GBASE-PRX-D2	OLT	10 Gb/s (tx) 1000 Mb/s (rx)	20	One single-mode fiber PON	75
10/1GBASE-PRX-U2	ONU	1000 Mb/s (tx) 10 Gb/s (rx)			
10/1GBASE-PRX-D3	OLT	10 Gb/s (tx) 1000 Mb/s (rx)	20	One single-mode fiber PON	75
10/1GBASE-PRX-U3	ONU	1000 Mb/s (tx) 10 Gb/s (rx)			
10/1GBASE-PRX-D4	OLT	10 Gb/s (tx) 1000 Mb/s (rx)	20	One single-mode fiber PON	75
10/1GBASE-PRX-U4	ONU	1000 Mb/s (tx) 10 Gb/s (rx)			
10GBASE-PR-D1	OLT	10 Gb/s	10	One single-mode fiber PON	75
10GBASE-PR-U1	ONU				
10GBASE-PR-D2	OLT	10 Gb/s	20	One single-mode fiber PON	75
10GBASE-PR-U1	ONU				

Table 56–1—Summary of EFM Physical Layer signaling systems *(continued)*

Name	Location	Rate[a]	Nominal reach (km)	Medium	Clause
10GBASE-PR-D3	OLT	10 Gb/s	20	One single-mode fiber PON	75
10GBASE-PR-U3	ONU				
10GBASE-PR-D4	OLT	10 Gb/s	20	One single-mode fiber PON	75
10GBASE-PR-U4	ONU				
10PASS-TS-O	CO[c]	10 Mb/s[d]	0.75[e]	One or more pairs of voice grade copper cable	62
10PASS-TS-R	Subscriber[c]				
2BASE-TL-O	CO[c]	2 Mb/s[f]	2.7[g]	One or more pairs of voice grade copper cable	63
2BASE-TL-R	Subscriber[c]				

[a] For 10/1G-EPON Physical Layer signaling systems transmit rate is denoted with the abbreviation “(tx)” to the location whereas the receive rate is denoted with the abbreviation “(rx)”.
[b] Symmetric
[c] In private networks, the network administrator designates one end of each link as the network end.
[d] Nominal rate stated at the nominal reach. Rate may vary depending on plant. Refer to Annex 62B for more information.
[e] Reach may vary depending on plant. Refer to Annex 62B for further information.
[f] Nominal rate stated at the nominal reach. Rate may vary depending on plant. Refer to Annex 63B for more information.
[g] Reach may vary depending on plant. Refer to Annex 63B for further information.

Table 56–2—Nomenclature and clause correlation for P2P systems

Nomenclature	Clause									
	57	58		59		61	62	63	66	
	OAM	100BASE-LX10 PMD	100BASE-BX10 PMD	1000BASE-LX10 PMD	1000BASE-BX10 PMD	Cu PCS	10PASS-TS PMA & PMD	2BASE-TL PMA & PMD	100BASE-X PCS, PMA	1000BASE-X PCS, PMA
2BASE-TL	O[a]					M		M		
10PASS-TS	O					M	M			
100BASE-LX10	O	M							M	
100BASE-BX10	O		M						M	
1000BASE-LX10	O			M						M
1000BASE-BX10	O				M					M

[a] O = Optional, M = Mandatory

56.1.4 Management

Managed objects, attributes, and actions are defined for all EFM components in Clause 30.

In addition to the management objects, attributes, and actions defined in Clause 30, EFM introduces Operations, Administration, and Maintenance (OAM) for subscriber access networks to Ethernet. OAM, as defined in Clause 57, includes a mechanism for communicating management information using OAM

Table 56–3—Nomenclature and clause correlation for P2MP systems[a]

Nomenclature	Clause											
	57	60				64	65		66	75	76	77
	OAM	1000BASE-PX10 PMD	1000BASE-PX20 PMD	1000BASE-PX30 PMD	1000BASE-PX40 PMD	P2MP MPMC	P2MP RS, PCS, PMA	FEC	1000BASE-X PCS, PMA	10/1GBASE–PRX or 10GBASE-PR PMDs	P2MP RS, PCS, PMA, FEC	10G-EPON P2MP MPMC
1000BASE-PX10-D	O	M				M	M	O	M			
1000BASE-PX10-U	O	M				M	M	O				
1000BASE-PX20-D	O		M			M	M	O	M			
1000BASE-PX20-U	O		M			M	M	O				
1000BASE-PX30-D	O			M		M	M	O	M			
1000BASE-PX30-U	O			M		M	M	O				
1000BASE-PX40-D	O				M	M	M	O	M			
1000BASE-PX40-U	O				M	M	M	O				
10/1GBASE-PRX-D1	O			M		M				M	M	M
10/1GBASE-PRX-U1	O			M		M				M	M	M
10/1GBASE-PRX-D2	O				M	M				M	M	M
10/1GBASE-PRX-U2	O				M	M				M	M	M
10/1GBASE-PRX-D3	O					M				M	M	M
10/1GBASE-PRX-U3	O					M				M	M	M
10/1GBASE-PRX-D4	O					M				M	M	M
10/1GBASE-PRX-U4	O					M				M	M	M
10GBASE-PR-D1	O									M	M	M
10GBASE-PR-U1	O									M	M	M
10GBASE-PR-D2	O									M	M	M
10GBASE-PR-D3	O									M	M	M
10GBASE-PR-U3	O									M	M	M
10GBASE-PR-D4	O									M	M	M
10GBASE-PR-U4	O									M	M	M

[a] O = Optional, M = Mandatory

frames, as well as functions for performing low-level diagnostics on a per link basis in an Ethernet subscriber access network.

56.1.5 Unidirectional transmission

In contrast to previous editions of IEEE Std 802.3, in certain circumstances a DTE is allowed to transmit frames while not receiving a satisfactory signal. It is necessary for a 1000BASE-PX-D OLT to do this to bring a PON into operation (although it is highly inadvisable for a 1000BASE-PX-U ONU to transmit without receiving). Clause 66 describes optional modifications to the 100BASE-X PHY, 1000BASE-X PHY and 10GBASE RS so that a DTE may signal remote fault using OAMPDUs. When unidirectional operation is not enabled, the sublayers in Clause 66 are precisely the same as their equivalents in Clause 24, Clause 36, and Clause 46.

56.2 State diagrams

State diagrams take precedence over text.

The conventions of 1.2 are adopted, along with the extensions listed in 21.5.

56.3 Protocol implementation conformance statement (PICS) proforma

The supplier of a protocol implementation that is claimed to conform to any part of IEEE 802.3, Clause 57 through Clause 66, demonstrates compliance by completing a protocol implementation conformance statement (PICS) proforma.

A completed PICS proforma is the PICS for the implementation in question. The PICS is a statement of which capabilities and options of the protocol have been implemented. A PICS is included at the end of each clause as appropriate. Each of the EFM PICS conforms to the same notation and conventions used in 100BASE-T (see 21.6).

57. Operations, Administration, and Maintenance (OAM)

57.1 Overview

57.1.1 Scope

This clause defines the Operations, Administration, and Maintenance (OAM) sublayer, which provides mechanisms useful for monitoring link operation such as remote fault indication and remote loopback control. In general, OAM provides network operators the ability to monitor the health of the network and quickly determine the location of failing links or fault conditions. The OAM described in this clause provides data link layer mechanisms that complement applications that may reside in higher layers.

OAM information is conveyed in Slow Protocol frames (see Annex 57A) called OAM Protocol Data Units (OAMPDUs). OAMPDUs contain the appropriate control and status information used to monitor, test and troubleshoot OAM-enabled links. OAMPDUs traverse a single link, being passed between peer OAM entities, and as such, are not forwarded by MAC clients (e.g., bridges or switches).

OAM does not include functions such as station management, bandwidth allocation, or provisioning functions, which are considered outside the scope of this standard.

For the remainder of this clause, the term OAM is specific to the link level OAM described here.

57.1.2 Summary of objectives and major concepts

This subclause provides details and functional requirements for the OAM objectives:

a) Remote Failure Indication
    1) A mechanism is provided to indicate to a peer that the receive path of the local DTE is non-operational.
    2) Physical Layer devices using Clause 66 may support unidirectional operation that allows OAM remote failure indication during fault conditions.
    3) Subscriber access Physical Layer devices using Clause 65 support unidirectional operation in the direction from OLT to ONU that allows OAM remote failure indication from OLT during fault conditions.
    4) Physical Layer devices other than those listed above do not support unidirectional operation allowing OAM remote failure indication during fault conditions. Some Physical Layer devices have specific remote failure signaling mechanisms in the Physical Layer.
b) Remote Loopback—A mechanism is provided to support a data link layer frame-level loopback mode.
c) Link Monitoring
    1) A mechanism is provided to support event notification that permits the inclusion of diagnostic information.
    2) A mechanism is provided to support polling of any variable in the Clause 30 MIB.
d) Miscellaneous
    1) Implementation and activation of OAM is optional.
    2) A mechanism is provided that performs OAM capability discovery.
    3) An extension mechanism is provided and made available for higher layer management applications.

These objectives support a subset of the user-plane OAM requirements found in ITU-T Y.1730 [B51].

57.1.3 Summary of non-objectives

This subclause explicitly lists certain functions that are not addressed by OAM. These functions, while valuable, do not fall within the scope of this standard.

a) Management functions not pertaining to a single link such as protection switching and station management are not covered by this clause. Such functions could be addressed using the extension mechanism.
b) Provisioning and negotiation functions such as bandwidth allocation, rate adaptation and speed/duplex negotiation are not supported by OAM.
c) Issues related to privacy of OAM data and authentication of OAM entities are beyond the scope of this standard.
d) The ability to set/write remote MIB variables is not supported.

57.1.4 Positioning of OAM within the IEEE 802.3 architecture

OAM comprises an optional sublayer between a superior sublayer (e.g., MAC client or optional Link Aggregation) and a subordinate sublayer (e.g., MAC or optional MAC Control sublayer). Figure 57–1 shows the relationship of the OAM sublayer to the ISO/IEC (IEEE) OSI reference model.

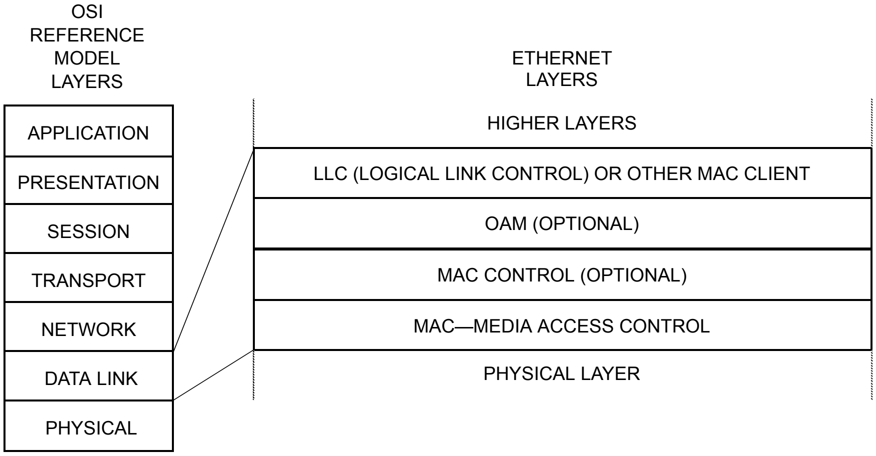

Figure 57–1—OAM sublayer relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

57.1.5 Compatibility considerations

57.1.5.1 Application

OAM is intended for point-to-point and emulated point-to-point IEEE 802.3 links. Implementation of OAM functionality is optional. A conformant implementation may implement the optional OAM sublayer for some ports within a system while not implementing it for other ports.

57.1.5.2 Interoperability between OAM capable DTEs

A DTE is able to determine whether or not a remote DTE has OAM functionality enabled. The OAM Discovery mechanism ascertains the configured parameters, such as maximum allowable OAMPDU size, and supported functions, such as OAM remote loopback, on a given link.

57.1.5.3 MAC Control PAUSE

MAC Control PAUSE, commonly referred to as Flow Control as defined in Annex 31B, inhibits the transmission of all MA_DATA.request service primitives, including OAMPDUs. This may delay or prevent the signaling of critical events such as unrecoverable failure conditions and link faults.

57.1.5.4 Interface to MAC Control client

MAC Control clients that generate MA_CONTROL.request service primitives (and which expect MA_CONTROL.indication service primitives in response) are not acted upon by the OAM sublayer. They communicate directly with the MAC Control entity as though no OAM sublayer exists.

57.1.5.5 Frame loss during OAM remote loopback

Invocations of OAM remote loopback may result in frame loss. OAM remote loopback is an intrusive operation that prevents a link from passing frames between the MAC client of the local DTE and the MAC client of the remote DTE. Refer to 57.2.11 for a complete description of OAM remote loopback operation.

57.1.6 State diagram conventions

Many of the functions specified in this clause are presented in state diagram notation. All state diagrams contained in this clause use the notation and conventions defined in 21.5. In the event of a discrepancy between the text description and the state diagram formalization of a function, the state diagrams take precedence.

57.2 Functional specifications

57.2.1 Interlayer service interfaces

Figure 57–2 depicts the usage of interlayer interfaces by the OAM sublayer.

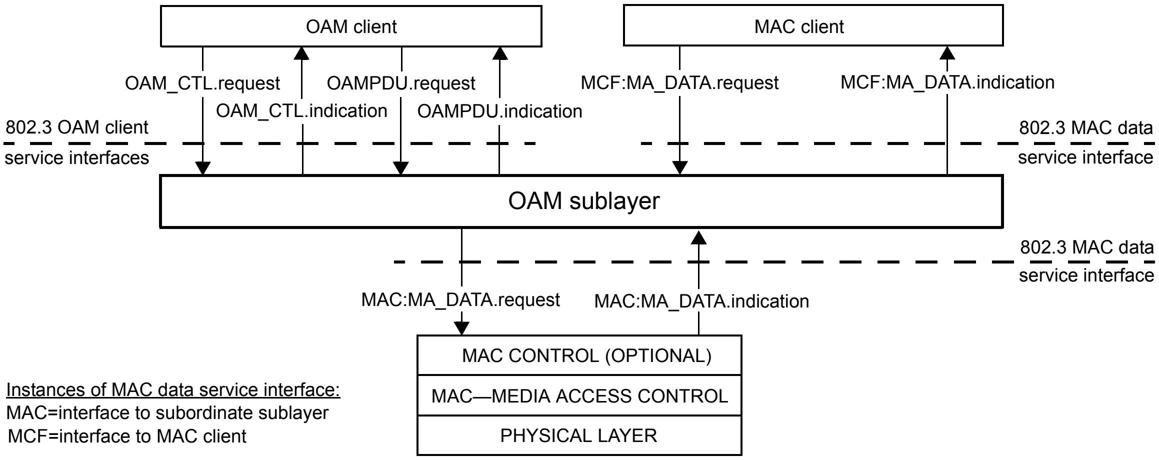

Figure 57–2—OAM sublayer support of interlayer service interfaces

57.2.2 Principles of operation

OAM employs the following principles and concepts:

a) The OAM sublayer presents a standard IEEE 802.3 MAC service interface to the superior sublayer. Superior sublayers include MAC client and Link Aggregation.
b) The OAM sublayer employs a standard IEEE 802.3 MAC service interface to the subordinate sublayer. Subordinate sublayers include MAC and MAC Control.
c) Frames from superior sublayers are multiplexed within the OAM sublayer with OAMPDUs.
d) The OAM sublayer parses received frames and passes OAMPDUs to the OAM client. In general, non-OAMPDUs are passed to the superior sublayer. When in OAM remote loopback mode, non-OAMPDUs are looped back to the subordinate sublayer. When the peer OAM entity is in OAM remote loopback mode, non-OAMPDUs are discarded by the OAM sublayer so that higher layer functions (e.g., bridging) do not process the looped back frames.
e) Knowledge of the underlying Physical Layer device is not required by the OAM sublayer.
f) OAMPDUs traverse a single link and are passed between OAM client entities or OAM sublayer entities. OAMPDUs are not forwarded by OAM clients.
g) OAM is extensible through the use of an Organization Specific OAMPDU, Organization Specific Information TLV, and Organization Specific Event TLV. These can be used for functions outside the scope of this standard.

57.2.3 Instances of the MAC data service interface

A superior sublayer such as the MAC client communicates with the OAM sublayer using the standard MAC data service interface specified in Clause 2. Similarly, the OAM sublayer communicates with a subordinate sublayer such as the MAC Control or MAC using the same standard service interfaces.

Since this clause uses two instances of the MAC data service interface, it is necessary to introduce a notation convention so that the reader can be clear as to which interface is being referred to at any given time. A prefix is therefore assigned to each service primitive, indicating which of the two interfaces is being invoked, as depicted in Figure 57–2. The prefixes are as follows:

a) MCF:, for primitives issued on the interface between the superior sublayer and the OAM sublayer (MCF is an abbreviation for MAC client frame)
b) MAC:, for primitives issued on the interface between the underlying subordinate sublayer (e.g., MAC) and the OAM sublayer

57.2.4 Responsibilities of OAM client

The OAM client plays an integral role in establishing and managing OAM on a link. The OAM client enables and configures the OAM sublayer entity. During the OAM Discovery process (see 57.3.2.1), the OAM client monitors received OAMPDUs from the remote DTE and based upon local and remote state and configuration settings allows OAM functionality to be enabled on the link.

After OAM has been established, the OAM client is responsible for adhering to the OAMPDU response rules. For example, the OAM client does not respond to illegal requests such as Variable Request and Loopback Control OAMPDUs from Passive DTEs. The OAM client is also expected to manage the OAM remote loopback mode (see 57.2.11). It does so by reacting to particular OAMPDUs and altering local configuration parameters.

Link events are signalled between peer OAM client entities. The OAM client transfers events by sending and receiving particular OAMPDUs. To increase the likelihood that a specific event is received by the remote DTE, the OAM client may send the event multiple times.

57.2.5 OAM client interactions

The OAM sublayer entity communicates with the OAM client using the following new interlayer service interfaces:

OAMPDU.request
OAMPDU.indication
OAM_CTL.request
OAM_CTL.indication

The OAMPDU.request, OAMPDU.indication, OAM_CTL.request and OAM_CTL.indication service primitives described in this subclause are mandatory.

57.2.5.1 OAMPDU.request

57.2.5.1.1 Function

This primitive defines the transfer of data from an OAM client entity to a peer OAM client entity.

57.2.5.1.2 Semantics of the service primitive

The semantics of the primitive are as follows:

```
OAMPDU.request          (
                        source_address,
                            flags,
                            code,
                            data
                            )
```

The source_address parameter specifies an individual MAC address. The flags parameter is used to create the Flags field within the OAMPDU to be transmitted. Only the indications corresponding to the Flags field bits 15:3 are contained in the flags parameter since the indications corresponding to Flags field bits 2:0 are contained in the OAM_CTL.request service primitive. The code parameter is used to create the Code field within the OAMPDU to be transmitted. The data parameter is used to create the Data field within the OAMPDU to be transmitted.

57.2.5.1.3 When generated

This primitive is generated by the OAM client entity whenever an OAMPDU is to be transferred to a peer entity. This can be in response to a request from the peer entity or from data generated internally to the OAM client.

57.2.5.1.4 Effect of receipt

The receipt of this primitive will cause the OAM sublayer entity to insert all OAMPDU specific fields, including DA, SA, Length/Type and Subtype, and pass the properly formed OAMPDU to the lower protocol layers for transfer to the peer OAM client entity according to the transmit rules as described in 57.3.2.2.6.

57.2.5.2 OAMPDU.indication

57.2.5.2.1 Function

This primitive defines the transfer of data from an OAM sublayer entity to an OAM client entity.

57.2.5.2.2 Semantics of the service primitive

The semantics of the primitive are as follows:

```
OAMPDU.indication        (
                                source_address,
                                flags,
                                code,
                                data
                                )
```

The source_address parameter is the MAC source address of the incoming OAMPDU. The flags parameter is the entire Flags field of the incoming OAMPDU. The code parameter is the Code field of the incoming OAMPDU. The data parameter is the Data field of the incoming OAMPDU.

57.2.5.2.3 When generated

This primitive is passed from the OAM sublayer entity to the OAM client entity to indicate the arrival of an OAMPDU to the local OAM sublayer entity that is destined for the OAM client. Such OAMPDUs are reported only if they are validly formed and received without error.

57.2.5.2.4 Effect of receipt

The effect of receipt of this primitive by the OAM client is unspecified.

57.2.5.3 OAM_CTL.request

57.2.5.3.1 Function

This primitive defines the transfer of control information from an OAM client entity to an OAM sublayer entity.

57.2.5.3.2 Semantics of the service primitive

The semantics of the primitive are as follows:

```
OAM_CTL.request          (
                         local_unidirectional,
                         local_link_status,
                         local_dying_gasp,
                         local_critical_event,
                         local_satisfied,
                         remote_state_valid,
                         remote_stable,
                         local_mux_action,
                         local_par_action,
                         information_data
                                )
```

When set, the local_unidirectional parameter is used to indicate the sending station supports transmission of OAMPDUs on unidirectional links as supported by some physical coding layers (see 57.2.12).

The local_link_status, local_dying_gasp, and local_critical_event parameters are used to indicate immediate event situations that should be transmitted to the peer OAM entity. The local_link_status parameter is used to convey the status of the link as determined by the underlying Physical Layer. When set to FAIL, the local_link_status parameter will cause the OAM sublayer entity to transmit an Information OAMPDU with the Link Fault bit of the Flags field set and no Information TLVs. The local_dying_gasp parameter is used to signal a local unrecoverable failure condition. When set, the local_dying_gasp parameter will cause the OAM sublayer to transmit an Information OAMPDU with the Dying Gasp bit of the Flags field set. The local_critical_event parameter is used to signal an unspecified critical link event condition. When set, the local_critical_event parameter will cause the OAM sublayer to transmit an Information OAMPDU with the Critical Event bit of the Flags field set.

The local_satisfied, remote_state_valid, and remote_stable parameters are used in the Discovery process. The local_satisfied parameter is set by the OAM client as a result of comparing its local configuration and the remote configuration found in the received Local Information TLV (see 57.3.2.1).

The local_mux_action and local_par_action parameters are used to control the state of the Multiplexer and Parser functions of the OAM sublayer (see 57.3.3 and 57.3.4).

The information_data parameter contains the Local Information TLV fields, and, if available, the Remote Information and Organization Specific Information TLV fields, to be included in Information OAMPDUs generated by the Transmit process (see 57.3.2.2).

57.2.5.3.3 When generated

This primitive is passed from the OAM client entity to the OAM sublayer to update control information.

57.2.5.3.4 Effect of receipt

The receipt of this primitive will cause the OAM sublayer to generate Information OAMPDUs or update specific fields of future Information OAMPDUs. Also, OAM functions will be re-evaluated based upon any changing control information.

57.2.5.4 OAM_CTL.indication

57.2.5.4.1 Function

This primitive defines the transfer of control information from an OAM sublayer entity to an OAM client entity.

57.2.5.4.2 Semantics of the service primitive

The semantics of the primitive are as follows:

```
OAM_CTL.indication      (
                        local_pdu,
                        local_stable,
                        local_lost_link_timer_done
                           )
```

The local_pdu and local_stable parameters are used by the OAM sublayer to indicate to the OAM client state information in the Discovery process (see 57.3.2.1). The local_lost_link_timer_done parameter is used to convey the expiration of the local_lost_link_timer.

57.2.5.4.3 When generated

This primitive is passed from the OAM sublayer entity to the OAM client entity to indicate local state information has changed.

57.2.5.4.4 Effect of receipt

The effect of receipt of this primitive by the OAM client is unspecified.

57.2.6 Instances of the OAM internal service interface

The OAM sublayer communicates internally using the OAM internal service interface. Since two instances of the OAM internal service interface are used, it is necessary to introduce a notation convention so that the reader can be clear as to which interface is being referred to at any given time. A prefix is therefore assigned to each service primitive, indicating which of the two interfaces is being invoked (see Figure 57–3). The prefixes are as follows:

a) LBF:, for primitives issued on the interface between the Parser and the Multiplexer (LBF is an abbreviation for loopback frame).
b) CTL:, for primitives issued on the interface between the Control and other OAM functions (CTL is an abbreviation for Control function).

57.2.7 Internal block diagram

Figure 57–3 depicts the major blocks within the OAM sublayer and their interrelationships.

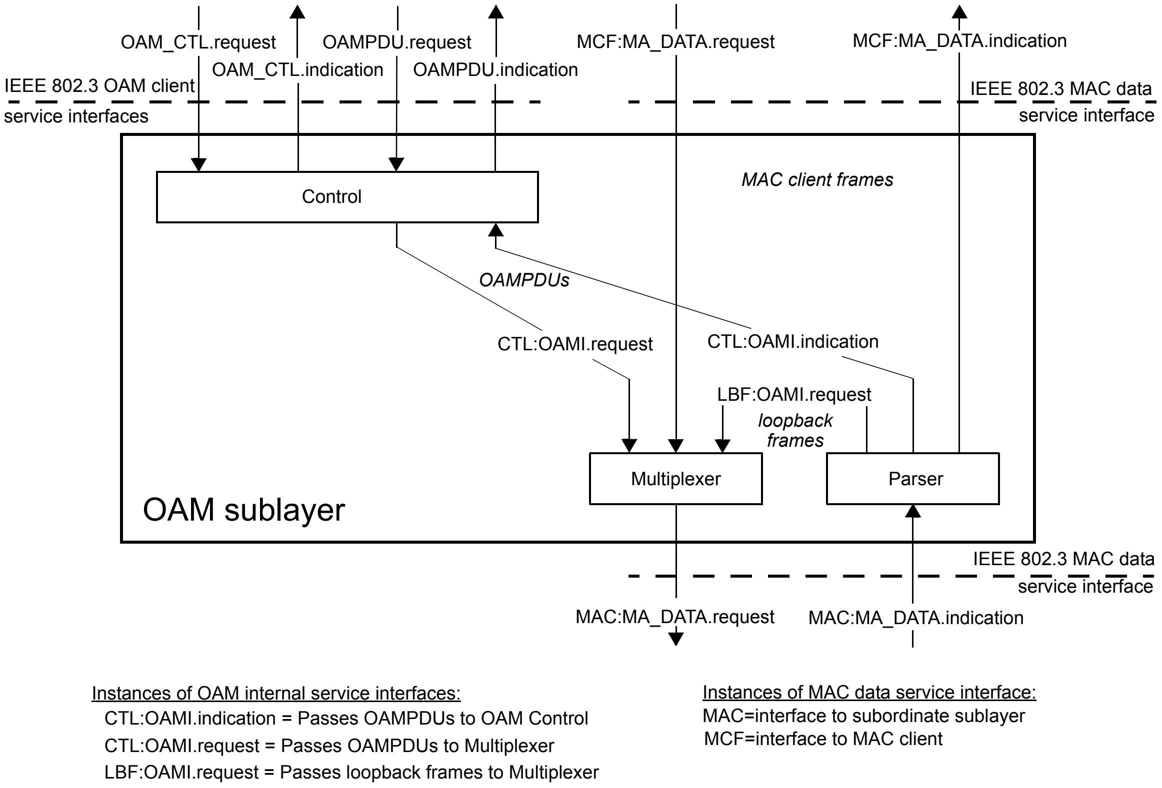

Figure 57–3—OAM sublayer block diagram

57.2.8 OAM internal interactions

The OAM sublayer entity employs the following new internal service interfaces:
OAMI.request
OAMI.indication

The OAMI.request and OAMI.indication service primitives described in this subclause are mandatory.

57.2.8.1 OAMI.request

57.2.8.1.1 Function

This primitive defines the transfer of frames to the Multiplexer function internal to the OAM sublayer.

57.2.8.1.2 Semantics of the service primitive

The semantics of the primitive are as follows:

```
OAMI.request           (
                       destination_address,
                       source_address,
                       oam_service_data_unit,
                           frame_check_sequence
                           )
```

The destination_address parameter specifies the Slow Protocols Multicast Address. The source_address parameter must specify an individual MAC address. The oam_service_data_unit parameter specifies the OAM service data unit to be transmitted within the OAM sublayer entity. This parameter includes the Length/Type, Subtype, Flags, Code and Data/Pad fields. There is sufficient information associated with the oam_service_data_unit for the OAM sublayer entity to determine the length of the data unit. The frame_check_sequence parameter, if present, must specify the frame check sequence field for the frame (see 3.2.9).

57.2.8.1.3 When generated

This primitive is generated by the Parser function whenever a frame is intended to be looped back to the remote DTE via the Multiplexer function. This primitive is also generated by the Control function whenever an OAMPDU is to be conveyed to the peer OAM entity via the Multiplexer function, internal to the OAM sublayer.

57.2.8.1.4 Effect of receipt

The receipt of this primitive will cause the Multiplexer function to pass the properly formed frame, subject to Figure 57–7, to the subordinate sublayer via the MAC data service interface (see 57.2.3).

57.2.8.2 OAMI.indication

57.2.8.2.1 Function

This primitive defines the transfer of frames to the Control function internal to the OAM sublayer.

57.2.8.2.2 Semantics of the service primitive

The semantics of the primitive are as follows:

OAMI.indication (
destination_address,
source_address,
oam_service_data_unit,
frame_check_sequence,
reception_status
)

The destination_address parameter is the Slow Protocols Multicast Address as specified by the DA field of the incoming frame. The source_address parameter is an individual address as specified by the SA field of the incoming frame. The oam_service_data_unit parameter specifies the OAM service data unit as received by the internal OAM function. The frame_check_sequence parameter, if present, is the cyclic redundancy check value (see 3.2.9) as specified by the FCS field of the incoming frame. The reception_status parameter is used to pass status information to the internal OAM function. Values for the reception_status parameter can be found in 4.3.2.

57.2.8.2.3 When generated

This primitive is generated whenever the Parser function intends to pass a received OAMPDU to the Control function, internal to the OAM sublayer. Frames are reported only if they are validly formed and received without error.

57.2.8.2.4 Effect of receipt

The receipt of this primitive will cause the Control function to update internal state variables and pass the OAMPDU to the OAM client via the OAMPDU.indication service primitive (see 57.2.5.2).

57.2.9 Modes

DTEs incorporating the OAM sublayer support Active and/or Passive mode. When OAM is enabled, a DTE capable of both Active and Passive modes shall select either Active or Passive. Table 57–1 contains the behavior of Active and Passive mode DTEs.

Table 57–1—Active and passive mode behavior

Capability	Active DTE	Passive DTE
Initiates OAM Discovery process	Yes	No
Reacts to OAM Discovery process initiation	Yes	Yes
Required to send Information OAMPDUs	Yes	Yes
Permitted to send Event Notification OAMPDUs	Yes	Yes
Permitted to send Variable Request OAMPDUs	Yes	No
Permitted to send Variable Response OAMPDUs	Yes[a]	Yes
Permitted to send Loopback Control OAMPDUs	Yes	No
Reacts to Loopback Control OAMPDUs	Yes[a]	Yes
Permitted to send Organization Specific OAMPDUs	Yes	Yes

[a] Requires the peer DTE to be in Active mode.

57.2.9.1 Active mode

DTEs configured in Active mode initiate the exchange of Information OAMPDUs as defined by the Discovery state diagram (see Figure 57–5). Once the Discovery process completes, Active DTEs are permitted to send any OAMPDU while connected to a remote OAM peer entity in Active mode. Active DTEs operate in a limited respect if the remote OAM entity is operating in Passive mode (see Table 57–1). Active devices should not respond to OAM remote loopback commands and variable requests from a Passive peer.

57.2.9.2 Passive mode

DTEs configured in Passive mode do not initiate the Discovery process. Passive DTEs react to the initiation of the Discovery process by the remote DTE. This eliminates the possibility of passive to passive links. Passive DTEs shall not send Variable Request or Loopback Control OAMPDUs.

57.2.10 OAM events

OAM defines a set of events that may impact link operation. OAM contains mechanisms to communicate such events to the remote DTE. The following sections provide an overview of these events and mechanisms.

57.2.10.1 Critical link events

Table 57–2 lists the defined critical link events. Critical link events are carried within the Flags field of each OAMPDU. Refer to 57.4.2.1 for the definition and encoding of the Flags field.

Table 57–2—Critical link event

Critical link event	Description
Link fault	The PHY has determined a fault has occurred in the receive direction of the local DTE.
Dying gasp	An unrecoverable local failure condition has occurred.
Critical event	An unspecified critical event has occurred.

NOTE—The definition of the specific faults comprising the Critical Event, Dying Gasp, and Link Fault flags is implementation specific and beyond the scope of this standard.

57.2.10.2 Link events

Link events are signaled via Link Event TLVs that are defined in 57.5.3. Examples of link events include Errored Symbol Period Event and Errored Frame Event.

57.2.10.3 Local event procedure

Local events are communicated to the remote DTE via one of two mechanisms described as follows:

a) Critical link events, defined in 57.2.10.1, are communicated to the OAM sublayer via the OAM_CTL.request service primitive. The OAM sublayer shall respond to critical link events by setting or clearing the appropriate bits within the Flags field on any subsequently generated OAMPDUs of any type.
b) The OAM client sends an Event Notification OAMPDU (see 57.4.3.2) containing a Link Event TLV (see Table 57–12) for every event not yet signaled to the remote DTE. The OAM client uses the OAMPDU.request service primitive to send Event Notification OAMPDUs. The OAM client may send duplicate Event Notification OAMPDUs to increase the probability of reception at the remote DTE on deteriorating links.

57.2.10.4 Remote event procedure

Remote events are detected by the local OAM client via one of two mechanisms described as follows:

a) Critical link events, defined in 57.2.10.1, shall be detected by the local OAM sublayer via the Flags field of any received OAMPDU. The OAM sublayer signals the Flags field to the OAM client using the OAMPDU.indication service primitive. When receiving Information OAMPDUs indicating Link Fault from the remote DTE, it is recommended that the local OAM client set the local_link_status parameter in the OAM_CTL.request service primitive to OK. This avoids the situation where both ends of a link are in a deadlock condition where neither DTE will be capable of receiving frames.
b) All other link events shall be detected by the local OAM sublayer via the reception of an Event Notification OAMPDU and the subsequent passing of the OAMPDU to the OAM client via the OAMPDU.indication service primitive. The OAM client discards any duplicate received Event Notification OAMPDU.

57.2.11 OAM remote loopback

OAM provides an optional data link layer frame-level loopback mode, which is controlled remotely. OAM remote loopback can be used for fault localization and link performance testing. Statistics from both the local and remote DTE can be queried and compared at any time while the remote DTE is in OAM remote loopback mode. These queries can take place before, during or after loopback frames have been sent to the remote DTE. In addition, an implementation may analyze loopback frames within the OAM sublayer to determine additional information about the health of the link (i.e., determine which frames are being dropped due to link errors). Figure 57–4 shows the path of frames traversing the layer stack of both the local and remote DTEs.

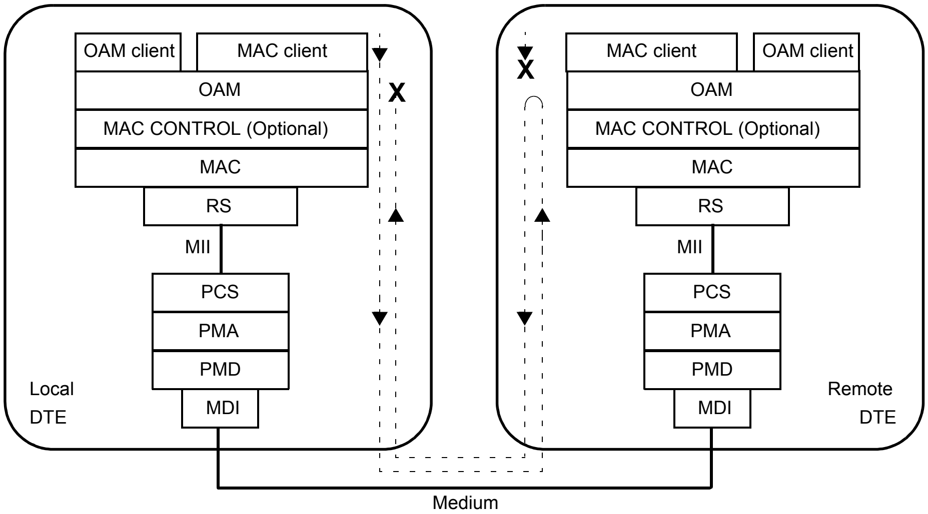

Figure 57–4—OAM remote loopback

57.2.11.1 Initiating OAM remote loopback

To initiate OAM remote loopback, the local OAM client sets its local_mux_action parameter to DISCARD and the local_par_action parameter to DISCARD via the OAM_CTL.request service primitive. The local OAM client sends a Loopback Control OAMPDU (see 57.4.3.5) with the Enable OAM Remote Loopback command. After receiving the Loopback Control OAMPDU, the remote OAM client first sets its local_par_action parameter to LB and its local_mux_action parameter to DISCARD via the OAM_CTL.request service primitive, and then sends an Information OAMPDU with updated state information reflecting its local_par_action set to LB and its local_mux_action parameter set to DISCARD. On the reception of an Information OAMPDU from the remote OAM client with updated state information, the local OAM client sets the local_mux_action to FWD.

If an OAM client has sent a Loopback Control OAMPDU and is waiting for the peer DTE to respond with an Information OAMPDU that indicates it is in OAM remote loopback mode, and that OAM client receives an OAM remote loopback command from the peer device, the following procedures are recommended:

a) If the local DTE has a higher source_address than the peer, it should enter OAM remote loopback mode at the command of its peer.
b) If the local DTE has a lower source_address than the peer, it should ignore the OAM remote loopback command from its peer and continue as if it were never received.

If OAM clients do not follow these guidelines, it may be possible for two OAM clients to issue simultaneous OAM remote loopback commands with indeterminate results.

57.2.11.2 During OAM remote loopback

This section elaborates on Figure 57–4 and describes the flow of frames within the local and remote DTEs and across the link during OAM remote loopback mode. While in OAM remote loopback mode:

a) The local DTE transmits frames from the MAC client and OAMPDUs from the local OAM client or OAM sublayer.
b) Within the remote OAM sublayer entity, every non-OAMPDU, including other Slow Protocol frames, is looped back without altering any field of the frame.
c) OAMPDUs received by the remote DTE are passed to the remote OAM client.
d) Both DTEs are required to send OAMPDUs to the peer DTE in order to keep the Discovery process from re-starting. Both are also permitted to send other OAMPDUs to the peer DTE.
e) Frames received by the local DTE are parsed by the OAM sublayer. OAMPDUs are passed to the OAM client and all other frames are discarded.

57.2.11.3 Exiting OAM remote loopback

When the local DTE wishes to end the OAM remote loopback test, the local OAM client sets its local_mux_action parameter to DISCARD. The local OAM client then sends a Loopback Control OAMPDU with the Disable OAM Remote Loopback command. After receiving a Loopback Control OAMPDU with the Disable OAM Remote Loopback command, the remote OAM client first sets the local_par_action and local_mux_action parameters to FWD via the OAM_CTL.request service primitive and then sends an Information OAMPDU with updated state information reflecting the local_par_action and local_mux_action parameters set to FWD. After receiving an Information OAMPDU with local_par_action and local_mux_action set to FWD, the local OAM client sets its local_par_action and local_mux_action parameters to FWD via the OAM_CTL.request service primitive. The remote Parser resumes passing received non-OAMPDUs up to the MAC client and the local Multiplexer resumes forwarding any frames sourced by the local MAC client.

57.2.11.4 Loss of OAMPDUs during OAM remote loopback

There is the possibility of OAMPDU loss before, during and after OAM remote loopback tests. Of particular interest to the operation of OAM remote loopback is the loss of Loopback Control OAMPDUs and Information OAMPDUs. The local OAM client is able to determine whether or not the remote OAM client received Loopback Control OAMPDUs by examining all received Information OAMPDUs. Since Information OAMPDUs are continually sent to keep the OAM Discovery process from restarting, the occasional loss of an Information OAMPDU should not adversely impact the operation of OAM remote loopback mode.

57.2.11.5 Loss of frames during OAM remote loopback

While the link is operating in OAM remote loopback mode, MAC client frames originating from the remote DTE are not transmitted by the remote OAM sublayer entity. Depending upon the remote DTE's implementation of OAM remote loopback, not every frame received is guaranteed to be looped back to the local DTE. Clock differences between the local and remote DTEs may also be a source of lost frames, as the delta in the rate of frames transmitted and received may overrun buffers within either DTE. As always, frames that incur errors during transit will be dropped by the MAC sublayer receiving the frame. Also, OAMPDUs inserted by the remote DTE impacts the bandwidth available to loopback frames. Implementations should take into account the topology (e.g., emulated point-to-point, asymmetrical links) when determining the rate at which to send frames during OAM remote loopback. When a bi-directional link has asymmetric data rates, frame loss may occur if the receive bandwidth is less than the transmit bandwidth.

Loopback frames that are discarded by the OAM sublayer within the remote DTE are counted and, if Clause 30 is present, are reflected in 30.3.6.1.46. This helps determine the health of the link by distinguishing between frames discarded due to link errors and those discarded within the OAM sublayer.

57.2.11.6 Timing considerations for OAM remote loopback

For effective OAM remote loopback operation, it is necessary to place an upper bound on the response time of the remote OAM client after receiving Loopback Control OAMPDUs.

To ensure correct operation, the OAM client needs to, within one second of receiving a Loopback Control OAMPDU with the Enable OAM Remote Loopback command

a) Set its local_par_action parameter to LB and the local_mux_action to DISCARD via the OAM_CTL.request service primitive.
b) Send an Information OAMPDU.

To ensure correct operation, the OAM client needs to, within one second of receiving a Loopback Control OAMPDU with the Disable OAM Remote Loopback command

c) Set its local_par_action and local_mux_action parameters to FWD via the OAM_CTL.request service primitive.
d) Send an Information OAMPDU.

It is possible for the remote MAC client to send frames before the remote OAM client can send the Information OAMPDU instructing the local DTE to change its local_par_action variable. As a result these remote MAC client frames will be discarded by the local DTE.

57.2.12 Unidirectional OAM operation

OAM provides an OAMPDU-based mechanism to notify the remote DTE when one direction of a link is non-operational and therefore data transmission is disabled. The ability to operate a link in a unidirectional mode for diagnostic purposes supports the maintenance objective of failure detection and notification.

Some Physical Layer devices support Unidirectional OAM operation (see 22.2.4.1.12, 22.2.4.2.8, and Clause 66). When a link is operating in Unidirectional OAM mode, the OAM sublayer ensures that only Information OAMPDUs with the Link Fault critical link event indication set and no Information TLVs are sent once per second across the link.

57.3 Detailed functions and state diagrams

As depicted in Figure 57–3, the OAM sublayer comprises the following functions:

a) ***Multiplexer.*** This function is responsible for passing frames received from the superior sublayer (e.g., MAC client sublayer), OAMPDUs from the Control function and loopback frames from the Parser, to the subordinate sublayer (e.g., MAC sublayer).
b) ***Parser.*** This function distinguishes among OAMPDUs, MAC client frames and loopback frames and passes each to the appropriate entity (Control, superior sublayer and Multiplexer, respectively).
c) ***Control.*** This function is responsible for providing the interface between the OAM client entity and the functions internal to the OAM sublayer. It incorporates the Discovery process which detects the existence and capabilities of OAM at the remote DTE. Also, it includes the Transmit process, which governs the transmission of OAMPDUs to the Multiplexer function and a set of Receive rules, which govern the reception of OAMPDUs.

57.3.1 State diagram variables

57.3.1.1 Constants

OAM_subtype
The value of the Subtype field for OAMPDUs (see Table 57A–3).

Slow_Protocols_Multicast
The value of the Slow Protocols Multicast Address. (see Table 57A–1.)

Slow_Protocols_Type
The value of the Slow Protocols Length/Type field. (see Table 57A–2.)

57.3.1.2 Variables

BEGIN
A variable that resets the functions within OAM.
Values: TRUE; when the OAM sublayer is reset, or when local_oam_enable is set to DISABLE.
FALSE; When (re-)initialization has completed and local_oam_enable is set to ENABLE.

ind_DA
ind_SA
ind_mac_service_data_unit
ind_reception_status
The parameters of the MA_DATA.indication service primitive, as defined in Clause 2.

ind_subtype
The value of the octet following the Length/Type field in a Slow Protocol frame (see Annex 57A).
Value: Integer

local_critical_event
A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This indicates the DTE has experienced an unspecified critical event condition.
Values: FALSE; A critical event condition has not occurred.
TRUE; A critical event condition has occurred.

local_dying_gasp
A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This indicates the DTE has experienced an unrecoverable failure condition.
Values: FALSE; An unrecoverable local failure condition has not occurred.
TRUE; An unrecoverable local failure condition has occurred.

local_link_status

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This indicates the status of the established link (see 67.6.3).

Values: FAIL; A link fault condition does exist.
OK; A link fault condition does not exist.

local_lost_link_timer_done

A parameter of the OAM_CTL.indication service primitive, as defined in 57.2.5.4. This is used to indicate the local_lost_link_timer has expired.

Values: TRUE; local_lost_link_timer has expired.
FALSE; local_lost_link_timer has not expired.

local_mux_action

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This governs the flow of frames from the MAC client through the Multiplexer function (see 57.3.3).

Values: FWD; Multiplexer passes MAC client frames to subordinate sublayer.
DISCARD; Multiplexer discards MAC client frames.

local_oam_enable

Used to enable and disable the OAM sublayer entity. If Clause 30 is present, this maps to 30.3.6.1.2 aOAMAdminState.

Values: DISABLE; The interface acts as it would if it had no OAM sublayer.
ENABLE; The interface employs the OAM sublayer and its functions.

local_oam_mode

Used to configure the OAM sublayer entity in either Active or Passive mode. If Clause 30 is present, this maps to 30.3.3.2 aOAMMode.

Values: PASSIVE; The OAM sublayer entity is configured in Passive mode.
ACTIVE; The OAM sublayer entity is configured in Active mode.

local_par_action

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This governs the flow of non-OAMPDUs through the Parser function (see 57.3.4).

Values: FWD; Parser passes received non-OAMPDUs to superior sublayer.
LB; Parser passes received non-OAMPDUs to Multiplexer during remote loopback test.
DISCARD; Parser discards received non-OAMPDUs.

local_pdu

This is used to govern the transmission and reception of OAMPDUs as part of the Discovery process (see 57.3.2.1).

Values: LF_INFO; Only Information OAMPDUs with the Link Fault critical link event set and without Information TLVs are allowed to be transmitted; only Information OAMPDUs are allowed to be received.
RX_INFO; No OAMPDUs are allowed to be transmitted; only Information OAMPDUs are allowed to be received.
INFO; Only Information OAMPDUs are allowed to be transmitted and received.
ANY; Any permissible OAMPDU is allowed to be transmitted and received (see Table 57–1).

local_satisfied

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This indicates the OAM client finds the local and remote OAM configuration settings are agreeable.

Values: FALSE; OAM client either has not seen or is not satisfied with local and remote settings.
TRUE; OAM client is satisfied with local and remote settings.

local_stable

A variable set by the Discovery state diagram (see Figure 57–5). This is used to indicate local OAM client acknowledgment of and satisfaction with remote OAM state information.

Values: FALSE; Indicates that local DTE either has not seen or is unsatisfied with remote state information.
TRUE; Indicates that local DTE has seen and is satisfied with remote state information.

local_unidirectional

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This indicates the DTE is capable of sending OAMPDUs when the link in the receive direction is not operational.

Values: FALSE; DTE is unable to send OAMPDUs when receive path is not operational.
TRUE; DTE is capable of sending OAMPDUs when receive path is not operational.

pdu_req

This represents a request to send an OAMPDU and is used within the Transmit state diagram (see Figure 57–6).

Values: NONE: No OAMPDU.request
CRITICAL: OAMPDU.request with one or more critical link event OAM_CTL.request parameters set (local_dying_gasp, local_link_status, local_critical_event).
NORMAL: OAMPDU.request with no critical link event(s) set.

remote_stable

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. OAM client extracts remote state information from received OAMPDUs. This is used to indicate remote OAM client acknowledgment of and satisfaction with local OAM state information.

Values: FALSE; Indicates that remote DTE either has not seen or is unsatisfied with local state information.
TRUE; Indicates that remote DTE has seen and is satisfied with local state information.

remote_state_valid

A parameter of the OAM_CTL.request service primitive, as defined in 57.2.5.3. This is used to indicate OAM client has received remote state information found within Local Information TLVs of received Information OAMPDUs.

Values: FALSE; Indicates that OAM client has not seen remote state information.
TRUE; Indicates that OAM client has seen remote state information.

req_DA
req_SA
req_mac_service_data_unit
req_frame_check_sequence

The parameters of the MA_DATA.request service primitive, as defined in Clause 2.

57.3.1.3 Messages

CTL:OAMI.indication

The service primitive used to pass a received frame to an internal OAM function with the specified parameters.

CTL:OAMI.request
LBF:OAMI.request

The service primitives used to transmit a frame with the specified parameters.

MAC:MA_DATA.indication

MCF:MA_DATA.indication
The service primitives used to pass a received frame to a client with the specified parameters.

MAC:MA_DATA.request
MCF:MA_DATA.request
The service primitives used to transmit a frame with the specified parameters.

MADI
Alias for
MA_DATA.indication(ind_DA, ind_SA, ind_mac_service_data_unit, ind_reception_status)

MADR
Alias for
MA_DATA.request(req_DA, req_SA, req_mac_service_data_unit, req_frame_check_sequence)

OAMII
Alias for
OAMI.indication(DA, SA, oam_service_data_unit, frame_check_sequence, reception_status)

OAMIR
Alias for
OAMI.request(DA, SA, oam_service_data_unit, frame_check_sequence)

RxOAMPDU
Alias for ind_DA = Slow_Protocols_Multicast * ind_Length/Type = Slow_Protocols_Type * ind_subtype = OAM_subtype

rxOK
Alias for ind_reception_status = receiveOK

valid_pdu_req
Alias for the following term:
(local_pdu≠RX_INFO * pdu_req=NORMAL * pdu_cnt≠0)
+ (local_pdu=ANY * pdu_req=CRITICAL)

57.3.1.4 Counters

pdu_cnt
This counter is used to limit the number of OAMPDUs transmitted per second and ensure at least one OAMPDU is sent each second within the Transmit state diagram (see Figure 57–6).

57.3.1.5 Timers

All timers operate in the manner described in 14.2.3.2 with the following addition. A timer is reset and stops counting upon entering a state where 'stop x_timer' is asserted.

local_lost_link_timer
Timer used to reset the Discovery state diagram (see Figure 57–5).
Duration: 5 s ± 10%.

pdu_timer
Timer used to ensure OAM sublayer adheres to maximum number of OAMPDUs per second and emits at least one OAMPDU per second.
Duration: 1 s ± 10%.

57.3.2 Control

The Control function provides the interfaces with the OAM client necessary to transmit and receive OAMPDUs and convey control and status parameters. The Control function also contains the Discovery process, which enables OAM to be established on a link, and the Transmit process, which governs the transmission of OAMPDUs to the Multiplexer block. Rules governing the reception of OAMPDUs are also contained within the Control function.

57.3.2.1 OAM Discovery

OAM provides a mechanism to detect the presence of an OAM sublayer at the remote DTE. This mechanism is called Discovery. OAM sublayer entities shall implement the OAM Discovery state diagram shown in Figure 57–5.

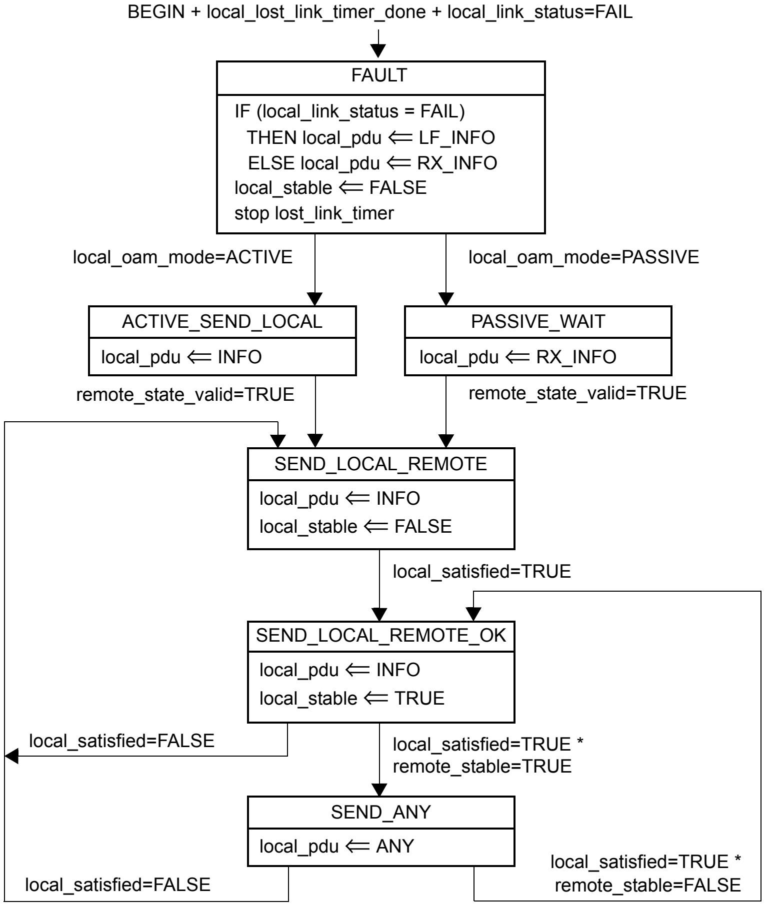

Figure 57–5—OAM Discovery state diagram

In each state, the OAM sublayer sends specified OAMPDUs in a periodic fashion, normally once a second. When local_pdu is set to LF_INFO, the OAM sublayer sends Information OAMPDUs with the Link Fault bit of the Flags field set and without any Information TLVs. When local_pdu is set to RX_INFO, the OAM sublayer does not send any OAMPDUs. When local_pdu is set to INFO, only Information OAMPDUs are sent. When local_pdu is set to ANY, all permissible OAMPDUs may be sent, subject to the restrictions found in Table 57–1.

57.3.2.1.1 FAULT state

Upon entering the FAULT state, local_pdu is set based on the value of local_link_status. If it is set to FAIL, local_pdu is set to LF_INFO, otherwise is it set to RX_INFO. Then, local_stable is set to FALSE and local_lost_link_timer is stopped. While local_link_status is set to FAIL, the DTE will remain in this state indicating to the remote DTE there is link fault. This is accomplished by sending Information OAMPDUs once per second with the Link Fault bit of the Flags field set and no Information TLVs in the Data field. The unidirectional transmission of Information OAMPDUs is supported by some physical coding sublayers (see 57.2.12).

If OAM is reset, disabled, the local_lost_link_timer expires or the local_link_status equals FAIL, the Discovery process returns to the FAULT state.

57.3.2.1.2 ACTIVE_SEND_LOCAL state

Once local_link_status is set to OK, the DTE evaluates local_oam_mode. A DTE configured in Active mode (see 57.2.9.1) sends Information OAMPDUs that only contain the Local Information TLV (see 57.5.2.1). This state is called ACTIVE_SEND_LOCAL. While in this state, the local DTE waits for Information OAMPDUs received from the remote DTE.

57.3.2.1.3 PASSIVE_WAIT state

A DTE configured in Passive mode (see 57.2.9.2) waits until receiving Information OAMPDUs with Local Information TLVs before sending any Information OAMPDUs with Local Information TLVs. This state is called PASSIVE_WAIT. By waiting until first receiving an Information OAMPDU with the Local Information TLV, a Passive DTE cannot complete the OAM Discovery process when connected to another Passive DTE.

57.3.2.1.4 SEND_LOCAL_REMOTE state

Once the local DTE has received an Information OAMPDU with the Local Information TLV from the remote DTE, the local DTE begins sending Information OAMPDUs that contain both the Local and Remote Information TLVs. This state is called SEND_LOCAL_REMOTE. If at any time the settings on either the local or remote DTE change resulting in the local OAM client becoming unsatisfied with the settings, the Discovery process returns to the SEND_LOCAL_REMOTE state.

57.3.2.1.5 SEND_LOCAL_REMOTE_OK state

If the local OAM client deems the settings on both the local and remote DTEs are acceptable, it enters the SEND_LOCAL_REMOTE_OK state. If at any time the settings on the local OAM client change resulting in the remote OAM client becoming unsatisfied with the settings, the OAM Discovery process returns to the SEND_LOCAL_REMOTE_OK state.

57.3.2.1.6 SEND_ANY state

Finally, once an OAMPDU has been received indicating the remote device is satisfied with the respective settings, the local device enters the SEND_ANY state. This is the expected normal operating state for OAM on fully operational links.

57.3.2.1.7 Sending Discovery status to peer

The Local Stable and Local Evaluating bits of the Flags field communicate the status of the local Discovery process to the peer. When the OAM Discovery process is started, the local DTE sets the Local Stable to 0 and Local Evaluating bits to 1 indicating OAM Discovery has not completed.

If, after learning of the remote OAM settings, the local OAM client determines it is unsatisfied it sets the Local Stable and Local Evaluating bits to 0 indicating Discovery cannot successfully complete. If the local OAM client is satisfied, the local DTE sets the Local Stable bit to 1 and Local Evaluating bit to 0 indicating the local OAM client is satisfied.

When Local Stable is set to 1 and Local Evaluating is set to 0 and Remote Stable is set to 1 and Remote Evaluating is set to 0 indicating that both OAM clients are satisfied, the OAM Discovery process has successfully completed and local_pdu is set to ANY. See Table 57–3 for more information.

57.3.2.2 Transmit

OAM sublayer entities shall implement the Transmit state diagram shown in Figure 57–6.

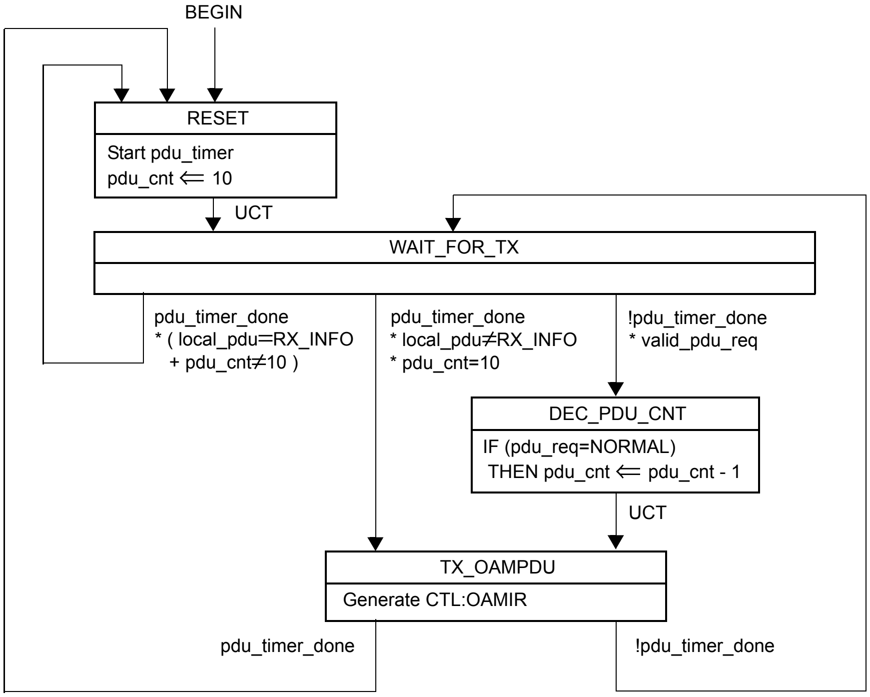

Figure 57–6—Transmit state diagram

57.3.2.2.1 RESET state

Upon initialization, the RESET state is entered. A one second timer is started called pdu_timer. The pdu_cnt variable is reset with a value of ten, the maximum number of OAMPDUs that may be sent in one second. Following RESET, the WAIT_FOR_TX state is entered.

57.3.2.2.2 WAIT_FOR_TX state

While in the WAIT_FOR_TX state, the Transmit process waits for the occurrence of one of three conditions. These three conditions are summarized as follows:

a) Expiration of pdu_timer:
    1) With one or more OAMPDUs sent within the last second
    2) Without any OAMPDUs being sent within the last second and without a valid pending request to send an OAMPDU
b) Valid request to send an OAMPDU present

57.3.2.2.3 Expiration of pdu_timer

While in the WAIT_FOR_TX state, if the pdu_timer expires and one or more OAMPDUs have been sent within the last second, the Transmit process transitions to the RESET state. If, however, the pdu_timer expires and no OAMPDUs have been sent within the last second and there is no valid request to send an OAMPDU present, the Transmit process transitions to the TX_OAMPDU state sending an Information OAMPDU. This prevents the Discovery process from restarting. If local_pdu is set to LF_INFO, the Transmit process ensures the Information OAMPDU has the Link Fault bit of the Flags field set and has no Information TLVs in the Data field.

If, however, the OAM sublayer entity is configured to not send any OAMPDUs, as indicated by the local_pdu variable set to RX_INFO, the Transmit function will simply restart the pdu_timer by returning to the RESET state.

57.3.2.2.4 Valid request to send an OAMPDU

While in the WAIT_FOR_TX state, if a valid request to send an OAMPDU is present, the Transmit process transmits the requested OAMPDU in the TX_OAMPDU state. If the Flags field of the OAMPDU to be sent does not contain any critical link events, the pdu_cnt variable is decremented in the DEC_PDU_CNT state. A valid request is either one of the following:

a) An OAMPDU.request service primitive from the OAM client with the local_pdu variable set to INFO or ANY and pdu_cnt not equal to zero.
b) An OAM_CTL.request service primitive from the OAM client with one or more critical event parameters set and the local_pdu variable set to ANY. When the local_pdu variable is set to ANY, the Discovery process has completed and is in the SEND_ANY state. The Discovery process needs to complete before critical events, other than Link Fault, may be sent to the peer OAM entity.

57.3.2.2.5 TX_OAMPDU state

The TX_OAMDPU state generates the CTL:OAMI.request service primitive, which requests the transmission of an OAMPDU to the Multiplexer process. After generating the request, the Transmit process returns to the RESET state if the pdu_timer is expired or the WAIT_FOR_TX state if the pdu_timer has not expired.

57.3.2.2.6 Transmit rules

The following rules govern the generation of the CTL:OAMIR service primitive:

a) While local_pdu is set to LF_INFO, only Information OAMPDUs with the Link Fault bit of the Flags field set and without any Information TLVs shall be generated.
b) While local_pdu is set to RX_INFO, CTL:OAMIR service primitives shall not be generated.
c) While local_pdu is set to INFO, only Information OAMPDUs shall be generated.
d) While local_pdu is set to ANY:
    1) An OAM_CTL.request service primitive with one or more of the critical link event parameters set shall generate a CTL:OAMIR service primitive, requesting the transmission of an Information OAMPDU with the appropriate bit(s) of the Flags field set.
    2) An OAMPDU.request service primitive shall generate a CTL:OAMIR service primitive, requesting the transmission of the particular OAMPDU.

57.3.2.3 Receive rules

CTL:OAMII service primitives indicate a received OAMPDU and in turn generate an OAMPDU.indication service primitive to the OAM client entity subject to the following rules:

a) When local_pdu is not set to ANY, Information OAMPDUs shall be passed to the OAM client and non-Information OAMPDUs are discarded.

b) When local_pdu is set to ANY, all OAMPDUs, including those with unknown Code fields shall be passed to the OAM client.[3] It is anticipated that the OAM client will ignore unknown or unsupported OAMPDUs.

57.3.3 Multiplexer

OAM sublayer entities shall implement the Multiplexer state diagram shown in Figure 57–7.

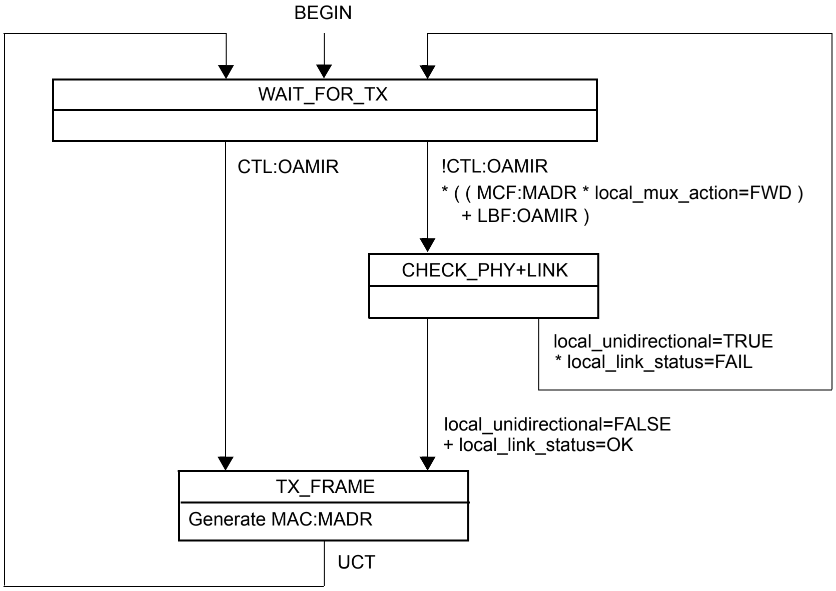

Figure 57–7—Multiplexer state diagram

57.3.3.1 WAIT_FOR_TX state

Upon initialization, the WAIT_FOR_TX state is entered. While in the WAIT_FOR_TX state, the Multiplexer waits for the occurrence of one of two conditions. These two conditions are summarized as follows:

a) Valid request to send an OAMPDU present
b) Valid request to forward a MAC client frame or loopback frame from Parser

57.3.3.1.1 Valid request to send an OAMPDU

While in the WAIT_FOR_TX state, if a request to send an OAMPDU is present, the Multiplexer function transmits the requested OAMPDU in the TX_FRAME state.

57.3.3.1.2 Valid request to forward or loopback frame

While in the WAIT_FOR_TX state, if a valid request to forward or loop back a frame is present and no request to send an OAMPDU is present, the Multiplexer will then check the status of the underlying Physical Layer and unidirectional configuration (in the CHECK_PHY+LINK state) and either transmit the frame in the TX_FRAME state or simply return to the WAIT_FOR_TX state.

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[3] The behavior of the OAM sublayer is different in this regard from the behavior of the MAC Control sublayer (see Clause 31 and Clause 64).

A valid request to forward a frame from the superior sublayer is indicated by the variable MCF:MADR with the Multiplexer configured to forward frames as indicated by the local_mux_action variable set to FWD. A request to loop back a frame from the Parser function is indicated by the variable LBF:OAMIR. When either request occurs, the local_unidirectional variable needs to be FALSE or the local_link_status variable needs to be OK in order for the frame to be sent to the subordinate sublayer via the TX_FRAME state. Since only Information OAMPDUs with the Link Fault critical link event indication set and no Information TLVs are sent on a unidirectional link, the status of the link is evaluated to ensure the same behavior as devices that do not support the optional Unidirectional OAM capability. When the local_link_status variable is OK, the MAC client frame will be transmitted regardless of the Unidirectional OAM capability or setting (see 57.2.12).

57.3.3.2 TX_FRAME state

Once the Multiplexer process reaches the TX_FRAME state, it shall provide transparent pass-through of frames submitted by the superior sublayer, the Transmit process and the Parser process. The transmission of an OAMPDU shall not affect the transmission of a frame that has been submitted to the subordinate sublayer (i.e., the MAC's TransmitFrame function is synchronous, and is never interrupted). After the frame has been sent to the subordinate sublayer, the Multiplexer process returns to the WAIT_FOR_TX state.

57.3.4 Parser

OAM sublayer entities shall implement the Parser state diagram shown in Figure 57–8.

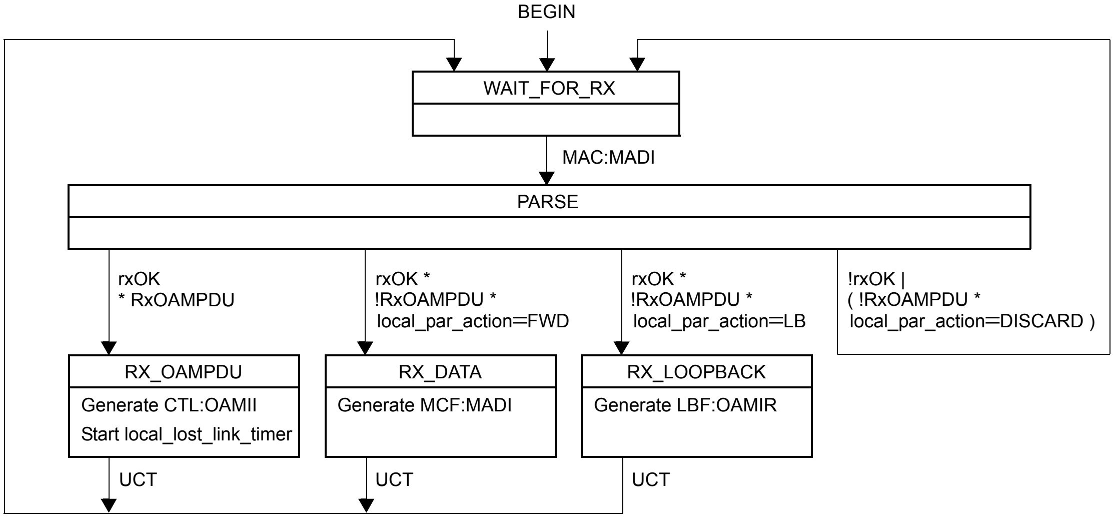


Figure 57–8—Parser state diagram

The Parser decodes frames received from the subordinate sublayer, passes OAMPDUs to the Control function, MAC client frames to the superior sublayer and loopback frames to the Multiplexer function. After reset, the Parser function enters the WAIT_FOR_RX state. The reception of a frame is detected when the MAC:MADI service primitive occurs. When a frame is received, the Parser function enters the PARSE state.

57.3.4.1 Reception of OAMPDU

The RX_OAMPDU state is entered when the receive frame is identified as an OAMPDU. Received OAMPDUs are sent to the OAM Control function via the CTL:OAMII service primitive. Following the receive rules in 57.3.2.3, the OAM Control function then passes the received OAMPDU to the OAM client. In addition, the local_lost_link_timer is reset. The Parser function then returns to the WAIT_FOR_RX state.

57.3.4.2 Reception of non-OAMPDUs

Received non-OAMPDUs are handled according to the setting of the local_par_action parameter. Refer to 57.2.11 for a complete description of OAM remote loopback operation and the local_par_action variable.

57.3.4.2.1 Reception of non-OAMPDU in FWD mode

The RX_DATA state is entered if the frame is determined to not be an OAMPDU and the local_par_action variable is set to FWD. The received frame is passed up to the superior sublayer via the MCF:MADI service primitive. The Parser then returns to the WAIT_FOR_RX state.

57.3.4.2.2 Reception of non-OAMPDU in LB mode

The RX_LOOPBACK state is entered if the frame is determined to not be an OAMPDU and the local_par_action parameter is set to LB. The received loopback frame is passed to the Multiplexer function via the LBF:OAMIR service primitive to be looped back to the remote DTE. After the frame is passed to the Multiplexer function, the Parser function returns to the WAIT_FOR_RX state.

57.3.4.2.3 Reception of non-OAMPDU in DISCARD mode

If the local_par_action parameter is set to DISCARD, the Parser function simply returns to the WAIT_FOR_RX state.

57.4 OAMPDUs

57.4.1 Ordering and representation of octets

All OAMPDUs comprise an integral number of octets. When the encoding of (an element of) an OAMPDU is depicted in a diagram:

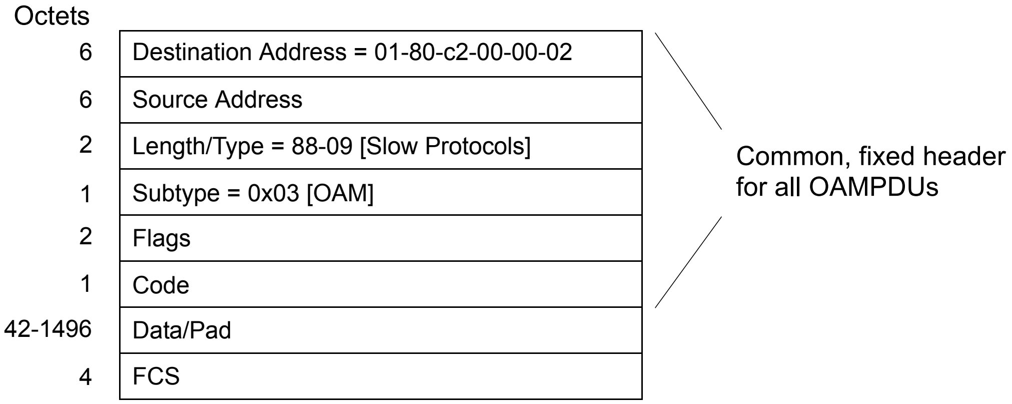
a) Octets are transmitted from top to bottom.
b) Within an octet, bits are shown with bit 0 to the left and bit 7 to the right.
c) When consecutive octets are used to represent a binary number, the octet transmitted first has the more significant value.
d) When consecutive octets are used to represent a MAC address, the least significant bit of the first octet is assigned the value of the first bit of the MAC address, the next most significant bit the value of the second bit of the MAC address, and so on for all the octets of the MAC address.

When the encoding of an element of an OAMPDU is depicted in a table, the least significant bit is bit 0.

The bit/octet ordering of any Organizationally Unique Identifier (OUI) or Company ID (CID) field within an OAMPDU is identical to the bit/octet ordering of the OUI portion of the DA/SA. Additional detail defining the format of OUIs and CIDs can be found in IEEE Std 802-2014.

57.4.2 Structure

The OAMPDU structure shall be as shown in Figure 57–9.



Octets	
6	Destination Address = 01-80-c2-00-00-02
6	Source Address
2	Length/Type = 88-09 [Slow Protocols]
1	Subtype = 0x03 [OAM]
2	Flags
1	Code
42-1496	Data/Pad
4	FCS

Figure 57–9—OAMPDU frame structure

OAMPDUs shall have the following fields:

a) ***Destination Address*** (DA). The DA in OAMPDUs is the Slow_Protocols_Multicast address. Its use and encoding are specified in Annex 57A.
b) ***Source Address*** (SA). The SA in OAMPDUs carries the individual MAC address associated with the port through which the OAMPDU is transmitted.
c) ***Length/Type***. The Length/Type in OAMPDUs carries the Slow_Protocols_Type field value as specified in 57A.4.
d) ***Subtype***. The Subtype field identifies the specific Slow Protocol being encapsulated. OAMPDUs carry the Subtype value 0x03.
e) ***Flags***. The Flags field contains status bits as defined in 57.4.2.1.
f) ***Code***. The Code field identifies the specific OAMPDU. The use and encoding of this field is specified in Table 57–4.
g) ***Data/Pad***. This field contains the OAMPDU data and any necessary pad. Implementations shall support OAMPDUs at least minFrameSize in length.
h) ***FCS***. This field is the Frame Check Sequence, as defined in Clause 4.

57.4.2.1 Flags field

The Flags field is encoded as individual bits within two octets as shown in Table 57–3. Additional diagnostic information may be sent using the Event Notification OAMPDU.

Table 57–3—Flags field

Bit(s)	Name	Description
15:7	*Reserved*	Reserved bits shall be set to zero when sending an OAMPDU, and should be ignored on reception for compatibility with future use of reserved bits.
6	Remote Stable	When remote_state_valid is set to TRUE, the Remote Stable and Remote Evaluating values shall be a copy of the last valid received Local Stable and Local Evaluating values from the remote OAM peer. Otherwise, the Remote Stable and Remote Evaluating bits shall be set to 0.
5	Remote Evaluating	

Table 57–3—Flags field *(continued)*

Bit(s)	Name	Description
4	Local Stable	Local Stable and Local Evaluating form a two-bit encoding shown below: 4:3 0x0 = Local DTE Unsatisfied, Discovery can not complete 0x1 = Local DTE Discovery process has not completed 0x2 = Local DTE Discovery process has completed 0x3 = Reserved. This value shall not be sent. If the value 0x3 is received, it should be ignored and not change the last received value.
3	Local Evaluating	
2	Critical Event	1 = A critical event has occurred. 0 = A critical event has not occurred.
1	Dying Gasp	1 = An unrecoverable local failure condition has occurred. 0 = An unrecoverable local failure condition has not occurred.
0	Link Fault	The PHY has detected a fault has occurred in the receive direction of the local DTE (e.g., link, Physical Layer). 1 = Local device's receive path has detected a fault. 0 = Local device's receive path has not detected a fault.

NOTE—The definition of the specific faults comprising the Critical Event, Dying Gasp, and Link Fault flags is implementation specific and beyond the scope of this standard.

57.4.2.2 Code field

The value of the Code field is set by the Transmit process in the Control function for Information OAMPDUs it generates. The OAM client sets the Code field for all OAMPDUs it generates. Table 57–4 contains the defined OAMPDU codes.

Table 57–4—OAMPDU codes

Code	OAMPDU	Comment	Source
00	Information	Communicates local and remote OAM information.	OAM client / OAM sublayer
01	Event Notification	Alerts remote DTE of link event(s).	OAM client
02	Variable Request	Requests one or more specific MIB variables.	OAM client
03	Variable Response	Returns one or more specific MIB variables.	OAM client
04	Loopback Control	Enables/disables OAM remote loopback.	OAM client
05-FD	*Reserved*	*Reserved*	OAM client
FE	Organization Specific	Reserved for Organization Specific Extensions, distinguished by Organizationally Unique Identifier.	OAM client
FF	*Reserved*	*Reserved*	OAM client

57.4.3 OAMPDU descriptions

The local OAM sublayer communicates with the remote OAM sublayer via OAMPDUs. OAMPDUs are identified with a specific code. OAMPDUs are formatted as compliant IEEE 802.3 frames, where the IEEE 802.3 frame header format is described in Clause 3. OAMPDUs are further defined, as shown in Figure 57–9, to include a Subtype field, a Flags field, and a Code field following the IEEE 802.3 defined Length/Type field. The Data field begins in a fixed location within the OAMPDU. The Data field contents are unique to the particular OAMPDU. The following sections provide a detailed description of each OAMPDU and its corresponding Data field. All received OAMPDUs, including those with reserved Code fields, are passed to the OAM client. OAMPDUs with reserved Code field values shall not be transmitted.

57.4.3.1 Information OAMPDU

The Information OAMPDU, identified by the Code field 0x00, is used to send OAM state information to the remote DTE. The Information OAMPDU frame structure shall be as depicted in Figure 57–10.

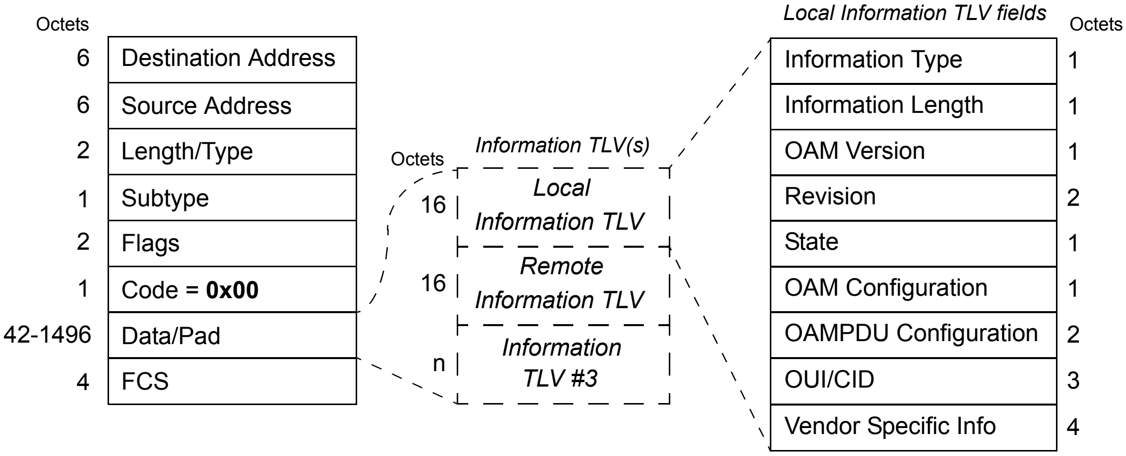


Figure 57–10—Information OAMPDU frame structure

When local_pdu is set to LF_INFO, the Information OAMPDU Data field shall not have any Information TLVs. When local_pdu is not set to LF_INFO, the Information OAMPDU Data field shall consist of the Local Information TLV (see 57.5.2.1) immediately following the Code field. In addition, if the Discovery state diagram variable remote_state_valid is TRUE, the Data field shall also contain the Remote Information TLV (see 57.5.2.2), immediately following the Local Information TLV and may also contain other Information TLVs found in Table 57–6.

57.4.3.2 Event Notification OAMPDU

The optional Event Notification OAMPDU, identified with the Code field set to 0x01, is used to alert the remote DTE of link events introduced in 57.2.10.2. The Event Notification OAMPDU frame structure shall be as depicted in Figure 57–11.

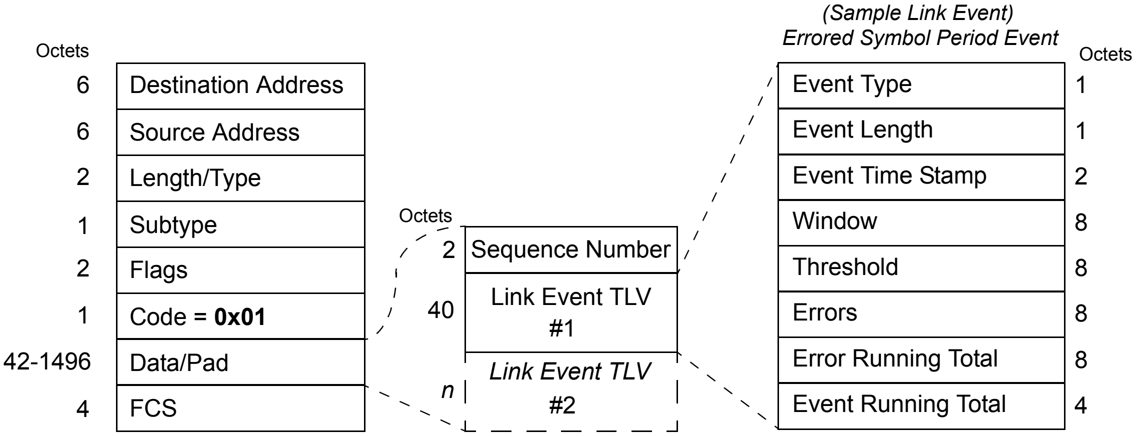


Figure 57–11—Event Notification OAMPDU frame structure

The first two octets of the Data field shall contain a Sequence Number, encoded as a 16-bit unsigned integer. As described in 57.2.3, the OAM client may send duplicate Event Notification OAMPDUs to increase the likelihood the remote DTE receives a particular event. The OAM client increments the Sequence Number for each unique Event Notification OAMPDU formed by the OAM client. A particular Event Notification OAMPDU may be sent multiple times with the same sequence number. It is recommended that any duplicate Event Notification OAMPDUs follow its original without a different, intervening Event Notification OAMPDU. A duplicate Event Notification OAMPDU should not be transmitted if a new Event Notification OAMPDU has already followed the original OAMPDU. Any particular event can be signaled in only one unique Event Notification OAMPDU (though that OAMPDU may be transmitted multiple times). Upon receiving an Event Notification OAMPDU, the OAM client compares the Sequence Number with the last received Sequence Number. If equal, the current event is a duplicate and is ignored by the OAM client.

Following the Sequence Number field, the Data field shall contain one or more optional Link Event TLVs which may provide useful information for troubleshooting events and faults. Link Event TLVs are defined in 57.5.3.

57.4.3.3 Variable Request OAMPDU

The optional Variable Request OAMPDU, identified with a Code field of 0x02, is used to request one or more MIB variables from the remote DTE. The Variable Request OAMPDU frame structure shall be as depicted in Figure 57–12.

The Variable Request OAMPDU Data field shall contain one or more Variable Descriptors. Variable Descriptors are defined in 57.6.1.

The Variable Request OAMPDU Data field may contain one or more Variable Containers, to determine the scope of subsequent Variable Descriptors, as described in 57.6.2.

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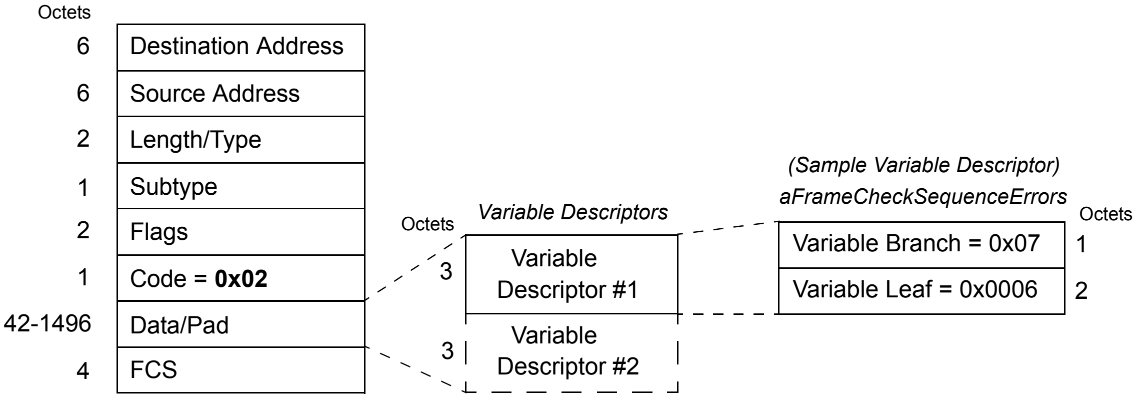

Figure 57–12—Variable Request OAMPDU frame structure

57.4.3.4 Variable Response OAMPDU

The optional Variable Response OAMPDU, identified with the Code field of 0x03, is used to return one or more MIB variables. The Variable Response OAMPDU frame structure shall be as depicted in Figure 57–13.

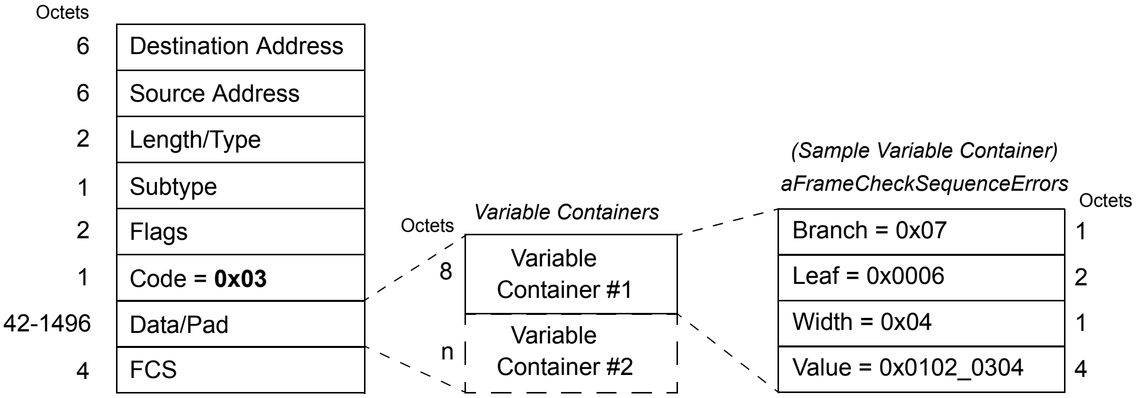

Figure 57–13—Variable Response OAMPDU frame structure

The Variable Response OAMPDU Data field shall contain one or more Variable Containers. Variable Containers are defined in 57.6.2. A Variable Response OAMPDU needs to be sent by the OAM client within one second of receipt of a Variable Request OAMPDU. If a DTE is unable to retrieve one or more variables, it needs to respond within one second and indicate the appropriate error(s) as found in Table 57–17. If a DTE is unable to retrieve one or more attributes within a package or object, it needs to either a) return the appropriate Variable Indication for the particular attribute(s) and return all other requested variables or b) return a Variable Indication for the entire package or object.

57.4.3.5 Loopback Control OAMPDU

The optional Loopback Control OAMPDU, identified with the Code field set to 0x04, is used to control the remote DTE's OAM remote loopback state. The Loopback Control OAMPDU frame structure shall be as depicted in Figure 57–14.

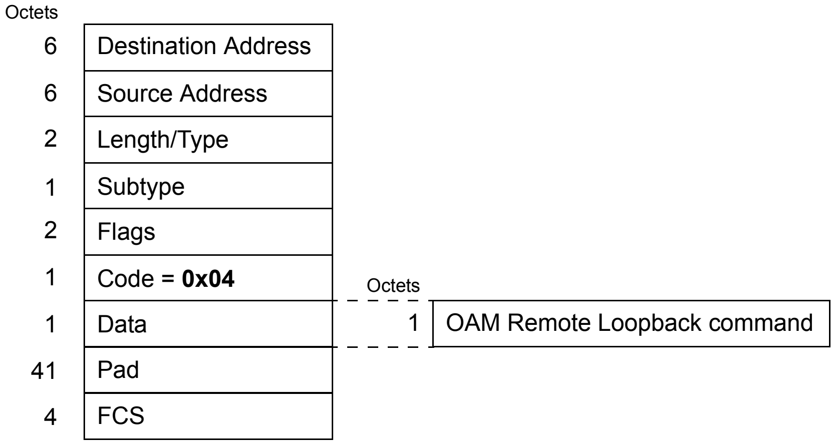

Figure 57–14—Loopback Control OAMPDU frame structure

The Loopback Control OAMPDU Data field shall consist of an OAM remote loopback command. Table 57–5 lists the defined OAM remote loopback commands.

Table 57–5—OAM remote loopback commands

Command	Description
0x00	*Reserved — shall not be transmitted, should be ignored on reception by OAM client*
0x01	Enable OAM Remote Loopback
0x02	Disable OAM Remote Loopback
0x03–0xFF	*Reserved — shall not be transmitted, should be ignored on reception by OAM client*

For a complete description of OAM remote loopback refer to 57.2.11.

57.4.3.6 Organization Specific OAMPDU

The optional Organization Specific OAMPDU, identified with the Code field set to 0xFE, is used for organization specific extensions. The Organization Specific OAMPDU frame structure shall be as depicted in Figure 57–15.

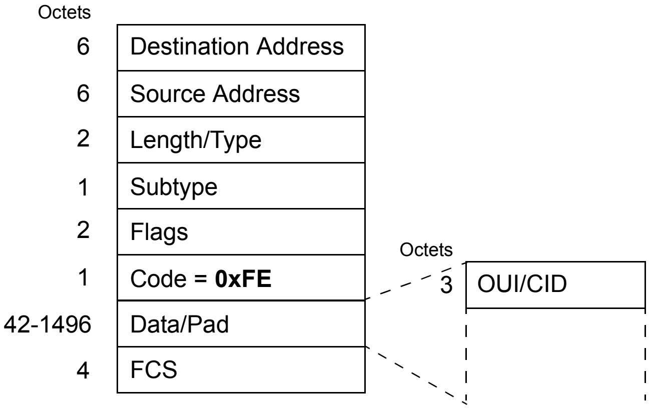

Figure 57–15—Organization Specific OAMPDU frame structure

The first three octets of the Organization Specific OAMPDU Data field shall contain the Organizationally Unique Identifier (OUI) or Company ID (CID).[4] The format and function of the rest of the Organization Specific OAMPDU Data field is dependent on OUI or CID value and is beyond the scope of this standard.

57.5 OAM TLVs

57.5.1 Parsing

The OAM client parses OAM TLVs. All OAM TLVs contain a single octet Type field and a single octet Length field. The Length field encompasses the entire TLV including the Type and Length fields. TLV processing should follow these recommendations:

a) Detection of a TLV type 0x00 should indicate there are no more TLVs to process (the length and value of the Type 0x00 TLV can be ignored).
b) TLVs with lengths 0x00 or 0x01 should be considered invalid, and the OAMPDU should be considered to have no more TLVs.
c) TLVs with unknown or unexpected types should be ignored.

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[4] Interested applicants should contact the IEEE Standards Department, Institute of Electrical and Electronics Engineers, http://standards.ieee.org/regauth/index.html, 445 Hoes Lane, Piscataway, NJ 08854, USA.

d) If the length of a TLV is less than that defined for the Type, that TLV should be ignored and the rest of the frame may be ignored. If the length of a TLV is greater than that defined for the Type, the expected fields of the TLV should be processed, and the remainder of the frame after the TLV should also be processed.
e) If a TLV length indicates that the TLV extends beyond the frame (e.g., the length cannot fit into the frame given its length and starting point), then the TLV should be ignored.

57.5.2 Information TLVs

This subclause contains the definitions for Information TLVs. Information TLVs are found in Information OAMPDUs. Table 57–6 contains the defined Information TLVs.

Table 57–6—Information TLV types

Type	Description
0x00	*End of TLV marker*
0x01	Local Information
0x02	Remote Information
0x03–0xFD	*Reserved —shall not be transmitted, should be ignored on reception by OAM client*
0xFE	Organization Specific Information
0xFF	*Reserved —shall not be transmitted, should be ignored on reception by OAM client*

The following subclauses describe the defined Information TLVs.

57.5.2.1 Local Information TLV

The Local Information TLV shall have the following fields:

a) ***Information Type*** = *Local Information*. This one-octet field indicates the nature of the data carried in this TLV-tuple. The encoding of this field is found in Table 57–6.
b) ***Information Length***. The one-octet field indicates the length (in octets) of this TLV-tuple. Local Information TLV uses a length value of 16 (0x10).
c) ***OAM Version***. This one-octet field indicates the version supported by the DTE. This field shall contain the value 0x01 to claim compliance with Version 1 of this protocol.
d) ***Revision.*** This two-octet field indicates the current revision of the Information TLV. The value of this field shall start at zero and be incremented each time something in the Information TLV changes. Upon reception of an Information TLV from a peer, an OAM client may use this field to decide if it needs to be processed (an Information TLV that is identical to the previous Information TLV does not need to be parsed as nothing in it has changed).
e) ***State***. This one-octet field contains OAM state information and shall be as shown in Table 57–7.
f) ***OAM Configuration***. This one-octet field contains OAM configuration variables and shall be as shown in Table 57–8.
g) ***OAMPDU Configuration***. This two-octet field contains OAMPDU configuration variables and shall be as shown in Table 57–9 and encoded as specified in 57.4.1 c).
h) ***OUI/CID***. This three-octet field contains the 24-bit Organizationally Unique Identifier or Company ID and shall be as shown in Table 57–10.
i) ***Vendor Specific Information***. This four-octet field contains the Vendor Specific Information field and shall be as shown in Table 57–11.

Table 57–7—State field

Bit(s)	Name	Description
7:3	*Reserved*	In Local Information TLVs, reserved bits shall be set to zero when sending an OAMPDU, and should be ignored on reception for compatibility with future use of reserved bits.
2	Multiplexer Action	0 = Device is forwarding non-OAMPDUs to the lower sublayer (local_mux_action = FWD). 1 = Device is discarding non-OAMPDUs (local_mux_action = DISCARD).
1:0	Parser Action	00 = Device is forwarding non-OAMPDUs to higher sublayer (local_par_action = FWD). 01 = Device is looping back non-OAMPDUs to the lower sublayer (local_par_action = LB). 10 = Device is discarding non-OAMPDUs (local_par_action = DISCARD). 11 = Reserved. In Local Information TLVs, this value shall not be sent. If the value 11 is received, it should be ignored and not change the last received value.

Table 57–8—OAM Configuration field

Bit(s)	Name	Description
7:5	*Reserved*	In Local Information TLVs, reserved bits shall be set to zero when sending an OAMPDU, and should be ignored on reception for compatibility with future use of reserved bits.
4	Variable Retrieval	1 = DTE supports sending Variable Response OAMPDUs. 0 = DTE does not support sending Variable Response OAMPDUs.
3	Link Events	1 = DTE supports interpreting Link Events. 0 = DTE does not support interpreting Link Events.
2	OAM Remote Loopback Support	1 = DTE is capable of OAM remote loopback mode. 0 = DTE is not capable of OAM remote loopback mode.
1	Unidirectional Support	1 = DTE is capable of sending OAMPDUs when the receive path is non-operational. 0 = DTE is not capable of sending OAMPDUs when the receive path is non-operational.
0	OAM Mode	1 = DTE configured in Active mode. 0 = DTE configured in Passive mode.

Table 57–9—OAMPDU Configuration field

Bit(s)	Name	Description
15:11	*Reserved*	In Local Information TLVs, reserved bits shall be set to zero when sending an OAMPDU, and should be ignored on reception for compatibility with future use of reserved bits.
10:0	Maximum OAMPDU Size	11-bit field which represents the largest OAMPDU, in octets, supported by the DTE. This value is compared to the remote's Maximum OAMPDU Size and the smaller of the two is used. The minimum value of this field is minFrameSize / 8. The maximum value of this field is equal to maxBasicFrameSize, which is defined in 4.4.2. Prior to exchanging Maximum OAMPDU Size and agreeing upon a maximum OAMPDU size, a DTE sends OAMPDUs of length minFrameSize / 8. The OAMPDUs transmitted by a DTE are limited by both the local DTE's Maximum OAMPDU Size and the remote DTE's Maximum OAMPDU Size as indicated in received Information OAMPDUs. A DTE is not required to change the value transmitted in this field after negotiation to an agreed size as each end will dynamically determine the correct maximum OAMPDU size to use.

Table 57–10—OUI/CID field

Bit(s)	Name	Description
23:0	OUI/CID[a]	24-bit Organizationally Unique Identifier or Company ID of the vendor.

[a] Organizations that have previously received OUIs or CIDs from the IEEE Registration Authority should use one of their allocated OUIs or CIDs consistently in this field.

Table 57–11—Vendor Specific Information field

Bit(s)	Name	Description
31:0	Vendor Specific Information	32-bit identifier that may be used to differentiate a vendor's product models/versions.

57.5.2.2 Remote Information TLV

The Remote Information TLV shall be a copy of the last received Local Information TLV from the remote OAM peer, with the exception of the Information Type field. The encoding of this field is found in Table 57–6.

57.5.2.3 Organization Specific Information TLV

The Organization Specific Information TLV shall have the following fields:

a) ***Information Type*** = *Organization Specific Information*. This one-octet field indicates the nature of the data carried in this TLV-tuple. The encoding of this field is found in Table 57–6.
b) ***Information Length.*** This one-octet field indicates the length (in octets) of this TLV-tuple. The length of an Organization Specific Information TLV is unspecified.
c) ***Organizationally Unique Identifier or Company ID.*** This three-octet field shall contain the 24-bit Organizationally Unique Identifier (OUI) or Company ID (CID).
d) ***Organization Specific Value.*** This field indicates the value of the Organization Specific Information TLV. This field's length and contents are unspecified.

57.5.3 Link Event TLVs

This subclause contains the definitions for Link Event TLVs. Link Event TLVs are found in Event Notification OAMPDUs. Table 57–12 contains the defined Link Event TLVs.

Table 57–12—Link Event TLV type value

Type	Description
0x00	*End of TLV marker*
0x01	Errored Symbol Period Event
0x02	Errored Frame Event
0x03	Errored Frame Period Event
0x04	Errored Frame Seconds Summary Event
0x05–0xFD	*Reserved—shall not be transmitted, should be ignored on reception by OAM client*
0xFE	Organization Specific Event
0xFF	*Reserved—shall not be transmitted, should be ignored on reception by OAM client*

The following subclauses describe the defined Link Event TLVs.

57.5.3.1 Errored Symbol Period Event TLV

The Errored Symbol Period Event TLV counts the number of symbol errors that occurred during the specified period. The period is specified by the number of symbols that can be received in a time interval on the underlying Physical Layer. This event is generated if the symbol error count is equal to or greater than the specified threshold for that period.

The Errored Symbol Period Event TLV shall have the following fields:

a) ***Event Type*** = *Errored Symbol Period Event*. This one-octet field indicates the nature of the information carried in this TLV-tuple. The encoding of this field is found in Table 57–12.
b) ***Event Length.*** This one-octet field indicates the length (in octets) of this TLV-tuple. Errored Symbol Period Event uses a length value of 40 (0x28).
c) ***Event Time Stamp.*** This two-octet field indicates the time reference when the event was generated, in terms of 100 ms intervals, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.35. When received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.42.
d) ***Errored Symbol Window.*** This eight-octet field indicates the number of symbols in the period, encoded as a 64-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.35. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.42.
    1) The default value is the number of symbols in one second for the underlying Physical Layer.
    2) The lower bound is the number of symbols in one second for the underlying Physical Layer.
    3) The upper bound is the number of symbols in one minute for the underlying Physical Layer.
e) ***Errored Symbol Threshold.*** This eight-octet field indicates the number of errored symbols in the period is required to be equal to or greater than in order for the event to be generated, encoded as a 64-bit unsigned integer. When generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.35. When received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.42.
    1) The default value is one symbol error.
    2) The lower bound is zero symbol errors.
    3) The upper bound is unspecified.
f) ***Errored Symbols.*** This eight-octet field indicates the number of symbol errors in the period, encoded as a 64-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.35. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.42.
g) ***Error Running Total.*** This eight-octet field indicates the sum of symbol errors since the OAM sublayer was reset. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.35. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.42.
h) ***Event Running Total.*** This four-octet field indicates the number of Errored Symbol Period Event TLVs that have been generated since the OAM sublayer was reset, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.35. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.42.

This event is generated at the end of the event window rather than when the threshold is crossed.

57.5.3.2 Errored Frame Event TLV

The Errored Frame Event TLV counts the number of errored frames detected during the specified period. The period is specified by a time interval. This event is generated if the errored frame count is equal to or greater than the specified threshold for that period. Errored frames are frames that had transmission errors as detected at the Media Access Control sublayer as communicated via the reception_status parameter of the MA_DATA.indication service primitive. Refer to 4.2.9 for the definition of detectable transmission errors during reception.

The Errored Frame Event TLV shall have the following fields:

a) ***Event Type*** = *Errored Frame Event*. This one-octet field indicates the nature of the information carried in this TLV-tuple. The encoding of this field is found in Table 57–12.
b) ***Event Length.*** This one-octet field indicates the length (in octets) of this TLV-tuple. Errored Frame Event uses a length value of 26 (0x1A).
c) ***Event Time Stamp.*** This two-octet field indicates the time reference when the event was generated, in terms of 100 ms intervals, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.37. When received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.43.
d) ***Errored Frame Window.*** This two-octet field indicates the duration of the period in terms of 100 ms intervals, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.37. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.43.
    1) The default value is one second.
    2) The lower bound is one second.
    3) The upper bound is one minute.
e) ***Errored Frame Threshold.*** This four-octet field indicates the number of detected errored frames in the period is required to be equal to or greater than in order for the event to be generated, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.37. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.43.
    1) The default value is one frame error.
    2) The lower bound is zero frame errors.
    3) The upper bound is unspecified.
f) ***Errored Frames.*** This four-octet field indicates the number of detected errored frames in the period, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.37. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.43.
g) ***Error Running Total.*** This eight-octet field indicates the sum of errored frames that have been detected since the OAM sublayer was reset. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.37. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.43.
h) ***Event Running Total.*** This four-octet field indicates the number of Errored Frame Event TLVs that have been generated since the OAM sublayer was reset, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.37. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.43.

This event is generated at the end of the event window rather than when the threshold is crossed.

57.5.3.3 Errored Frame Period Event TLV

The Errored Frame Period Event TLV counts the number of errored frames detected during the specified period. The period is specified by a number of received frames. This event is generated if the errored frame count is greater than or equal to the specified threshold for that period (for example, if the errored frame count is greater than or equal to 10 for the last 1 000 000 frames received). Errored frames are frames that had transmission errors as detected at the Media Access Control sublayer as communicated via the reception_status parameter of the MA_DATA.indication service primitive. Refer to 4.2.9 for the definition of detectable transmission errors during reception.

The Errored Frame Period Event TLV shall have the following fields:

a) ***Event Type*** = *Errored Frame Period Event*. This one-octet field indicates the nature of the information carried in this TLV-tuple. The encoding of this field is found in Table 57–12.
b) ***Event Length.*** This one-octet field indicates the length (in octets) of this TLV-tuple. Errored Frame Period Event uses a length value of 28 (0 x 1C).
c) ***Event Time Stamp.*** This two-octet field indicates the time reference when the event was generated, in terms of 100 ms intervals, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.39. When received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.44.
d) ***Errored Frame Window.*** This four-octet field indicates the duration of period in terms of frames, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.39. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.44.
    1) The default value is the number of minFrameSize frames that can be received in one second on the underlying Physical Layer.
    2) The lower bound is the number of minFrameSize frames that can be received in 100 ms on the underlying Physical Layer.
    3) The upper bound is the number of minFrameSize frames that can be received in one minute on the underlying Physical Layer.
e) ***Errored Frame Threshold.*** This four-octet field indicates the number of errored frames in the period is required to be equal to or greater than in order for the event to be generated, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.39. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.44.
    1) The default value is one frame error.
    2) The lower bound is zero frame errors.
    3) The upper bound is unspecified.
f) ***Errored Frames.*** This four-octet field indicates the number of frame errors in the period, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.39. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.44.
g) ***Error Running Total.*** This eight-octet field indicates the sum of frame errors that have been detected since the OAM sublayer was reset. When this event is generated by the local DTE and if Clause 30 is present, this maps to 330.3.6.1.39. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.44.
h) ***Event Running Total.*** This four-octet field indicates the number of Errored Frame Period Event TLVs that have been generated since the OAM sublayer was reset, encoded as a 32-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.39. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.44.

This event is generated at the end of the event window rather than when the threshold is crossed.

57.5.3.4 Errored Frame Seconds Summary Event TLV

The Errored Frame Seconds Summary Event TLV counts the number of errored frame seconds that occurred during the specified period. The period is specified by a time interval. This event is generated if the number of errored frame seconds is equal to or greater than the specified threshold for that period. An errored frame second is a one second interval wherein at least one frame error was detected. Errored frames are frames that had transmission errors as detected at the Media Access Control sublayer and communicated via the reception_status parameter of the MA_DATA.indication service primitive. Refer to 4.2.9 for the definition of detectable transmission errors during reception.

The Errored Frame Seconds Summary Event TLV shall have the following fields:

a) ***Event Type*** = *Errored Frame Seconds Summary Event*. This one-octet field indicates the nature of the information carried in this TLV-tuple. The encoding of this field is found in Table 57–12.
b) ***Event Length.*** This one-octet field indicates the length (in octets) of this TLV-tuple. Errored Frame Seconds Summary Event uses a length value of 18 (0x12).
c) ***Event Time Stamp.*** This two-octet field indicates the time reference when the event was generated, in terms of 100 ms intervals, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.41. When received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.45.
d) ***Errored Frame Seconds Summary Window.*** This two-octet field indicates the duration of the period in terms of 100 ms intervals, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.41. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.45.
    1) The default value is 60 seconds.
    2) The lower bound is 10 seconds.
    3) The upper bound is 900 seconds.
e) ***Errored Frame Seconds Summary Threshold.*** This two-octet field indicates the number of errored frame seconds in the period is required to be equal to or greater than in order for the event to be generated, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.41. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.45.
    1) The default value is one errored second.
    2) The lower bound is zero errored seconds.
    3) The upper bound is unspecified.
f) ***Errored Frame Seconds Summary.*** This two-octet field indicates the number of errored frame seconds in the period, encoded as a 16-bit unsigned integer. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.41. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.45.
g) ***Error Running Total.*** This four-octet field indicates the sum of errored frame seconds that have been detected since the OAM sublayer was reset. When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.41. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.45.
h) ***Event Running Total.*** This four-octet field indicates the number of Errored Frame Seconds Summary Event TLVs that have been generated since the OAM sublayer was reset, encoded as a 32-bit unsigned integer.When this event is generated by the local DTE and if Clause 30 is present, this maps to 30.3.6.1.41. When this event is received from the remote DTE and if Clause 30 is present, this maps to 30.3.6.1.45.

This event is generated at the end of the event window rather than when the threshold is crossed.

57.5.3.5 Organization Specific Event TLVs

The optional Organization Specific Event TLV may be used by organizations to define extensions to the Event mechanisms in this clause. Organization Specific Event TLVs shall have the following fields:

a) ***Event Type*** = *Organization Specific Event*. This one-octet field indicates the nature of the information carried in this TLV-tuple. The encoding of this field is found in Table 57–12.
b) ***Event Length.*** This one-octet field indicates the length (in octets) of this TLV-tuple. The length of the Organization Specific Event is unspecified.
c) ***Organizationally Unique Identifier.*** This three-octet field shall contain a 24-bit Organizationally Unique Identifier.
d) ***Organization Specific Value.*** This field indicates the value of the Organization Specific Event. This field's length and contents are unspecified.

57.6 Variables

MIB variables are queried through the use of Variable Request OAMPDUs and returned through the use of Variable Response OAMPDUs. Variable Request OAMPDUs, defined in 57.4.3.3, use data structures called Variable Descriptors (see 57.6.1). An OAM client may request one or more variables in each Variable Request OAMPDU.

Variable Response OAMPDUs, defined in 57.4.3.4, use data structures called Variable Containers (see 57.6.2). Each returned Variable Container resides within a single Variable Response OAMPDU. If a Variable Container does not fit within a Variable Response OAMPDU, an error code is returned. In returning requested variables, an OAM client generates at least one and perhaps additional Variable Response OAMPDUs per received Variable Request OAMPDU. The following subclauses describe the format of Variable Descriptors and Variable Containers.

See 57.6.3 for a description of the parsing rules for Variable Descriptors and Variable Containers.

57.6.1 Variable Descriptors

A Variable Descriptor is used to request MIB attributes, objects and packages and uses the encodings found in Annex B of IEEE Std 802.3.1. The Variable Descriptor structure shall be as shown in Table 57–13.

Table 57–13—Variable Descriptor format

Octet(s)	Name	Description
1	Variable Branch	As defined in Annex B of IEEE Std 802.3.1, Variable Branches may reference attributes, objects or packages. If an object or package is referenced, only the attributes within the object or package shall be found within the Variable Container. Actions shall not be found within Variable Containers.
2	Variable Leaf	The Variable Leaf field is derived from the encodings found in Annex B of IEEE Std 802.3.1.

57.6.2 Variable Containers

Variable Containers are used to return MIB attributes, objects and packages. One or more Variable Containers may exist in the Data field of a Variable Response OAMPDU (see 57.4.3.4).

57.6.2.1 Format of Variable Containers when returning attributes

The Variable Container structure for an attribute shall be as shown in Table 57–14.

Table 57–14—Variable Container format when returning an attribute

Octet(s)	Name	Description
1	Variable Branch	Derived from the encodings found in Annex B of IEEE Std 802.3.1, Variable Branches may reference attributes, objects or packages. If an object or package is referenced, only the attributes within the object or package shall be found within the Variable Container. Actions shall not be found within Variable Containers.
2	Variable Leaf	The Variable Leaf field is derived from the encodings found in Annex B of IEEE Std 802.3.1.
1	Variable Width	When bit 7 = 1, bits 6:0 represent a Variable Indication. Refer to Table 57–17 for the encoding of bits 6:0. There is no Variable Value field when bit 7 = 1. When bit 7 = 0, bits 6:0 represent the length of the Variable Value field in octets. An encoding of 0x00 equals 128 octets. All other encodings represent actual lengths.
varies	Variable Value	The Variable Value field may be 1 to 128 octets in length. Its width is determined by the Variable Width field.

The first field is the one-octet Variable Branch field. The second field is the two-octet Variable Leaf field. See Table 57–16 for examples of Variable Branch and Variable Leaves. The third field is the dual purpose one-octet Variable Width field. This field either contains the actual width of the attribute or a Variable Indication providing information as to the reason this particular attribute could not be returned. See Table 57–17 for the defined Variable Indications. If the Variable Width field contains a width value, the fourth field is the Variable Value field, which contains the attribute. This field may be up to 128 octets in length. Octets of the attribute are ordered most significant first, followed by each successive octet. If the Variable Width field contains a Variable Indication, the Variable Value field does not exist.

Additionally, a special Variable Container with Variable Branch and Leaf values corresponding to an object identification number (such as 7/330 for a PME ID, or 7/282 for an EPON LLID), Variable Width equal to 2, and Variable Value equal to a 2-octet identification number, may be used in a Variable Request OAMPDU to select a particular instance of a managed object of which multiple instances exist in the remote MIB.

The Variable Value identifies which instance is being addressed. Subsequent Variable Descriptors shall be understood to target the attributes of the selected instance until an other instance selector is received or the Variable Request OAMPDU ends. Each instance selector shall be acknowledged with a Variable Container indicating the same Branch/Leaf and the identifier that was selected, preceding the concerned variables. If no explicit instance selection has taken place, all instances of the concerned object are addressed. In this case, each subsequent Variable Descriptor shall be understood to consecutively target the attributes of all existing instances until an instance selector is received or the Variable Request OAMPDU ends.

The Variable Containers returned by the far-end OAM client may be transmitted in one or more OAMPDUs, respecting the OAMPDU size limitations.

NOTE—In the case of PME Aggregation, each PME is identified by a bit position in a 32-bit string during the Handshake process. This position should be transformed into a number between 0 and 31 before transmission in the Variable Value field.

57.6.2.2 Format of Variable Containers when returning packages and objects

The Variable Container structure for packages and objects shall be as shown in Table 57–15.

Table 57–15—Variable Container format when returning packages and objects

Octet(s)	Name	Description
1	Variable Branch	Derived from the encodings found in Annex B of IEEE Std 802.3.1, Variable Branches may reference attributes, objects or packages. If an object or package is referenced, only the attributes within the object or package shall be found within the Variable Container. Actions shall not be found within Variable Containers.
2	Variable Leaf	The Variable Leaf field is derived from the encodings found in Annex B of IEEE Std 802.3.1.
1	Variable Width	When bit 7 = 1, bits 6:0 represent a Variable Indication. Refer to Table 57–17 for the encoding of bits 6:0. There is no Variable Value field when bit 7 = 1. When bit 7 = 0, bits 6:0 represent the length of the Variable Value field in octets. An encoding of 0x00 equals 128 octets. All other encodings represent actual lengths.
varies	Variable Value	The Variable Value field may be 1 to 128 octets in length. Its width is determined by the Variable Width field.

A package is defined as a set of MIB attributes and/or actions. An object is a set of packages, which in turn are made up of MIB attributes and/or actions. Variable Containers provide an efficient method for returning packages and objects. Objects are returned in the order they are listed in Annex B of IEEE Std 802.3.1.

The Variable Container structure for packages and objects is similar to the structure for attributes. The first field is the one-octet Variable Branch field for the specific package or object being returned. The second field is the two-octet Variable Leaf field for the specific package or object being returned. See Table 57–16 for examples of Variable Branch and Variable Leaves. The third field is the dual purpose one-octet Variable Width field of the first attribute within the package or object being returned. This field either contains the actual width of the attribute or a Variable Indication providing information as to the reason this particular attribute could not be returned. See Table 57–17 for the defined Variable Indications. If the Variable Width field contains a width value, the fourth field is the Variable Value field, which contains the first attribute of the package or object being returned. This field may be up to 128 octets in length. Octets of the attribute are ordered most significant first, followed by each successive octet. If the Variable Width field contains a Variable Indication, the Variable Value field does not exist.

For each successive attribute within the package, the third field (Variable Width) and fourth field (Variable Value), if applicable, are repeated.

For each successive attribute within each successive package of the object, the third field (Variable Width) and fourth field (Variable Value), if applicable, are repeated.

57.6.3 Parsing

The OAM client parses Variable Descriptors and Variable Containers. All Variable Descriptors/Containers contain a one-octet Variable Branch field and a two-octet Variable Leaf field. Variable Descriptor/Container processing should follow these recommendations:

a) Detection of a Variable Branch field equal to 0x00 should indicate there are no more Variable Descriptors/Containers to process (subsequent fields can be ignored).
b) Variable Branch or Variable Leaf fields with unknown or unexpected values should be ignored.
c) If a Variable Width field indicates Variable Container extends beyond the frame (e.g., the length cannot fit into the frame given its length and starting point), then the Variable Container should be ignored.

d) Detection of a Variable Indication value equal to 0x40 should indicate there are no more attributes within the object to process.
e) Detection of a Variable Indication value equal to 0x60 should indicate there are no more objects within the package to process.
f) Detection of a Variable Container in a Variable Request OAMPDU indicates that subsequent Variable Descriptors shall be applied to the instance of the managed object corresponding to the identification number expressed in the Variable Value field of the Variable Container. In the corresponding Variable Response OAMPDU, a Variable Container indicating the selected instance shall immediately precede the Variable Containers pertaining to objects of which a particular instance was selected.

57.6.4 Variable Branch/Leaf examples

Table 57–16 contains a set of example branch and leaf values for attributes, packages and objects.

Table 57–16—Variable Branch/Leaf examples

Variable Type	Variable Name	Variable Branch	Variable Leaf
attribute	aFramesTransmittedOK	0x07	0x0002
attribute	aFramesReceivedOK	0x07	0x0005
package	pMandatory	0x04	0x0001
package	pRecommended	0x04	0x0002
object	oMACEntity	0x03	0x0001
object	oPHYEntity	0x03	0x0002

57.6.5 Variable Indications

If a DTE is unable to retrieve one or more variables, the Variable Container is used to return the appropriate Variable Indication for the particular variable(s). The Variable Indications are defined in Table 57–17.

Table 57–17—Variable indications

Coding	Indication
0x00	*Reserved - shall not be transmitted, should be ignored on reception by OAM client*
0x01	Length of requested Variable Container(s) exceeded OAMPDU data field.
0x02 to 0x1F	*Reserved—shall not be transmitted, should be ignored on reception by OAM client*
Attribute Indications	
0x20	Requested attribute was unable to be returned due to an undetermined error.
0x21	Requested attribute was unable to be returned because it is not supported by the local DTE.
0x22	Requested attribute may have been corrupted due to reset.
0x23	Requested attribute unable to be returned due to a hardware failure.
0x24	Requested attribute experienced an overflow error.
0x25 to 0x3F	*Reserved—shall not be transmitted, should be ignored on reception by OAM client*
Object Indications	
0x40	End of object indication.

Table 57–17—Variable indications *(continued)*

Coding	Indication
0x41	Requested object was unable to be returned due to an undetermined error.
0x42	Requested object was unable to be returned because it is not supported by the local DTE.
0x43	Requested object may have been corrupted due to reset.
0x44	Requested object unable to be returned due to a hardware failure.
0x45 to 0x5F	*Reserved—shall not be transmitted, should be ignored on reception by OAM client*
Package Indications	
0x60	End of package indication.
0x61	Requested package was unable to be returned due to an undetermined error.
0x62	Requested package was unable to be returned because it is not supported by the local DTE.
0x63	Requested package may have been corrupted due to reset.
0x64	Requested package unable to be returned due to a hardware failure.
0x65 to 0x7F	*Reserved—shall not be transmitted, should be ignored on reception by OAM client*

57.7 Protocol implementation conformance statement (PICS) proforma for Clause 57, Operations, Administration, and Maintenance (OAM)[5]

57.7.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 57, Operations, Administration, and Maintenance (OAM), shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

57.7.2 Identification

57.7.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

57.7.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 57, Operations, Administration, and Maintenance (OAM)
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[5] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

57.7.2.3 Major capabilities/options

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
OM	OAM object class	30.3.6		O	Yes [ ] No [ ]
CSI	OAM client service interfaces	57.2.5		M	Yes [ ]
ISI	Internal service interfaces	57.2.8		M	Yes [ ]
*ACTV	Active mode	57.2.9		O.1	Yes [ ] No [ ]
*PASS	Passive mode	57.2.9		O.1	Yes [ ] No [ ]
*LB	OAM remote loopback	57.2.11, Table 57–8		O	Yes [ ] No [ ]
UNI	Unidirectional operation	57.2.12, Table 57–8	Requires support for unidirectional operation as defined in Clause 66.	O	Yes [ ] No [ ]
*EVNT	Link Events	57.4.3.2, 57.5.3		O	Yes [ ] No [ ]
*VAR	Variable Retrieval	57.4.3.3, 57.4.3.4		O	Yes [ ] No [ ]
*OSP	Organization Specific OAMPDU	57.4.3.6		O	Yes [ ] No [ ]
*OSE	Organization Specific Events	57.5.3.5		O	Yes [ ] No [ ]
OSI	Organization Specific Information TLV	57.5.2.3		O	Yes [ ] No [ ]

57.7.3 PICS proforma tables for Operation, Administration, and Maintenance (OAM)

57.7.3.1 Functional specifications

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
OFS1	Passive mode limited transmission	57.2.9.2	Cannot send Variable Request or Loopback Control OAMPDUs	PASS:M	Yes [ ] No [ ] N/A [ ]
OFS2	Discovery state diagram	57.3.2.1	Implemented as defined in Figure 57–5	M	Yes [ ]
OFS3	Transmit state diagram	57.3.2.2	Implemented as defined in Figure 57–6	M	Yes [ ]
OFS4	OAMPDU transmission when local_pdu is set to LF_INFO	57.3.2.2.6	Only Information OAMPDUs with Link Fault bit of Flags field and without Information TLVs can be transmitted	M	Yes [ ]
OFS5	OAMPDU transmission when local_pdu is set to RX_INFO	57.3.2.2.6	No OAMPDU transmission allowed	M	Yes [ ]
OFS6	OAMPDU transmission when local_pdu is set to INFO	57.3.2.2.6	Only Information OAMPDUs can be transmitted	M	Yes [ ]

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
	OAMPDU transmission when local_pdu is set to ANY:				
OFS7	OAM_CTL.request service primitive with one or more critical link event parameters	57.3.2.2.6	Requests transmission of Information OAMPDU with appropriate bits of Flags field set	M	Yes [ ]
OFS8	OAMPDU.request service primitive	57.3.2.2.6	Requests transmission of OAMPDU	M	Yes [ ]
	OAMPDU Flags field reserved encodings				
OFS9	Remote Stable and Remote Evaluating bits	Table 57–3	Encoding of 0x3 is not transmitted	M	Yes [ ]
OFS10	Local Stable and Local Evaluating bits	Table 57–3	Encoding of 0x3 is not transmitted	M	Yes [ ]
OFS11	Reserved bits	Table 57–3	Reserved bits are zero on transmission	M	Yes [ ]
OFS12	OAMPDU Code field	57.4.2.2	Only defined Code field values are permitted in transmitted OAMPDUs	M	Yes [ ]
OFS13	OAMPDU reception when local_pdu is not set to ANY	57.3.2.3	Only Information OAMPDUs are sent to OAM client entity	M	Yes [ ]
OFS14	OAMPDU reception when local_pdu is set to ANY	57.3.2.3	All OAMPDUs are sent to OAM client entity	M	Yes [ ]
OFS15	Multiplexer state diagram	57.3.3	Implemented as defined in Figure 57–7	M	Yes [ ]
OFS16	Multiplexer transparent pass-through	57.3.3.2	Provide transparent pass-through of frames from superior sublayer to subordinate sublayer	M	Yes [ ]
OFS17	Effect of OAMPDU on a frame already submitted to subordinate sublayer	57.3.3.2	Has no effect	M	Yes [ ]
OFS18	Parser state diagram	57.3.4	Implemented as defined in Figure 57–8	M	Yes [ ]

57.7.3.2 Event Notification Generation and Reception

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
EV1	Response to Critical Events	57.2.10.3	Set/clear Flag bits based on OAM_CTL.request service primitive	M	Yes [ ]
EV2	Critical Event reception	57.2.10.4	Indicated via Flags field of OAMPDU.indication service primitive	M	Yes [ ]
EV3	Link Event reception	57.2.10.4	Indicated via OAMPDU.indication service primitive with all received Event Notification OAMPDUs	EVNT:M	Yes [ ] N/A [ ]

57.7.3.3 OAMPDUs

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
PDU2	OAMPDU structure	57.4.2	As defined in Figure 57–9 and field definitions	M	Yes [ ]
PDU3	Minimum OAMPDU size	57.4.2	Support OAMPDUs minFrameSize in length	M	Yes [ ]
PDU4	Information OAMPDU frame structure	57.4.3.1	Shown in Figure 57–10	M	Yes [ ]
PDU5	Information OAMPDU when local_pdu set to LF_INFO	57.4.3.1	Data field contains zero Information TLVs	M	Yes [ ]
	Information OAMPDU when local _pdu not set to LF_INFO				
PDU6	remote_state_valid=FALSE	57.4.3.1	Data field contains Local Information TLV	M	Yes [ ]
PDU7	remote_state_valid=TRUE	57.4.3.1	Data field contains Local and Remote Information TLVs	M	Yes [ ]
PDU8	Type values 0x03-0xFD	Table 57–6	Not to be sent	M	Yes [ ]
PDU9	Type value 0xFF	Table 57–6	Not to be sent	M	Yes [ ]
PDU10	Event Notification OAMPDU frame structure	57.4.3.2	Shown in Figure 57–11	EVNT:M	Yes [ ] N/A [ ]
PDU11	Event Notification OAMPDU Sequence Number	57.4.3.2	The first two bytes of the Data field contain a Sequence Number encoded as an unsigned 16-bit integer	EVNT:M	Yes [ ] N/A [ ]
PDU12	Event Notification OAMPDU Event(s)	57.4.3.2	Data field containing one or more Link Event TLVs following the Sequence Number	EVNT:M	Yes [ ] N/A [ ]
PDU13	Variable Request OAMPDU frame structure	57.4.3.3	Shown in Figure 57–12	VAR * ACTV:M	Yes [ ] No [ ] N/A [ ]
PDU14	Variable Request OAMPDU Data field	57.4.3.3	Data field contains one or more Variable Descriptors	VAR * ACTV:M	Yes [ ] N/A [ ]
PDU15	Variable Response OAMPDU frame structure	57.4.3.4	Shown in Figure 57–13	VAR:M	Yes [ ] N/A [ ]
PDU16	Variable Response OAMPDU Data field	57.4.3.4	Data field contains one or more Variable Containers	VAR:M	Yes [ ] N/A [ ]
PDU17	Loopback Control OAMPDU frame structure	57.4.3.5	Shown in Figure 57–14	!PASS * LB:M	Yes [ ] N/A [ ]
PDU18	Loopback Control OAMPDU Data field	57.4.3.5	Data field contains a single OAM Remote Loopback command from Table 57–5	!PASS * LB:M	Yes [ ] N/A [ ]
PDU19	Command value 0x00	Table 57–5	Not to be sent	!PASS * LB:M	Yes [ ] N/A [ ]
PDU20	Command values 0x03–0xFF	Table 57–5	Not to be sent	!PASS * LB:M	Yes [ ] N/A [ ]
PDU21	Organization Specific OAMPDU frame structure	57.4.3.6	Shown in Figure 57–15	OSP:M	Yes [ ] N/A [ ]
PDU22	Organization Specific OAMPDU Organizationally Unique Identifier field	57.4.3.6	Contains 24-bit Organizationally Unique Identifier	OSP:M	Yes [ ] N/A [ ]

57.7.3.4 Local Information TLVs

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
LIT1	Local Information TLV	57.5.2.1	Contains the following fields: Information Type, Information Length, OAM Version, Revision, State, OAM Configuration, OAMPDU Configuration, OUI/CID, Vendor Specific Information	M	Yes [ ]
LIT2	Local Information TLV OAM Version field	57.5.2.1	Contains 0x01 to claim compliance to this specification	M	Yes [ ]
LIT3	Local Information TLV Revision Field	57.5.2.1	Starts at zero and incremented each time a Local Information TLV field changes	M	Yes [ ]
LIT4	Local Information TLV State field	57.5.2.1	As defined in Table 57–7	M	Yes [ ]
LIT5	Local Information TLV State field Parser Action 0x3 value	57.5.2.1	Is not transmitted	M	Yes [ ]
LIT6	Reserved bits	Table 57–7	Reserved bits are zero on transmission	M	Yes [ ]
LIT7	Local Information TLV OAM Configuration field	57.5.2.1	As defined in Table 57–8	M	Yes [ ]
LIT8	Reserved bits	Table 57–8	Reserved bits are zero on transmission	M	Yes [ ]
LIT9	Local Information TLV OAMPDU Configuration field	57.5.2.1	As defined in Table 57–9	M	Yes [ ]
LIT10	Local Information TLV OUI/ CID field	57.5.2.1	As defined in Table 57–10	M	Yes [ ]
LIT11	Reserved bits	Table 57–9	Reserved bits are zero on transmission	M	Yes [ ]
LIT12	Local Information TLV Vendor Specific Information field	57.5.2.1	As defined in Table 57–11	M	Yes [ ]

57.7.3.5 Remote Information TLVs

Item	Feature	Subclause	Value/Comment	Status	Support
RIT1	Remote Information TLV	57.5.2.2	Contains the Information Type field specifying the Remote Information TLV Type value and all remaining fields are copied from the last received Local Information TLV from remote OAM peer	M	Yes [ ]

57.7.3.6 Organization Specific Information TLVs

Item	Feature	Subclause	Value/Comment	Status	Support
OIT1	Organization Specific Information TLV	57.5.2.3	Contains the following fields: Information Type, Information Length, OUI/CID, Organization Specific Value	M	Yes [ ]
OIT2	Organization Specific Information TLV OUI field	57.5.2.3	Contains 24-bit OUI/CID	M	Yes [ ]

57.7.4 Link Event TLVs

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
ET1	Errored Symbol Period Event TLV structure	57.5.3.1	Contains the following fields: Event Type, Event Length, Event Time Stamp, Errored Symbol Window, Errored Symbol Threshold, Errored Symbols, Error Running Total, Event Running Total	EVNT:M	Yes [ ] N/A [ ]
ET2	Errored Frame Event TLV structure	57.5.3.2	Contains the following fields: Event Type, Event Length, Event Time Stamp, Errored Frame Window, Errored Frame Threshold, Errored Frames, Error Running Total, Event Running Total	EVNT:M	Yes [ ] N/A [ ]
ET3	Errored Frame Period Event TLV structure	57.5.3.3	Contains the following fields: Event Type, Event Length, Event Time Stamp, Errored Frame Window, Errored Frame Threshold, Errored Frames, Error Running Total, Event Running Total	EVNT:M	Yes [ ] N/A [ ]
ET4	Errored Frame Seconds Summary Event TLV structure	57.5.3.4	Contains the following fields: Event Type, Event Length, Event Time Stamp, Errored Frame Seconds Summary Window, Errored Frame Seconds Summary Threshold, Errored Frame Seconds Summary, Error Running Total, Event Running Total	EVNT:M	Yes [ ] N/A [ ]
ET5	Organization Specific Event TLV structure	57.5.3.5	Contains the following fields: Event Type, Event Length, Organizationally Unique Identifier, Organization Specific Value	EVNT * OSE:M	Yes [ ] N/A [ ]
ET6	Organization Specific Event Organizationally Unique Identifier field	57.5.3.5	Contains 24-bit Organizationally Unique Identifier	EVNT * OSE:M	Yes [ ] N/A [ ]
ET7	Type values 0x05 to 0xFD	Table 57–12	Not to be sent	EVNT:M	Yes [ ] N/A [ ]
ET8	Type value 0xFF	Table 57–12	Not to be sent	EVNT:M	Yes [ ] N/A [ ]

57.7.5 Variables Descriptors and Containers

Item	Feature	Subclause/ Table	Value/Comment	Status	Support
VAR1	Variable Descriptor structure	57.6.1	As defined in Table 57–13	VAR * ACTV:M	Yes [ ] N/A [ ]
	Variable Descriptor / Variable Branch				
VAR2	references attributes	57.6.1	If an object or package is referenced, only attributes can be found within Variable Container	VAR * ACTV:M	Yes [ ] N/A [ ]
VAR3	does not reference actions	57.6.1	Actions are not found in Variable Containers	VAR * ACTV:M	Yes [ ] N/A [ ]
VAR4	Variable Container structure for an attribute	57.6.2	As defined in Table 57–14	VAR:M	Yes [ ] N/A [ ]
	Variable Container / Variable Branch				
VAR5	references attributes	57.6.2	If an object or package is referenced, only attributes can be found within Variable Container	VAR:M	Yes [ ] N/A [ ]
VAR6	does not reference actions	57.6.2	Actions are not found in Variable Containers	VAR:M	Yes [ ] N/A [ ]
VAR7	Type value 0x00	Table 57–16	Not to be sent	VAR:M	Yes [ ] N/A [ ]
VAR8	Type values 0x02 to 0x1F	Table 57–16	Not to be sent	VAR:M	Yes [ ] N/A [ ]
VAR9	Type values 0x25 to 0x2F	Table 57–16	Not to be sent	VAR:M	Yes [ ] N/A [ ]
VAR10	Type values 0x45 to 0x5F	Table 57–16	Not to be sent	VAR:M	Yes [ ] N/A [ ]
VAR11	Type values 0x65 to 0x7F	Table 57–16	Not to be sent	VAR:M	Yes [ ] N/A [ ]

58. Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 (Long Wavelength) and 100BASE-BX10 (BiDirectional Long Wavelength)

58.1 Overview

The 100BASE-LX10 and 100BASE-BX10 PMD sublayers provide point-to-point 100 Mb/s Ethernet links over a pair of single-mode fibers or an individual single-mode fiber, respectively, up to at least 10 km. They complement 100BASE-TX (twisted-pair cable, see Clause 25) and 100BASE-FX (multimode fiber, see Clause 26).

This clause specifies the 100BASE-LX10 PMD and the 100BASE-BX10 PMDs for operation over single-mode fiber. A PMD is connected to the 100BASE-X PMA of 66.1, and to the medium through the MDI. A PMD is optionally combined with the management functions that may be accessible through the management interface defined in Clause 22 or by other means.

Table 58–1 shows the primary attributes of each PMD type.

Table 58–1—Classification of 100BASE-LX10 and 100BASE-BX10

Description	100BASE-LX10	100BASE-BX10-D	100BASE-BX10-U	Unit
Fiber type	B1.1, B1.3 SMF[a]			
Number of fibers	2	1		
Typical transmit direction	Any	Downstream	Upstream	
Nominal transmit wavelength	1310	1550	1310	nm
Minimum range	0.5 m to 10 km			
Maximum channel insertion loss[b]	6.0	5.5	6.0	dB

[a] Specified in IEC 60793-2.
[b] At the nominal wavelength.

A 100BASE-LX10 link uses 100BASE-LX10 PMDs at each end while a 100BASE-BX10 link uses a 100BASE-BX10-D PMD at one end and a 100BASE-BX10-U PMD at the other. Typically, the 1550 nm band is used to transmit away from the center of the network (“downstream”) and the 1310 nm band towards the center (“upstream”), although this arrangement, or the notion of hierarchy, is not required. The suffixes “D” and “U” indicate the PMDs at each end of a link which transmit in these directions and receive in the opposite directions.

Two optional temperature ranges are defined; see 58.8.4 for further details. Implementations may be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

58.1.1 Goals and objectives

The following are the objectives of 100BASE-LX10 and 100BASE-BX10:

a) Point-to-point on optical fiber
b) 100BASE-X up to at least 10 km over single-mode fiber (SMF)
c) BER better than or equal to 10^{-12} at the PHY service interface

58.1.2 Positioning of this PMD set within the IEEE 802.3 architecture

Figure 58–1 depicts the relationships of the PMD (shown shaded) with other sublayers and the ISO/IEC Open System Interconnection (OSI) reference model.

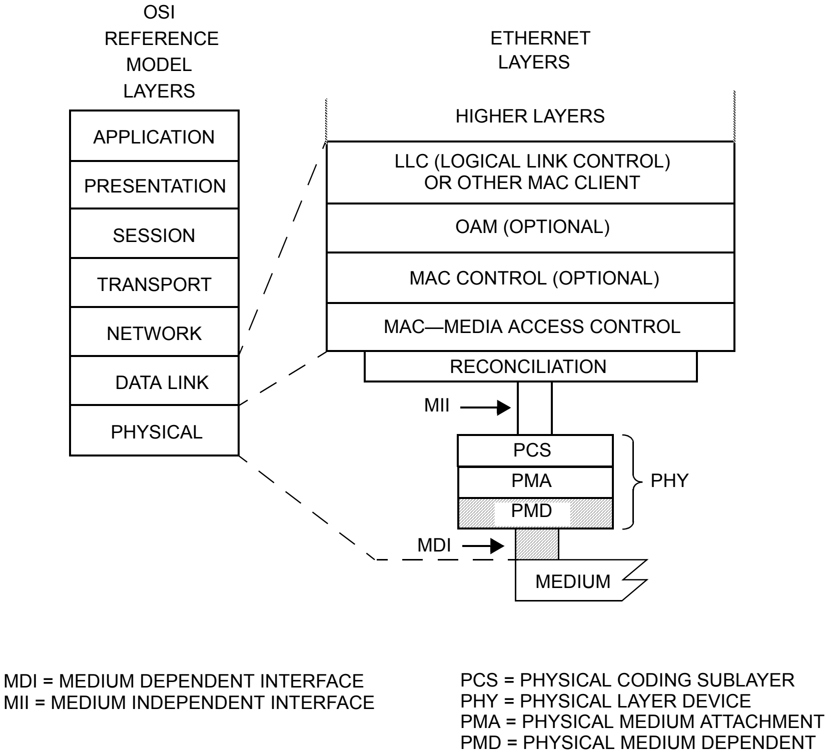


Figure 58–1—100BASE-LX10 and 100BASE-BX10 PMDs relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

58.1.3 Terminology and conventions

The following list contains references to terminology and conventions used in this clause:

Basic terminology and conventions, see 1.1 and 1.2.

Normative references, see 1.3.

Definitions, see 1.4.

Abbreviations, see 1.5.

Informative references shown referenced in the format [Bn], see Annex A.

Introduction to 100 Mb/s baseband networks, see Clause 21.

Introduction to Ethernet for subscriber access networks, see Clause 56

58.1.4 Physical Medium Dependent (PMD) sublayer service interface

The following specifies the services provided by the 100BASE-LX10 and 100BASE-BX10 PMDs. These PMD sublayer service interfaces are described in an abstract manner and do not imply any particular implementation.

The PMD service interface supports the exchange of NRZI encoded 4B/5B bit streams between the PMA and PMD entities. The PMD translates the serialized data of the PMA to and from signals suitable for the specified medium.

The following primitives are defined:

PMD_UNITDATA.request
PMD_UNITDATA.indication
PMD_SIGNAL.indication

58.1.4.1 Delay constraints

Delay requirements which affect the PMD layer are specified in 24.6. Of the budget, up to 12 ns is reserved for each of the transmit and receive functions of the PMD to account for those cases where the PMD includes a pigtail.

58.1.4.2 PMD_UNITDATA.request

This primitive defines the transfer of a serial data stream from the PMA to the PMD.

The semantics of the service primitive are PMD_UNITDATA.request(tx_bit). The data conveyed by PMD_UNITDATA.request is a continuous stream of bits where the tx_bit parameter can take one of two values: ONE or ZERO. The PMA continuously sends the appropriate stream of bits to the PMD for transmission on the medium, at a nominal 125 MBd signaling speed. Upon receipt of this primitive, the PMD converts the specified stream of bits into the appropriate signals at the MDI.

58.1.4.3 PMD_UNITDATA.indication

This primitive defines the transfer of data from the PMD to the PMA.

The semantics of the service primitive are PMD_UNITDATA.indication(rx_bit). The data conveyed by PMD_UNITDATA.indication is a continuous stream of bits where the rx_bit parameter can take one of two values: ONE or ZERO. The PMD continuously sends a stream of bits to the PMA corresponding to the signals received from the MDI.

58.1.4.4 PMD_SIGNAL.indication

This primitive is generated by the PMD to indicate the status of the signal being received from the MDI.

The semantics of the service primitive are PMD_SIGNAL.indication(SIGNAL_DETECT). The SIGNAL_DETECT parameter can take on one of two values: OK or FAIL, indicating whether the PMD is detecting light at the receiver (OK) or not (FAIL). When SIGNAL_DETECT = FAIL, PMD_UNITDATA.indication(rx_bit) is undefined. The PMD generates this primitive to indicate a change in the value of SIGNAL_DETECT.

NOTE—SIGNAL_DETECT = OK does not guarantee that PMD_UNITDATA.indication(rx_bit) is known good. It is possible for a poor quality link to provide sufficient light for a SIGNAL_DETECT = OK indication and still not meet the specified bit error ratio.

58.2 PMD functional specifications

The 100BASE-X PMDs perform the transmit and receive functions that convey data between the PMD service interface and the MDI.

58.2.1 PMD block diagram

The PMD sublayer is defined at the four reference points shown in Figure 58–2. Two points, TP2 and TP3, are compliance points. TP1 and TP4 are reference points for use by implementers. The optical transmit signal is defined at the output end of a patch cord (TP2), between 2 and 5 m in length, of single-mode fiber. Unless specified otherwise, all transmitter measurements and tests defined in 58.7 are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3) connected to the receiver. Unless specified otherwise, all receiver measurements and tests defined in 58.7 are made at TP3.

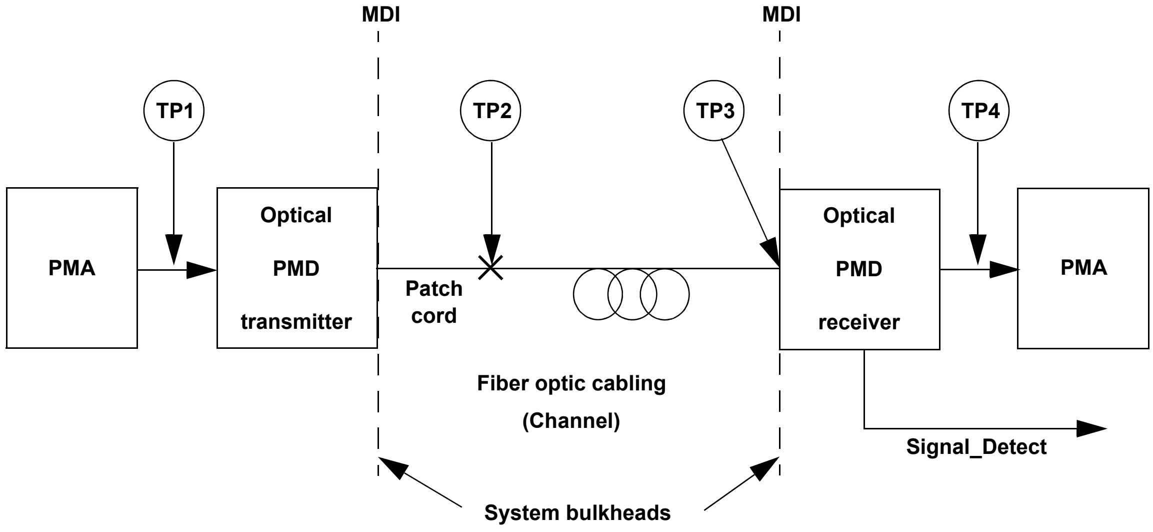


Figure 58–2—100BASE-X block diagram

The electrical specifications of the PMD service interface (TP1 and TP4) are not system compliance points (these are not readily testable in a system implementation). It is expected that in many implementations, TP1 and TP4 will be common between 100BASE-LX10, 100BASE-BX10-D, 100BASE-BX10-U, and 100BASE-FX (multimode fiber, see Clause 26).

58.2.2 PMD transmit function

The PMD transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the optical specifications in this clause. The higher optical power level should correspond to tx_bit = ONE.

NOTE—Because the NRZI coding distinguishes between a transition and no transition on the line, as opposed to 0 and 1, an inverted signal is usable.

58.2.3 PMD receive function

The PMD receive function shall convey the bits received from the MDI according to the optical specifications in this clause to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). The higher optical power level should correspond to rx_bit = ONE.

NOTE—Because the NRZI coding distinguishes between a transition and no transition on the line, as opposed to 0 and 1, an inverted signal is usable.

58.2.4 100BASE-LX10 and 100BASE-BX10 signal detect function

The PMD signal detect function shall report to the PMD service interface, using the message PMD_SIGNAL.indication(SIGNAL_DETECT), which is signaled continuously. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence.

The value of the SIGNAL_DETECT parameter for 100BASE-LX10 and 100BASE-BX10 shall be generated according to the conditions defined in Table 58–2. The PMD receiver is not required to verify whether a compliant 100BASE-LX10 signal or 100BASE-BX10 signal is being received. This standard imposes no response time requirements on the generation of the SIGNAL_DETECT parameter.

Table 58–2—100BASE-LX10 and 100BASE-BX10 SIGNAL_DETECT value definition

Receive conditions		SIGNAL_DETECT value
100BASE-LX10	**100BASE-BX10**	
Average input optical power ≤ Signal detect threshold (min) in Table 58–4	Average input optical power ≤ Signal detect threshold (min) in Table 58–6	FAIL
Average input optical power ≥ Receiver sensitivity (max) in Table 58–4 with a compliant 100BASE-LX10 signal input	Average input optical power ≥ Receiver sensitivity (max) in Table 58–6 with a compliant 100BASE-BX10 signal input at the specified receiver wavelength	OK
All other conditions		Unspecified

As an unavoidable consequence of the requirements for the setting of the SIGNAL_DETECT parameter, implementations must provide adequate margin between the input optical power level at which the SIGNAL_DETECT parameter is set to OK, and the inherent noise level of the PMD due to cross talk, power supply noise, etc.

Various implementations of the signal detect function are permitted by this standard, including implementations that generate the SIGNAL_DETECT parameter values in response to the amplitude of the modulation of the optical signal and implementations that respond to the average optical power of the modulated optical signal.

58.3 PMD to MDI optical specifications for 100BASE-LX10

The operating range for 100BASE-LX10 is defined in Table 58–1. A 100BASE-LX10 compliant transceiver operates over the media types listed in Table 58–1 according to the specifications described in 58.9. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

NOTE—In this subclause and 58.4, the specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is explained in 58.7.6.

58.3.1 Transmitter optical specifications

The 100BASE-LX10 transmitter’s signaling speed, operating wavelength, spectral width, average launch power, extinction ratio, return loss tolerance, OMA, eye and TDP shall meet the specifications defined in Table 58–3 per measurement techniques described in 58.7. Its $\mathrm{RIN}_{12}\mathrm{OMA}$ should meet the value listed in Table 58–3 per measurement techniques described in 58.7.7.

Table 58–3—100BASE-LX10 transmit characteristics

Description	Type B1.1, B1.3 SMF	Unit
Transmitter type[a]	Longwave laser	
Signaling speed (range)	125 ± 50 ppm	MBd
Operating wavelength range[b]	1260 to 1360	nm
RMS spectral width (max)	7.7	nm
Average launch power (max)	–8	dBm
Average launch power (min)	–15	dBm
Average launch power of OFF transmitter (max)	–45	dBm
Extinction ratio (min)	5	dB
$\mathrm{RIN}_{12}\mathrm{OMA}$[c] (max)	–110	dB/Hz
Optical return loss tolerance (max)	12	dB
Launch OMA (min)	–14.8 (33.1)	dBm (μW)
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3, Y4}	{0.18, 0.29, 0.35, 0.35, 0.38, 0.4, 0.55}	UI
Transmitter and dispersion penalty (max)	4.5	dB
Decision timing offsets for transmitter and dispersion penalty (min)	±1.6	ns

[a] The nominal transmitter type is not intended to be a requirement on the source type, and any transmitter meeting the transmitter characteristics specified may be substituted for the nominal transmitter type.

[b] The great majority of the transmitted spectrum must fall within the operating wavelength range, see 58.7.2.

[c] The $\mathrm{RIN}_{12}\mathrm{OMA}$ recommendation is informative not mandatory.

58.3.2 Receiver optical specifications

The 100BASE-LX10 receiver’s signaling speed, operating wavelength, damage, overload, sensitivity, reflectance and signal detect shall meet the specifications defined in Table 58–4 per measurement techniques defined in 58.7. Its stressed receive characteristics should meet the values listed in Table 58–4 per measurement techniques described in 58.7.11. The receiver sensitivity includes the extinction ratio penalty.

A compliant receiver may be shown to deliver an error ratio lower than that in the table at the received power shown in the table, or shown to deliver an error ratio lower than 10^{-10} at a received power 1 dB lower than the value in the table. Sensitivity measurement is described in 58.7.10. Similarly, stressed receiver conformance may be shown for the error ratio and power shown in the table, or for 10^{-10} and 1 dB lower power. The 10^{-10} limits are more demanding but can be verified more accurately with reasonable test times.

Table 58–4—100BASE-LX10 receive characteristics

Description	Type B1.1, B1.3 SMF	Unit
Signaling speed (range)	125 ± 50 ppm	MBd
Operating wavelength range	1260 to 1360	nm
Bit error ratio (max)	10^{-12}	

Table 58–4—100BASE-LX10 receive characteristics *(continued)*

Description	Type B1.1, B1.3 SMF	Unit
Average received power[a] (max)	–8	dBm
Receiver sensitivity (max)	–25	dBm
Receiver sensitivity as OMA (max)	–24.8 (3.3)	dBm (μW)
Receiver reflectance[b] (max)	–12	dB
Stressed receiver sensitivity[c]	–20.1	dBm
Stressed receiver sensitivity as OMA (max)	–19.9 (10.2)	dBm (μW)
Vertical eye-closure penalty[d] (min)	3.7	dB
Stressed eye jitter (min)	0.25	UI pk-pk
Jitter corner frequency	20	kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	0.05, 0.15	UI
Signal detect threshold (min)	–45	dBm

[a] The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having a power level equal to the average received power (max) plus at least 1 dB.
[b] See 1.4 for definition of reflectance.
[c] The stressed receiver sensitivity is optional.
[d] Vertical eye closure penalty and the jitter specifications are test conditions for measuring stressed receiver sensitivity. They are not required characteristics of the receiver.

58.4 PMD to MDI optical specifications for 100BASE-BX10

The operating range for 100BASE-BX10 is defined in Table 58–1. A 100BASE-BX10-D or 100BASE-BX10-U compliant transceiver operates over the media types listed in Table 58–1 according to the specifications described in 58.9. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

NOTE—In this subclause and 58.3, the specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is explained in 58.7.6.

58.4.1 Transmit optical specifications

The 100BASE-BX10 transmitters' signaling speed, operating wavelength, spectral width, average launch power, extinction ratio, return loss tolerance, OMA, eye and TDP shall meet the specifications defined in Table 58–5 per measurement techniques described in 58.7. Its $RIN_{12}OMA$ should meet the value listed in Table 58–5 per measurement techniques described in 58.7.7.

Table 58–5—100BASE-BX10 transmit characteristics

Description	100BASE-BX10-D	100BASE-BX10-U	Unit
Nominal transmitter type[a]	Longwave laser		
Signaling speed (range)	125 ± 50 ppm		MBd
Operating wavelength range[b]	1480 to 1580	1260 to 1360	nm
RMS spectral width (max)	4.6	7.7	nm

Table 58–5—100BASE-BX10 transmit characteristics *(continued)*

Description	100BASE-BX10-D	100BASE-BX10-U	Unit
Average launch power (max)	–8		dBm
Average launch power (min)	–14		dBm
Average launch power of OFF transmitter (max)	–45		dBm
Extinction ratio (min)	6.6		dB
$RIN_{12}OMA$[c] (max)	–110		dB/Hz
Optical return loss tolerance (max)	12		dB
Launch OMA (min)	–12.9 (51.0)		dBm (µW)
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3, Y4}	{0.18, 0.29, 0.35, 0.35, 0.38, 0.4, 0.55}		UI
Transmitter and dispersion penalty (max)	4.5		dB
Decision timing offsets for transmitter and dispersion penalty (min)	±1.6		ns

[a] The nominal transmitter type is not intended to be a requirement on the source type, and any transmitter meeting the transmitter characteristics specified may be substituted for the nominal transmitter type.

[b] The great majority of the transmitted spectrum must fall within the operating wavelength range, see 58.7.2.

[c] The $RIN_{12}OMA$ recommendation is informative not mandatory.

58.4.2 Receiver optical specifications

The 100BASE-BX10 receivers' signaling speed, operating wavelength, damage, overload, sensitivity, reflectance and signal detect shall meet the specifications defined in Table 58–6 per measurement techniques defined in 58.7. Its stressed receive characteristics should meet the values listed in Table 58–6 per measurement techniques described in 58.7.11. The receiver sensitivity includes the extinction ratio penalty.

Table 58–6—100BASE-BX10 receive characteristics

Description	100BASE-BX10-D	100BASE-BX10-U	Unit
Signaling speed (range)	125 ± 50 ppm		MBd
Operating wavelength range[a]	1260 to 1360	1480 to 1600	nm
Bit error ratio (max)	10^{-12}		
Average received power[b] (max)	–8		dBm
Receiver sensitivity (max)	–28.2		dBm
Receiver sensitivity as OMA (max)	–27.1 (1.94)		dBm (µW)
Receiver reflectance[c] (max)	–12		dB
Stressed receiver sensitivity[d]	–23.3		dBm
Stressed receiver sensitivity as OMA (max)	–22.3 (6.0)		dBm (µW)
Vertical eye-closure penalty[e] (min)	3.8		dB

Table 58–6—100BASE-BX10 receive characteristics *(continued)*

Description	100BASE-BX10-D	100BASE-BX10-U	Unit
Stressed eye jitter (min)	0.25		UI pk-pk
Jitter corner frequency	20		kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	0.05, 0.15		UI
Signal detect threshold (min)	–45		dBm

[a] The receiver wavelength range of 100BASE-BX10-U is wider than the associated transmitter to allow interoperation with existing implementations of 100 Mb/s bi-directional transceivers.
[b] The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having a power level equal to the average received power (max) plus at least 1 dB.
[c] See 1.4 for definition of reflectance.
[d] The stressed receiver sensitivity is optional.
[e] Vertical eye closure penalty and jitter specifications are test conditions for measuring stressed receiver sensitivity. They are not required characteristics of the receiver.

A compliant receiver may be shown to deliver an error ratio lower than that in the table at the received power shown in the table, or shown to deliver an error ratio lower than 10^{-10} at a received power 1 dB lower than the value in the table. Sensitivity measurement is described in 58.7.10. Similarly, stressed receiver conformance may be shown for the error ratio and power shown in the table, or for 10^{-10} and 1 dB lower power. The 10^{-10} limits are more demanding but can be verified more accurately with reasonable test times.

58.5 Illustrative 100BASE-LX10 and 100BASE-BX10 channels and penalties (informative)

Illustrative channels and penalties for 100BASE-LX10 and 100BASE-BX10 are shown in Table 58–7.

NOTE—The budgets include an allowance for –12 dB reflection at the receiver.

Table 58–7—Illustrative 100BASE-LX10 and 100BASE-BX10 channels and penalties

Description	100BASE-LX10	100BASE-BX10-D	100BASE-BX10-U	Unit
Fiber type	B1.1, B1.3 SMF			
Measurement wavelength for fiber	1310	1550	1310	nm
Nominal distance	10			km
Available power budget	10	14.2		dB
Maximum channel insertion loss[a]	6.0	5.5	6.0	dB
Allocation for penalties[b]	4.0	8.7	8.2	dB

[a] The maximum channel insertion loss is based on the cable attenuation at the target distance and nominal measurement wavelength. The channel insertion loss also includes the loss for connectors, splices and other passive components.
[b] The allocation for penalties is the difference between the available power budget and the channel insertion loss; insertion loss difference between nominal and worst-case operating wavelength is considered a penalty. For 100BASE-X, it is possible for the allocation for penalties to be less than the TDP limit, as some penalties measured by TDP may arise in the receiver and need not be counted twice.

58.6 Jitter at TP1 and TP4 for 100BASE-LX10 and 100BASE-BX10 (informative)

The entries in Table 58–8 represent high-frequency jitter (above 20 kHz) and do not include low frequency jitter or wander. The informative Table 58–8 shows jitter specifications which may be of interest to implementers. High probability jitter at TP2 is constrained by the eye mask. Total jitter at TP3 (and therefore at TP2 also) is constrained by the error detector timing offsets. High levels of high probability jitter at TP2, TP3 and TP4 are expected, caused by high probability baseline wander. The jitter difference between TP2 and TP3 is expected to be lower than for higher speed PMDs.

Table 58–8—100BASE-LX10 and 100BASE-BX10 jitter budget (informative)

[a]	**Total jitter**		**High probability jitter (*W*)**	
Reference point	**UI**	**ns**	**UI**	**ns**
TP1	0.09	0.72	0.05	0.40
TP2	0.40	3.2	0.305	2.44
TP3	0.43	3.54	0.305	2.44
TP4	0.51	4.04	0.305	2.44

[a] Informative jitter values are chosen to be compatible with the limits for eye mask and TDP (see 58.7.9). Because of the way the different components may interact, the differences in jitter between test points cannot be used to indicate a performance level of the intervening sections.

Total jitter in this table is defined at 10^{-12} BER. In a commonly used model,

$$TJ_{12} = 14.1\sigma + W \text{ at } 10^{12} \tag{58–1}$$

The total jitter at 10^{-10} BER may be calculated assuming

$$TJ_{10} = 12.7\sigma + W \tag{58–2}$$

NOTE—As an example, TJ_{10} at TP1 is 0.085 UI (0.69 ns).

W is similar but not necessarily identical to deterministic jitter (DJ). A jitter measurement procedure is described in 58.7.12. Jitter at TP2 or TP3 is defined with a receiver of the same bandwidth as specified for the transmitted eye.

58.7 Optical measurement requirements

The following subclauses describe definitive patterns and test procedures for certain PMDs of this standard. implementers using alternative verification methods must ensure adequate correlation and allow adequate margin such that specifications are met by reference to the definitive methods.

All optical measurements, except TDP and RIN, shall be made through a short patch cable, between 2 m and 5 m in length.

NOTE—58.7.5, 58.7.6, 58.7.7, 58.7.9, 58.7.10, 58.7.11, and 58.7.12 apply to Clause 58, Clause 59, and Clause 60. Clause 59 (1000BASE-LX10) uses multimode fiber, although Clause 58 (100BASE-LX10 and 100BASE-BX10) and Clause 60 (1000BASE-PX10 and 1000BASE-PX20) do not.

58.7.1 Test patterns

Compliance is to be achieved in normal operation. The definitive patterns for testing are shown in Table 58–9.

Table 58–9—List of test patterns and tests

Test pattern	Test	Related subclause
Valid 100BASE-X signal	Wavelength Spectral width	58.7.2
Valid balanced NRZI encoded 4B/5B bit stream	Optical power	58.7.3
Idle or far-end fault indication (see Clause 24)	Extinction ratio OMA $\mathrm{RIN_xOMA}$	58.7.4 58.7.5 58.7.7
Optical frame-based test pattern of 58.7.1.1	Eye mask TDP Receiver sensitivity Stressed receiver sensitivity Jitter measurements	58.7.8 58.7.9 58.7.10 58.7.11 58.7.12

58.7.1.1 100BASE-X optical frame-based test pattern

Transmit eye mask, TDP and sensitivity are to be assured against the test pattern defined below. This represents an extremely untypical pattern. The BER in service can be expected to be lower than with the test pattern. In this clause, extinction ratio, OMA and $\mathrm{RIN_xOMA}$ are referred to the idle pattern (1010… for 4B/5B NRZI) or the nearly identical far-end fault indication.

The following test pattern is intended for frame-based testing of the 100BASE-LX10 and 100BASE-BX10 PMDs. It contains compliant Ethernet frames with adequate user defined fields to allow them to be passed through a system to the point of the test. Further information on frame-based testing is included in Annex 58A. The test suite and the recommended patterns are shown in Table 58–9.

NOTE—Users are advised to take care that the system under test is not connected to a network in service.

The test pattern shall be constructed as follows.

A test pattern for base line wander is composed of a sequence of three frames continuously repeated. Each frame has a 1500 octet length client data field and a zero length pad field. The contents of the destination address, source address, length/type fields and the first 32 octets of the client data field are at the discretion of the tester and may be implementation specific. The remaining 1468 octets of the client data field are filled with symbols with an even number of ones in the 4B/5B encoded data prior to NRZI transmission as shown in Table 58–10.

Frames are separated by a near minimum interpacket gap (IPG) of 14 octets.

Within the limits of the three bit maximum run length of the 4B/5B code this sequence gives a near worst case ISI pattern and provides alternating periods of high and low transition density to test clock and data recovery (CDR) performance.

The first 32 octets of the client data field are configured such that, after the frame check sequence (FCS) is added, there are an even number of ones in the first two packets and an odd number of ones in the third packet. This results in a six frame sequence on the line (after NRZI) with three frames containing near 40% ones density and three frames with near 60% ones density. Table 58–11 shows a pattern, nearly identical to the pattern in Table 58–10, that ends in 0 rather than 1 and can be used to join a 40% section to a 60% section. The “flipping” content causes a different frame check sequence which in turn causes the following idle to be inverted.

When transmitted with a near minimum interpacket gap the resulting data stream has baseline wander at 1.35 kHz. In the example shown, IEEE Std 802.2 logical link control headers are used to form TEST command PDUs with null DSAP and SSAP addresses.

Table 58–10—Example unbalanced pattern

Item	Number of octets	Code-group name or hexa-decimal value	TXD<3:0>[a] (binary)		4B/5B encoded (binary)		NRZI encoded (binary)			
			1st nibble	2nd nibble	1st code-group[b]	2nd code-group	40% mark ratio		60% mark ratio	
Idle	13	I	Idle	Idle	11111	11111	10101	01010	01010	10101
Start-of-stream delimiter (SSD)	1	/J/K/			11000	10001	10000	11110	01111	00001
Remainder of preamble	6	55	0101	0101	01011	01011	01101	10010	10010	01101
Start of frame delimiter	1	D5	0101	1101	01011	11011	01101	01101	10010	10010
Destination address[c]	6	FF	1111	1111	11101	11101	01001	01001	10110	10110
Source address	6	00	0000	0000	11110	11110	01011	01011	10100	10100
Length/type	2	05	0101	0000	01011	11110	10010	10100	01101	01011
		DC	1100	1101	11010	11011	10011	01101	01100	10010
DSAP	1	00	0000	0000	11110	11110	01011	01011	10100	10100
SSAP	1	00	0000	0000	11110	11110	01011	01011	10100	10100
Control	1	F3	0011	1111	10101	11101	11001	01001	00110	10110
Implementation specific (example)	1	06	0110	0000	01110	11110	10100	10100	01011	01011
	28	00	0000	0000	11110	11110	10100	10100	01011	01011
Low transition density[d]	968	42	0010	0100	10100	01010	11000	01100	00111	10011
		24	0100	0010	01010	10100	01100	11000	10011	00111
Mixed	8	00	0000	0000	11110	11110	10100	10100	01011	01011
		D2	0010	1101	10100	11011	11000	10010	00111	01101
High transition density	484	07	0111	0000	01111	11110	01010	10100	10101	01011
		70	0000	0111	11110	01111	10100	01010	01011	10101
Mixed	8	00	0000	0000	11110	11110	10100	10100	01011	01011
		D2	0010	1101	10100	11011	11000	10010	00111	01101
Frame check sequence 1[e]	1	FF	1111	1111	11101	11101	10110	10110	01001	01001
Frame check sequence 2	1	13	0011	0001	10101	01001	00110	01110	11001	10001
Frame check sequence 3	1	9E	1110	1001	11100	10011	10111	00010	01000	11101
Frame check sequence 4	1	59	1001	0101	10011	01011	11101	10010	00010	01101
End-of-stream delimiter (ESD)	1	/T/R/			01101	00111	01001	11010	10110	00101

[a] See Table 24–2.
[b] The five bit code-groups are transmitted left most bit first.
[c] Use of the example broadcast address may cause problems in a system test; any unicast address is preferable. Other source and destination addresses may be chosen.
[d] The first row precedes the second row and the sub-sequence is repeated 16 times. This pattern can be varied to cause the disparity to remain the same or flip.
[e] The frame check sequence for another pattern may be calculated following 3.2.9 and Clause 24.

Table 58–11—Example unbalanced pattern to flip polarity

Item	Number of octets	Code-group name or hexa-decimal value	TXD<3:0> (binary)		4B/5B encoded (binary)		NRZI encoded (binary)			
			1st nibble	2nd nibble	1st code-group	2nd code-group	40% mark ratio		60% mark ratio	
Idle, SSD, preamble, SFD, DA, SA, Length/type, DSAP, SSAP, Control	38	As in Table 58–10								
Flipping	1	05	0101	0000	01011	11110	10010	10100	01101	01011
Implementation specific, and pattern	1496	As in Table 58–10								
Frame check sequence 1	1	0B	1011	0000	10111	11110	11010	10100	00101	01011
Frame check sequence 2	1	E2	0010	1110	10100	11100	11000	10111	00111	01000
Frame check sequence 3	1	08	1000	0000	10010	11110	00011	01011	11100	10100
Frame check sequence 4	1	3B	1011	0011	10111	10101	00101	11001	11010	00110
End-of-stream delimiter (ESD)	1	/T/R/			01101	00111	10110	00101	01001	11010

NOTE—While it is expected that these frames will be counted by a DTE under test, the likelihood of additional behavior means that the DTE should not be connected to a network in service while being tested.

58.7.2 Wavelength and spectral width measurements

The wavelength and spectral width (RMS) shall meet specifications according to TIA-455-127-A, under modulated conditions using a valid 100BASE-X signal.

NOTE—The great majority of the transmitted spectrum must fall within the operating wavelength range. The allowable range of central wavelengths is narrower than the operating wavelength range by the actual RMS spectral width at each extreme.

58.7.3 Optical power measurements

Optical power shall meet specifications according to the methods specified in ANSI/EIA-455-95. A measurement may be made with the port transmitting any valid balanced NRZI encoded 4B/5B bit stream.

58.7.4 Extinction ratio measurements

Extinction ratio shall meet specifications according to IEC 61280-2-2 with the port transmitting the NRZI encoded 4B/5B idle pattern (1010…) or far-end fault indication, that may be interspersed with OAM packets per 57A.2 and with minimal back reflections into the transmitter, lower than –20 dB. The extinction ratio is expected to be similar for other valid balanced NRZI encoded 4B/5B bit streams. The test receiver has the frequency response as specified for the transmitter optical waveform measurement.

58.7.5 Optical modulation amplitude (OMA) measurements (informative)

The normative way of measuring transmitter characteristics is extinction ratio and mean power. The following clause is intended to inform on how the OMA measurement is performed.

In this clause, OMA is the difference in optical power for “1” and “0” levels of the optical signal in an idle (10101… for 100BASE-LX10 and 100BASE-BX10) sequence or far-end fault indication. It may be found using waveform averaging or histogram means. The measurement is recommended to be equivalent to that described below.

The recommended technique for measuring optical modulation amplitude is illustrated in Figure 58–3. A fourth-order Bessel-Thomson filter as specified for measuring the transmitter concerned is to be used with the O/E converter. The measurement system consisting of the O/E converter, the filter and the oscilloscope is calibrated at the appropriate wavelength for the transmitter under test.

With the device under test transmitting the idle pattern or far-end fault indication, use the following procedure to measure optical modulation amplitude:

a) Configure the test equipment as illustrated in Figure 58–3.
b) Measure the mean optical power P_1 of the logic “1” as defined over the center 20% of the time interval, here 1 UI long, where the signal is in the high state.
c) Measure the mean optical power P_0 of the logic “0” as defined over the center 20% of the time interval, here 1 UI long, where the signal is in the low state.
d) $OMA = P_1 - P_0$.

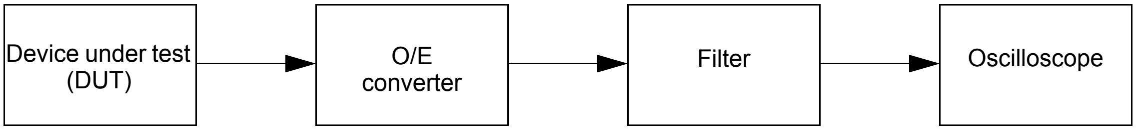


Figure 58–3—Recommended test equipment for measurement of optical modulation amplitude

A method of approximating OMA is shown in Figure 58–9.

Similarly, the optical power measure A_N is to be measured with a square wave pattern consisting of four to eleven consecutive ones followed by an equal run of zeros. Five ones followed by five zeros is convenient (the /H/ code-group in Clause 24, or K28.7 in 1000BASE-X which is the “Low-frequency test pattern” of 36A.2). The OMA of Clause 52 is A_N, and OMA here may differ.

NOTE—This OMA measurement procedure applies to Clause 58, Clause 59, and Clause 60.

58.7.6 OMA relationship to extinction ratio and power measurements (informative)

The normative way of measuring transmitter characteristics is extinction ratio and mean power. The following clause is intended to inform on how the three quantities OMA, extinction ratio, and mean power, are related to each other.

Optical modulation amplitude (OMA) is the difference between light levels for “1” and “0”. Extinction ratio is the ratio between light levels for “1” and “0”. If a signal contains equal density of “1” and “0” bits, and does not suffer from duty cycle distortion, the mean power is close to the mean of the light levels for “1” and “0”.

$$OMA = P_1 - P_0 \tag{58–3}$$

OMA may be expressed in Watts or dBm.

$$ER = \frac{P_1}{P_0} \tag{58–4}$$

Extinction ratio may be expressed in dB, as 10 × $\log_{10} (P_1 / P_0)$, or directly as a ratio. Sometimes extinction ratio is defined as P_0 / P_1.

$$P_{mean} \approx \frac{P_0 + P_1}{2} \tag{58–5}$$

Mean power may be expressed in Watts or dBm.

P_1 and P_0 are usually measured with a standardized instrument bandwidth to reduce the effects of overshoot. It should be noted that the values of P_1 and P_0 depend on the measurement technique and pattern to be used, which vary with PMD type. For some PMD types, e.g. 10GBASE, different patterns leading to different values of P_1 and P_0 are used for OMA on the one hand, and extinction ratio on the other.

Aside from these differences:

$$P_1 \approx 2 \times P_{mean} \times \frac{ER}{ER + 1} \tag{58–6}$$

$$P_0 \approx 2 \times \frac{P_{mean}}{ER + 1} \tag{58–7}$$

$$OMA \approx 2 \times P_{mean} \times \frac{ER - 1}{ER + 1} \tag{58–8}$$

Receiver sensitivity, which is an optical power, can be expressed in OMA or mean power terms according to the same relations.

NOTE—The OMA relationship to extinction ratio and power measurements applies to Clause 52, Clause 53, Clause 58, Clause 59, and Clause 60.

58.7.7 Relative intensity noise optical modulation amplitude (RIN$_x$OMA) measuring procedure

This procedure describes a component test that may not be appropriate for a system level test depending on the implementation. If used, the procedure is performed as described in 58.7.7.1, 58.7.7.2, and 58.7.7.3.

NOTE—This RIN$_x$OMA measurement procedure applies to Clause 58, Clause 59, and Clause 60.

58.7.7.1 General test description

The test arrangement is shown in Figure 58–4. The optical path between the Device Under Test (DUT) and the detector has a single discrete reflection with the specified optical return loss as seen by the DUT.

Both the OMA power and noise power are measured by AC-coupling the O/E converter into the electrical power meter. If needed, an amplifier may be used to boost the signal to the power meter. A low-pass filter is used between the photo detector and the power meter to limit the noise measured to the passband appropriate to the data rate of interest. In order to measure the noise, the modulation to the DUT is turned off.

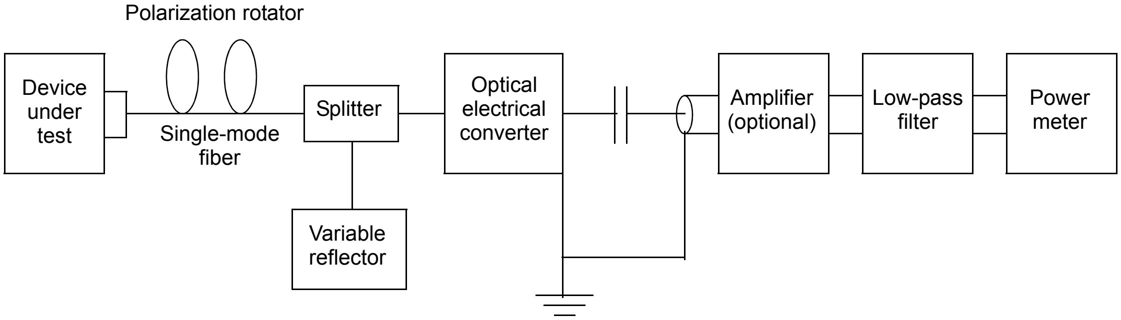


Figure 58–4—RIN$_x$OMA measurement setup

58.7.7.2 Component descriptions

The optical path and detector combination must be configured for a single dominant reflection with an optical return loss as specified in the appropriate transmitter table, e.g., Table 58–3. (The optical return loss may be determined by the method of FOTP-107.) The length of the fiber is not critical but should be in excess of 2 m.

The polarization rotator is capable of transforming an arbitrary orientation elliptically polarized wave into a fixed orientation linearly polarized wave.

If necessary, the noise may be amplified to a level consistent with accurate measurement by the power meter.

The upper –3 dB limit of the measurement apparatus is as specified for the transmitter optical waveform test. The bandwidth used in the RIN calculation takes the low-frequency cutoff of the DC-blocking capacitor into consideration. The low-frequency cutoff is recommended to be less than 1 MHz. The filter should be placed in the circuit as the last component before the power meter so that any high-frequency noise components generated by the detector/amplifier are eliminated. If the power meter used has a very wide bandwidth, care should be taken to ensure that the filter does not lose its rejection at extremely high frequencies.

The RMS electrical power meter should be capable of being zeroed in the absence of input optical power to remove any residual noise.

58.7.7.3 Test procedure

Use the following procedure to test relative intensity noise optical modulation amplitude:

a) With the DUT disconnected, zero the power meter;
b) Connect the DUT, turn on the laser, and ensure that the laser is not modulated;
c) Operate the polarization rotator while observing the power meter output to maximize the noise read by the power meter. Note the maximum power, P_N;
d) Turn on the modulation to the laser using the pattern specified for the PMD type (e.g., in 58.7.1 and 59.7.1) and note the power measurement, P_M. It may be necessary to change or remove the effective reflection to obtain an accurate reading;
e) Calculate RIN from the observed electrical signal power and noise power by use of Equation (58–9).

$$RIN_xOMA = 10 \times \log_{10}\frac{P_N}{BW \times P_M} \text{ [dB/Hz]} \qquad (58\text{–}9)$$

where:

RIN_xOMA = Relative Intensity Noise referred to optical modulation amplitude measured with x dB

reflection,
P_N = Electrical noise power in Watts with modulation off,
P_M = Electrical power in Watts with modulation on,
BW = Low-pass bandwidth of apparatus – high-pass bandwidth of apparatus due to DC-blocking capacitor [noise bandwidth of the measuring system (Hz)].

For testing multimode components or systems, the polarization rotator is removed from the setup and the single-mode fiber replaced with a multimode fiber. Step c) of the test procedure is eliminated.

58.7.8 Transmitter optical waveform (transmit eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 58–5 for 100BASE-LX10 and 100BASE-BX10. Compliance is to be assured during system operation. The transmitter optical waveform of a port transmitting the test pattern specified for the PMD type, e.g., in 58.7.1, shall meet specifications according to the methods specified below.

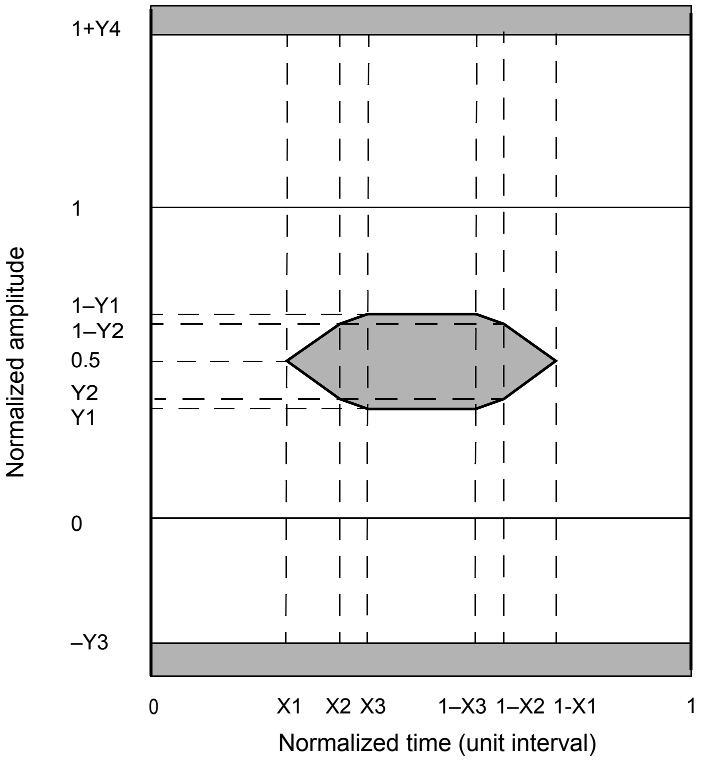


Figure 58–5—Transmitter eye mask definition

NOTE—This transmitter optical waveform measurement procedure applies to Clause 58, Clause 59, and Clause 60.

Normalized amplitudes of 0 and 1 represent the amplitudes of logic ZERO and ONE respectively. These are defined by the means of the lower and upper halves of the central 0.2 UI of the eye. 0 and 1 on the unit interval scale are to be determined by the eye crossing means. A clock recovery unit (CRU) may be used to trigger the scope for mask measurements as shown in Figure 58–6. It should have a high-frequency corner bandwidth of less than or equal to the jitter corner frequency in the appropriate table for the transmitter's peer receiver, e.g., Table 58–4 or Table 58–6, and a slope of –20 dB/decade. The CRU tracks acceptable levels of low frequency jitter and wander. The frequency response of the measurement instrument (e.g., oscilloscope) extends substantially lower than the test pattern repetition frequency. A DC-coupled instrument is convenient.

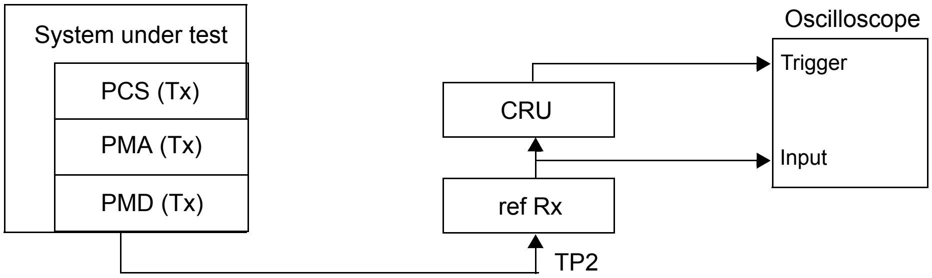


Figure 58–6—Transmitter optical waveform test block diagram

For 100BASE-LX10 and 100BASE-BX10, the eye is measured with respect to the mask of the eye using a receiver with a fourth-order Bessel-Thomson response with nominal f_r of 116.64 MHz as specified for STM-1 in ITU-T G.957, with the tolerances there specified. Receiver responses for other PMD types are specified in the appropriate clause. The Bessel-Thomson receiver is not intended to represent the noise filter used within a compliant optical receiver, but is intended to provide uniform measurement conditions at the transmitter.

The transmitter shall achieve a hit ratio lower than 5×10^{-5} hits per sample, where "hits" are the number of samples within the grey areas of Figure 58–5, and the sample count is the total number of samples from 0 UI to 1 UI.

NOTE—As an example, if an oscilloscope records 1350 samples/screen, and the timebase is set to 0.2 UI/div with 10 divisions across the screen, and the measurement is continued for 200 waveforms, then a transmitter with an expectation of less than 6.75 hits is compliant:

$$5 \times 10^{-5} \times 200 \times \frac{1350}{(0.2 \times 10)} = 6.75 \qquad (58\text{–}10)$$

Likewise, if a measurement is continued for 1000 waveforms, then an expectation of less than 33.75 hits is compliant. An extended measurement is expected to give a more accurate result, and a single reading of 6 hits in 200 waveforms would not give a statistically significant pass or fail. Measurements to "zero hits," which involve finding the position of the worst single sample in the measurement, have degraded reproducibility because random processes cause the position of such a single low-probability event to vary.

The hit ratio limit has been chosen to avoid misleading results due to transmitter and oscilloscope noise, and to give the best correlation to transmitter penalty; see 58.7.9.5.

Further information on optical eye pattern measurement procedures may be found in IEC 61280-2-2.

58.7.9 Transmitter and dispersion penalty (TDP) measurement

The TDP of a port transmitting the appropriate test pattern test shall meet specifications according to the methods specified below. The transmitter and dispersion penalty (TDP) measurement tests for transmitter impairments with chromatic effects for a transmitter to be used with single-mode fiber, and for transmitter impairments with modal (not chromatic) dispersion effects for a transmitter to be used with multimode fiber. Possible causes of impairment include intersymbol interference, jitter, RIN and mode partition noise. Meeting the separate requirements (e.g., eye mask, spectral characteristics) does not in itself guarantee the TDP. The procedure tests for pattern dependent effects; for 100BASE-LX10 and 100BASE-BX10, a standardized element of pattern dependent baseline wander is included in the reference channel.

Transmitter and dispersion penalty may be measured with apparatus shown in Figure 58–7, consisting of a reference transmitter, the transmitter under test, a controlled optical reflection, an optical attenuator, a test fiber, and a reference receiver system containing a reference receiver front end (optical to electrical converter), a transversal filter to emulate multimode fiber, if appropriate, and a bit error ratio tester. All BER and sensitivity measurements are made with the test patterns specified for the PMD type, e.g., in 58.7.1

NOTE 1—This TDP measurement procedure applies to Clause 58, Clause 59, and Clause 60.

NOTE 2—Multimode fiber is not used with 100BASE-LX10 or 100BASE-BX10.

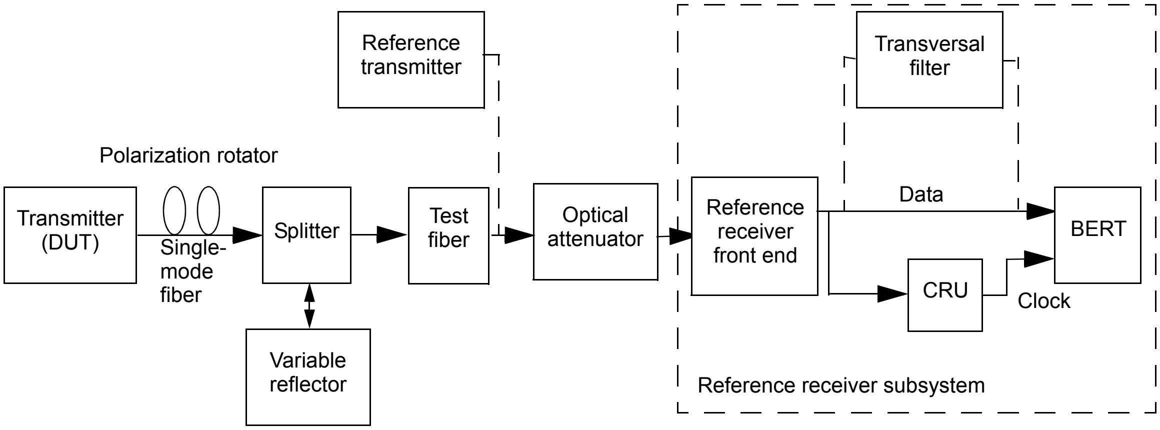


Figure 58–7—Test setup for measurement of transmitter and dispersion penalty

58.7.9.1 Reference transmitter requirements

The reference transmitter is a high-quality instrument-grade device, which can be implemented by a CW laser modulated by a high-performance modulator. It should meet the following basic requirements:

a) The rise/fall times should be less than 0.15 UI at 20% to 80%.
b) The output optical eye is symmetric and with good margin to the eye mask test for the transmitter (PMD) type under test.
c) In the center 20% region of the eye, the worst-case vertical eye closure penalty, as defined in 58.7.11.2, is less than 0.5 dB.
d) Jitter less than 0.20 UI peak-peak.
e) $\mathrm{RIN}_{12}\mathrm{OMA}$ should be minimized to less than –120 dB/Hz for 100BASE-X and –125 dB/Hz for 1000BASE-X.

58.7.9.2 Channel requirements

The transmitter is tested using an optical and electrical channel that meets the requirements specified for the PMD type listed in Table 58–12.A transmitter is to be compliant with a total dispersion at least as negative as the “minimum dispersion” and at least as positive as the “maximum dispersion” columns specified for the wavelength of the device under test. This may be achieved with a channel or channels consisting of fibers with lengths chosen to meet the dispersion requirements.

To verify that the fiber has the correct amount of dispersion, the measurement method defined in ANSI/TIA/EIA-455-175A-92 may be used. The measurement is made in the linear power regime of the fiber.

When emulating a multimode fiber link, the optical channel is a 2 m to 5 m patch cord meeting the appropriate specifications. In this case, the link bandwidth is emulated in the electrical domain.

The channel provides a maximum optical return loss specified as “Optical return loss tolerance (maximum)” in the specification of the transmitter under test. For a single-mode fiber channel, the state of polarization of the back reflection is adjusted to create the greatest RIN. The methods of 58.7.7.2 and 58.7.7.3 may be used.

The BERT's receiver sensitivity must be adequate to meet the BER with the worst-case test signal and minimum attenuation.

Table 58–12—Transmitter compliance channel specifications

PMD transmitter wavelength, fiber type	Optical channel			Electrical channel
	Dispersion[a] (ps/nm)		Optical return loss[b] (max)	Differential delay (ps)
	Minimum	Maximum		
1310 nm band for SMF	$0.02325 \cdot L$[c]$\cdot \lambda \cdot [1-(1324/\lambda)^{4}]$	$0.02325 \cdot L \cdot \lambda \cdot [1-(1300/\lambda)^{4}]$	See ORLT in Transmitter spec	N/A
1550 nm band for SMF	0	$0.02325 \cdot L \cdot \lambda \cdot [1-(1300/\lambda)^{4}]$		N/A

[a] The dispersion is specified for the actual wavelength of the device under test.
[b] The optical return loss is applied with respect to TP2.
[c] L is the upper operating range limit (reach) as defined e.g. in Table 58–1.

58.7.9.3 Reference receiver requirements

The reference receiver system should have the bandwidth specified for the transmitter optical waveform measurement for the transmitter under test. The sensitivity of the reference receiver system should be limited by Gaussian noise. The receiver system should have minimal threshold offset, deadband, hysteresis, deterministic jitter or other distortions. Decision sampling should be instantaneous with minimal uncertainty and setup/hold properties. When testing 100BASE-X optical transmitters, the receiver should have a passband not extending below 10 kHz at the –3 dBe (electrical) point, so as to emulate the pattern-induced baseline wander expected in a compliant receiver.

For all transmitter and dispersion penalty measurements, determination of the center of the eye is required. The center of the eye is defined as the time halfway between the left and right sampling points within the eye where the measured BERs are equal to each other, and greater than or equal to 10^{-3} (the BER at the eye center is much lower). The decision threshold is to occur at the average signal level.

For a transmitter to be used with multimode fiber the reference receiver is followed by a transversal filter with two equal amplitude paths with a differential delay as specified for the transmitter. In this case, the receiver front end should be operating in its linear regime (not clipping). For a transmitter to be used with single-mode fiber, the transversal filter is not used.

The clock recovery unit (CRU) used in the TDP measurement has a corner frequency of less than or equal to the jitter tolerance frequency specified for the appropriate receiver (the peer PMD to the transmitter under test), and a slope of 20 dB/decade. When using a clock recovery unit as a clock for BER measurements, passing of low-frequency jitter from the data to the clock removes this low-frequency jitter from the measurement.

The nominal sensitivity of the reference receiver system, S, is measured in OMA using the apparatus described above but with a short patchcord in place of the test fiber and without any transversal filter. The sensitivity S must be corrected for any significant reference transmitter impairments including any vertical eye closure. It should be measured while sampling at the eye center or corrected for off-center sampling. It is calibrated at the wavelength of the transmitter under test. For 100BASE-LX10 and 100BASE-BX10, TDP includes a pattern dependent penalty. It may be inconvenient or impossible to obtain reference transmitters and receivers which are immune to this penalty. For these cases, S may be measured with a benign pattern e.g., PRBS7.

58.7.9.4 Test procedure

To measure the transmitter and dispersion penalty (TDP) the following procedure is used. The sampling instant is displaced from the eye center by the amount specified for decision timing offsets in e.g., Table 58–3 or Table 58–5. The following procedure is repeated for early and late decision and the larger TDP value is used:

a) Configure the test equipment as described above and illustrated in Figure 58–7.
b) Adjust the attenuation of the optical attenuator to obtain a BER of 10^{-12}. Extrapolation techniques may be used with care.
c) Record the optical power in OMA at the input to the reference receiver, P_DUT, in dBm.
d) If P_DUT is larger than S, the transmitter and dispersion penalty (TDP) for the transmitter under test is the difference between P_DUT and S, TDP = P_DUT – S. Otherwise the transmitter and dispersion penalty is zero, TDP = 0.

It is to be ensured that the measurements are made in the linear power regime of the fiber.

58.7.9.5 Approximate measures of TDP (informative)

Transmitter and dispersion penalty may be considered as a transmitter penalty (TP) followed by a dispersion penalty, which is also attributable to the transmitter. Measurements at TP2 can reveal the transmitter penalty. TP can be related to eye mask margin (MM) as follows.

In the absence of any noise or significant jitter,

$$TP = 10 \times \log_{10}\left(\frac{1}{H}\right) \tag{58–11}$$

$$MM = \frac{H - M}{1 - M} \tag{58–12}$$

where H is height of inner eye and M is the height of the central polygon of the mask.

Transmitter noise or noise-like impairments degrade both apparent MM and actual TP. To obtain a useful correlation between the two, MM is defined to an appropriate percentile of measured samples, to give the right weight to this noise; see 58.7.8. Oscilloscope noise degrades apparent MM only. This would distort the correlation, but in many measurement circumstances the error is reduced at the appropriate percentile. The one-dimensional statistics of MM measurement and the hit ratio are related by the frequency of relevant bit patterns in a stream (typically 1/4 of bits are flanked by two opposite bits) and by a factor related to mask dimensions.

This approach could be applied to a situation with combinations of noise of jitter.

It may be feasible to correlate TDP to eye measurements at TP3. However, the signal at TP3 is weaker, so oscilloscope noise is more of a concern.

The following suggestions apply to 100 Mb/s optical PMDs.

In practice it may be necessary to do without the clock recovery unit at 100 Mb/s. Experimentally, timing stability at this rate may be acceptable, and the jitter due to the CRU could be accounted for by adjusting the eye mask length and the TDP decision timing offsets.

A significant component of TDP is baseline wander. A wander of ± OMA/10 will be created by many receivers if it is not already present in the transmitted signal. Higher levels of pattern dependent penalty can in some cases be estimated from the mask margin (if necessary, by ignoring the upper and lower mask regions). The mask margin may also be measured with an AC-coupled measurement instrument with a high-pass filter of 10 kHz. It is likely that compliant implementations will pass the transmitter mask with both DC and AC-coupling. Certain implementations may be characterized by comparing the transmitted signal with the STM-1 mask, using a benign pattern such as PRBS7.

The accuracy of these approaches have not been established by the committee. Oscilloscope measurements at TP3 may be degraded by instrument noise.

58.7.10 Receiver sensitivity measurements

Receiver sensitivity is defined for an ideal input signal. The test signal should have negligible impairments such as intersymbol interference (ISI), jitter and RIN (but see the end of this subclause). The test pattern shall be as specified in 58.7.1, 59.7.1 or 60.9.1 as appropriate. Sensitivity is defined by the specified bit error ratio, which may be determined by counting bit or byte errors or errored frames. Extrapolation techniques may be used with care. Sensitivity is measured at a low but compliant extinction ratio, and correction made for any difference between the measurement extinction ratio and the specified minimum extinction ratio. This assurance should be met with asynchronous data flowing out of the optical transmitter of the system under test. The output data pattern from the transmitter of the system under test is the same pattern as defined for this measurement.

The sampling point is set by the system under test. While this standard applies to complete data terminal equipment (DTE), the test may be used as a diagnostic for testing components with appropriate margin, in which case the sampling point should be set at the average optical power level and at the specified timing offsets from the eye center, which may be found as the mid-point between the 10^{-3} BER points.

An implementer may use a combination of extrapolation and margin to assure compliance. This can entail a statistical analysis which could be implementation specific. As an example, with a small margin, it might not be advisable to extrapolate beyond a limited optical power difference; this represents an extrapolation in BER terms which varies according to circumstance.

In the case of 100BASE-X, systematic baseline wander of the input signal is to be expected. This may be generated with AC-coupling above 10 kHz within the transmitter, and/or with the interfering signal technique as described in 58.7.11.2. A standardized baseline wander of ± OMA/10 is defined for these PMD types. This causes some jitter in the test signal, which is acceptable.

For 100BASE-LX10 and 100BASE-BX10 only, sensitivities are defined for 10^{-12} and 10^{-10} bit error ratios. It is sufficient to show compliance to either of these. The 10^{-10} limit is the more demanding but can be verified more accurately with reasonable test times.

NOTE—This receiver sensitivity measurement applies to Clause 58, Clause 59, and Clause 60.

58.7.11 Stressed receiver conformance test

The stressed receiver conformance test is intended to screen against receivers with poor frequency response or timing characteristics that could cause errors when combined with a distorted but compliant signal at TP3. Modal (MMF) or chromatic (SMF) dispersion can cause distortion. Stressed receiver tolerance testing may be performed in accordance with the requirements of 58.7.11.1, 58.7.11.2, and 58.7.11.3. If this test is applied the receiver shall be compliant to for example Table 58–4.

A receiver should receive a conditioned input signal that combines vertical eye closure and jitter according to this clause with BER specified in the receiver tables. This assurance should be met with asynchronous data flowing out of the optical transmitter of the system under test. The output data pattern from the transmitter of the system under test is to be the same pattern as defined for this measurement.

NOTE 1—The length of the test pattern, low signaling rate and narrow rate tolerance of 100BASE-X means that the input and output patterns beat very slowly. Long test times or a slight modification to the length of one pattern may be appropriate.

NOTE 2—This stressed receiver conformance test applies to Clause 58, Clause 59, and Clause 60.

58.7.11.1 Stressed receiver conformance test block diagram

A block diagram for the receiver conformance test is shown in Figure 58–8. A pattern generator continuously generates a signal or test pattern as specified for the receiver under test, e.g., in 58.7.1. The optical test signal is conditioned (stressed) using the methodology, as defined in 58.7.11.2, while applying sinusoidal jitter, as specified e.g., in 58.7.11.4. The receiver of the system under test is tested for conformance by counting bit or byte errors or errored frames. The optical power penalty for the stressed eye is intended to be similar to its vertical eye closure penalty. This is not necessarily the same as the highest TDP anticipated in service, but represents a standardized test condition for the receiver.

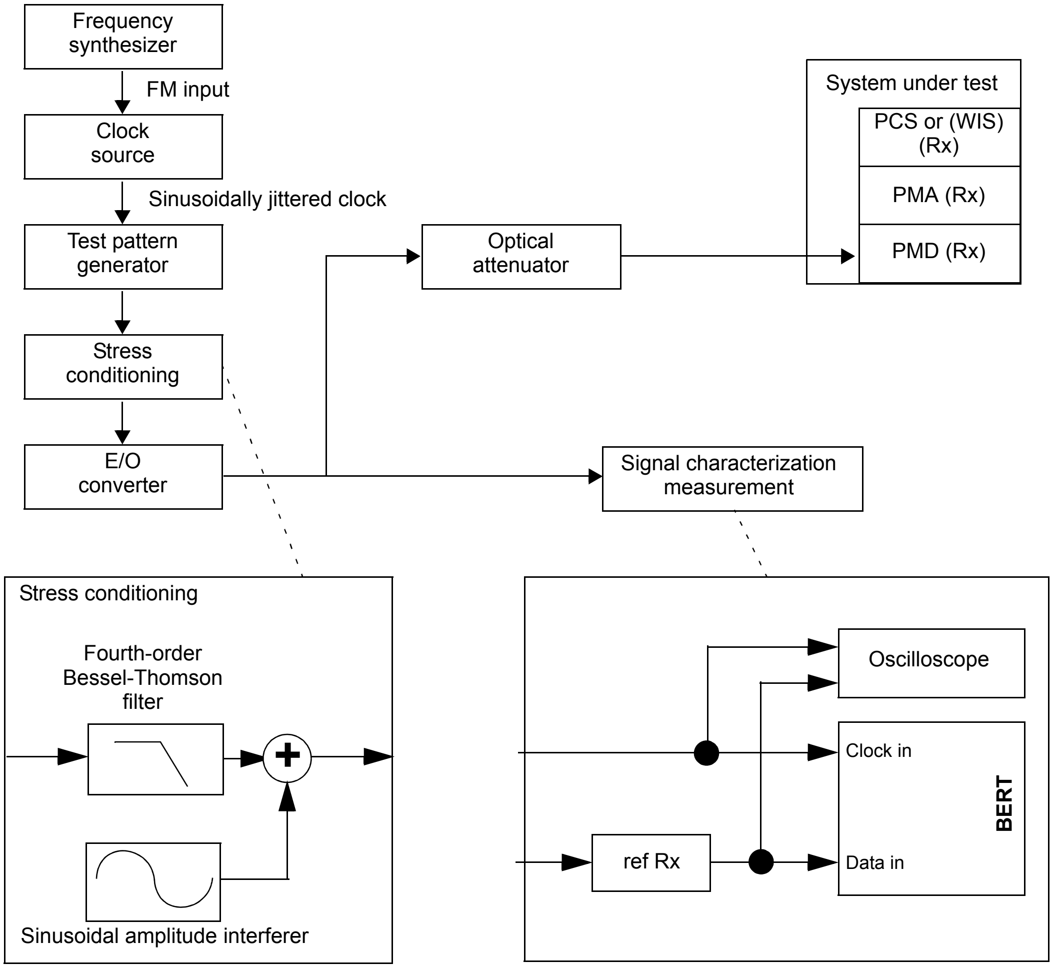


Figure 58–8—Stressed receiver conformance test block diagram

A suitable test set is needed to characterize and verify that the signal used to test the receiver has the appropriate characteristics. The test fiber called out for single-mode fiber based PMD layers and the transversal filter called out to emulate multimode fiber are not needed to characterize the receiver input signal; nor are they used during testing.

The fourth-order Bessel-Thomson filter is used to create ISI-induced vertical eye closure. The sinusoidal amplitude interferer causes additional eye closure, but in conjunction with the slowed edge rates from the filter, also causes jitter. The nature of the jitter is intended to emulate instantaneous bit shrinkage that can occur with DDJ. This type of jitter cannot be created by simple phase modulation. The sinusoidal phase modulation represents other forms of jitter and also verifies that the receiver under test can track low-frequency jitter.

For improved visibility for calibration, it is imperative that the Bessel-Thomson filter and all other elements in the signal path (cables, DC blocks, E/O converter, etc.) have wide and smooth frequency response and linear phase response throughout the spectrum of interest. Overshoot and undershoot should be minimized. If this is achieved, then data dependent effects should be minimal, and short data patterns can be used for calibration with the benefit of providing much improved trace visibility on sampling oscilloscopes. Actual patterns for testing the receiver are specified in the appropriate clause.

To further improve visibility for calibration, random noise effects, such as RIN and random clock jitter, should also be minimized. A small amount of residual noise and jitter from all sources is unavoidable, but should be less than 0.25 UI peak-peak of jitter.

The test pattern generator, filter and E/O converter should together have a frequency response to result in the appropriate level of initial ISI eye closure before the sinusoidal terms are added. The E/O converter should have a linear response if electrical summing is used, linearity of all elements including the E/O modulator is critical. Summing with an optical coupler after the modulator is an option that eases linearity requirements, but requires a second source for the interfering signal, will complicate settings of extinction ratio, and will add more RIN. In either case, a typical optical transmitter with built-in driver is not linear and not suitable.

The vertical and horizontal eye closures to be used for receiver conformance testing are verified using an optical reference receiver with the response specified for the appropriate transmitter (the peer PMD to the receiver under test) e.g., in 58.7.8. Use of standard tolerance filters may significantly degrade this calibration. Care should be taken to ensure that all the light from the fiber is collected by the fast photo detector and (if using multimode fiber) that there is negligible mode selective loss, especially in the optical attenuator and the optical coupler, if used. The reference receiver and oscilloscope should achieve adequately low noise and jitter.

The clock output from the clock source in Figure 58–8 will be modulated with the sinusoidal jitter. To use an oscilloscope to calibrate the final stressed eye jitter that includes the sinusoidal jitter component, a separate clock source (clean clock of Figure 58–8) is required that is synchronized to the source clock, but not modulated with the jitter source.

58.7.11.2 Stressed receiver conformance test signal characteristics and calibration

The conformance test signal is used to validate that the PMD receiver meets BER requirements with near worst case waveforms at TP3 including pulse width shrinkage, power, simulated channel penalties, and a swept frequency sinusoidal jitter contribution.

Signal characteristics are described below along with a suggested approach for calibration.

The test signal includes vertical eye closure and high-probability jitter components. Vertical eye closure is measured at the time center of the eye (halfway between 0 and 1 on the unit interval scale as determined by the eye crossing means) and is the vertical eye closure penalty (VECP) when calculated relative to the measured A_N value. J is measured at the average optical power, which can be obtained with AC-coupling. The values of these components are defined as below by their histogram results. The vertical eye closure penalty is given in Equation (58–13):

$$\text{Vertical eye closure penalty [dB, optical]} = 10 \times \log_{10}\frac{A_N}{A_O} \qquad (58\text{–}13)$$

where, A_O is the amplitude of the eye opening and A_N is the normal amplitude without ISI, as shown in Figure 58–9. A_N can be approximated with histograms as suggested in Figure 58–9. However, the definition for A_N is given in 58.7.5.

For this test, VECP is defined by the 99.95th percentile of the histogram of the lower half of the signal and the 0.05th percentile of the histogram of the upper half of the signal, and jitter is defined by the 0.5th and 99.5th percentiles of the jitter histogram. Histograms should include at least 10 000 hits, and should be about

1%-width in the direction not being measured. Residual low-probability noise and jitter should be minimized—that is, the outer slopes of the final histograms should be as steep as possible down to very low probabilities.

The following steps describe a suggested method for calibrating a stressed eye generator:

a) Set the signaling speed of the test-pattern generator as specified for the appropriate transmitter. Sinusoidal interference and jitter signals should be turned off at this point.
b) Turn on the calibration pattern. A repetitive pattern may be used for calibration if the conditions described in 58.7.11.1 are met, but this increases the risk that the longer test pattern used during testing will overstress the device under test.
c) Set the extinction ratio to approximately the extinction ratio (minimum) value as specified for the appropriate transmitter. If optical summing is used, the extinction ratio may need to be adjusted after the sinusoidal interference signal is added below.
d) Measure the settled signal amplitude A_N of the test signal (without attenuation). A_N may be measured according to 58.7.5 using a square wave pattern, although for the purposes of this clause, OMA is to be measured with a different pattern; A_N and OMA are not likely to be equal.
e) The requirements for vertical eye closure and jitter of the stressed eye test signal are given by the vertical eye closure penalty (VECP) and stressed eye jitter (J) values given in the appropriate receiver specification table.

   There are three components involved in calibration for vertical closure and J. These are a linear phase filter, sinusoidal interference, and sinusoidal jitter.

   In general, the majority of the vertical eye closure penalty value should be created by use of a linear phase, low jitter filter (such as Bessel-Thomson). In the case of 100BASE-X, the majority of the vertical eye closure penalty value should be created by baseline wander or sinusoidal interference. The filter should be tested with the prescribed test patterns to verify that residual jitter is small, less than 0.25 UI peak-peak. If not, the stress may be more than desired, leading to conservative results. However, compensation is not allowed. Once done, revert to the calibration pattern, if different than the specified test pattern.

   Any remaining vertical eye closure required must be created with sinusoidal interference or sinusoidal jitter.

   To emulate the effects of DCD or data-dependent jitter, at least 0.05 but no more than 0.15 UI peak-peak of pulse shrinkage jitter should have been achieved. This imposes a limit of less than 1.2 dB of vertical closure from sinusoidal interference, applied after vertical closure created by filtering.

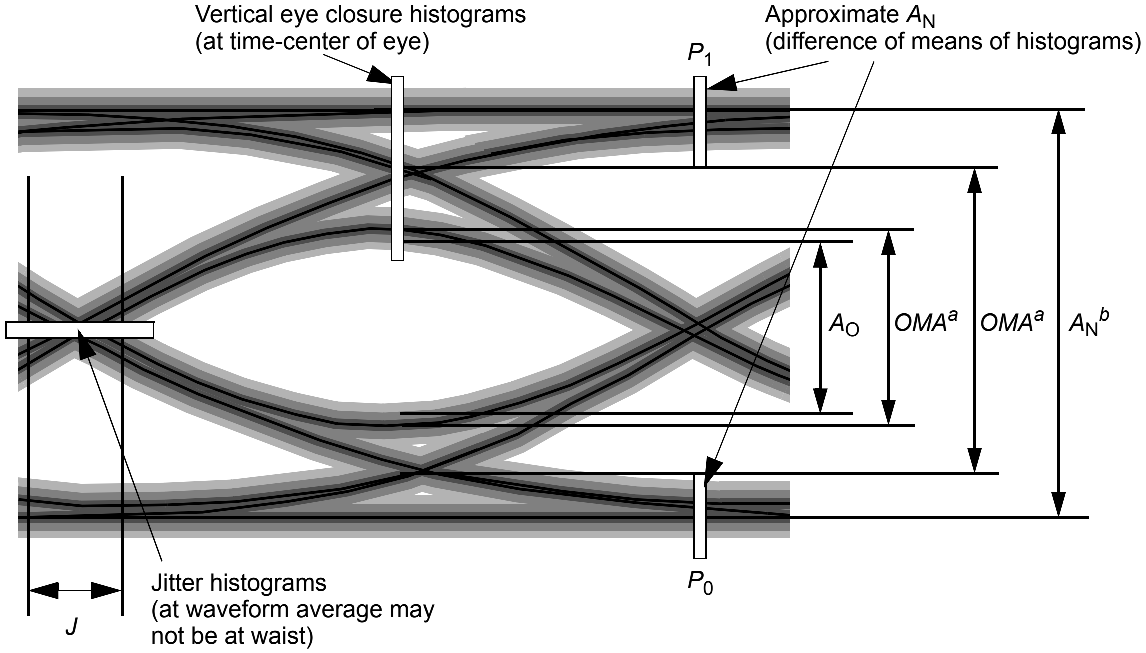
   The frequency of the sinusoidal interference may be set at any frequency between B / 100 and B / 5 where B is the signaling speed, although care should be taken to avoid a harmonic relationship between the sinusoidal interference, the sinusoidal jitter, the signaling speed and the pattern repetition rate.
   Sinusoidal jitter (phase modulation) must be added according to the appropriate jitter specification. For calibration purposes, sinusoidal jitter frequencies must be well within the flat portion of the template above the corner frequency.

   Iterate the filter bandwidth and the settings for sinusoidal interference and/or jitter until all constraints are met, including jitter (J), vertical eye closure penalty (VECP), and that sinusoidal jitter above the corner frequency is as specified.

   Verify that the optical power penalty for the stressed eye (relative to the reference transmitter per 58.7.9.1) is greater than or equal to VECP.

f) Decrease the amplitude with the optical attenuator until the OMA complies with the OMA values specified for the receiver under test.

g) For testing, turn on the actual required test pattern(s).



[a] This measure of OMA on the eye of the conformance test signal differs between 100BASE-X, 1000BASE-X and 10GBASE-R/W.
[b] This is also OMA for 10GBASE-R/W.

Figure 58–9—Required characteristics of the conformance test signal at TP3

Care should be taken when characterizing the signal used to make receiver tolerance measurements. In the case of a transmit jitter measurement, excessive and/or uncalibrated noise/jitter in the test system makes it more difficult to meet the specification and may have a negative effect on yield but will not impact interoperability. Running the receiver tolerance test with a signal that is under-stressed may result in the deployment of non-compliant receivers. Care should be taken to minimize and/or correct for the noise/jitter introduced by the reference receiver, filters, oscilloscope, and BERT. While the details of measurement and test equipment are beyond the scope of this standard it is recommended that the implementers fully characterize their test equipment and apply appropriate guard bands to ensure that the receive input signal meets the specified requirements.

58.7.11.3 Stressed receiver conformance test procedure

The test apparatus is set up as described in 58.7.11.1 and 58.7.11.2. The sinusoidal jitter is then stepped across the specified frequency and amplitude range while monitoring errors at the receiver. The BER is to be compliant at all jitter frequencies in the specified frequency range. This method does not result in values for jitter contributed by the receiver. It does, however, ensure that a receiver meeting the requirements of this test will operate with the worst-case optical input.

58.7.11.4 Sinusoidal jitter for receiver conformance test

The sinusoidal jitter is used to test receiver jitter tolerance. Sinusoidal jitter may vary over a magnitude range as required to accurately calibrate a stressed eye per 58.7.11.2. The range is limited by the constraints of Table 58–13 as illustrated in Figure 58–10, where *f2*, *SJ1,* and *SJ2* are specified in the appropriate receiver table: Table 58–4, Table 58–6, Table 59–6, Table 59–8, Table 60–5, Table 60–6, or Table 60–14. The frequency *f2* is specified as “Jitter corner frequency” in the receiver tables. *SJ1* and *SJ2* are defined as “sinusoidal jitter limits for stressed receiver conformance test (min, max)” in e.g., Table 58–4.

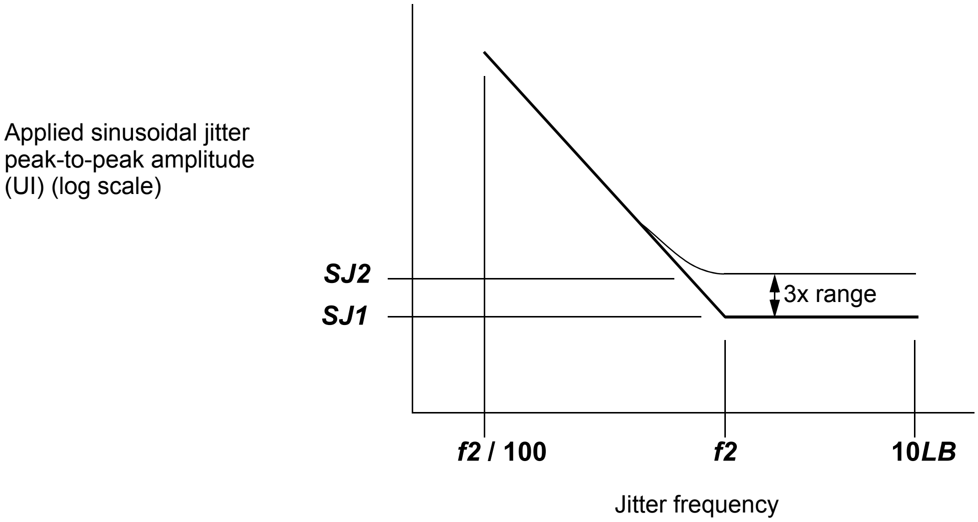


Figure 58–10—Mask of the sinusoidal component of jitter tolerance (informative)

Table 58–13—Applied sinusoidal jitter

Frequency range	Sinusoidal jitter (UI pk-pk)
$f < f2 / 100$	N/A
$f2 / 100 < f \leq f2$	$0.05 \times f2 / f + S - 0.05$[a]
$f2 < f < 10 \times LB$[b]	$SJ1 \leq S \leq SJ2$[a]

[a] *S* is the magnitude of sine jitter actually used in the calibration of the stressed eye per the methods of 58.7.11.2.
[b] *LB* = Loop Bandwidth; Upper frequency bound for added sine jitter should be at least 10 times the loop bandwidth of the receiver being tested.

58.7.12 Jitter measurements (informative)

A jitter measurement method for use at 100 Mb/s or 1000 Mb/s is described in this subclause. The measurement is performed after any relevant fiber dispersion (at virtual TP3). The test pattern is specified in 58.7.1 or 59.7.1 as appropriate.

The transmit jitter is tested using a bit error ratio tester (BERT), where the tester scans the eye opening horizontally (varying the decision time) at the average optical power, at a virtual TP3 (hereafter referred to as simply TP3) and measures the bit error ratio at each point in time. The plot of BER as a function of sampling time is called the “bathtub curve.” The channel and receiver are as specified in e.g., 58.7.9.2 and 58.7.9.3. The receiver includes a defined filter function. The test pattern is the same as for receiver sensitivity measurements.

NOTE—The parameter *W* may also be estimated from jitter histograms using an oscilloscope. Jitter of an optical signal is measured with a test optical receiver with the receiver bandwidth specified (e.g., for eye mask conformance) for the transmitter under test concerned.

The experimental curve is compared with a mask defined by Equation (58–14) and Equation (58–15) and illustrated in Figure 58–11:

$$\log_{10}(BER) \le A - B\left(\frac{t - 0.5W}{\sigma}\right)^2 \tag{58–14}$$

$$\log_{10}(BER) \le A - B\left(\frac{1 - t - 0.5W}{\sigma}\right)^2 \tag{58–15}$$

where:

$$A = -1.75, B = \frac{\log_{10}(e)}{2} \approx 0.217$$

and t is the decision time specified in unit intervals (UI). $t = 0$ at the mean crossing time, which may be estimated as the mid-point between the 10^{-3} BER points.

The BER mask is defined for $10^{-12} < \text{BER} < 10^{-6}$. All points on the BER “bathtub curve” must fall within the white area or below. It can be seen that in the case of an asymmetric measured bathtub curve, the worse side determines W and σ.

W (“high probability jitter”) and deterministic jitter (DJ) are not necessarily the same, but may be similar. The quantity σ can be similar to random jitter (RJ) although it is determined by low probability pattern dependent jitter also. “Total jitter” (TJ) is taken to be $W + 14\sigma$.

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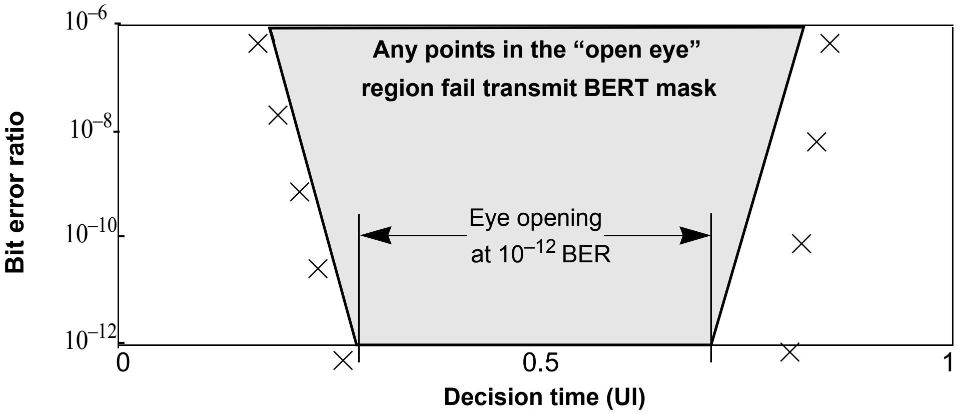

Figure 58–11—Example transmit BER mask at TP3

NOTE—This jitter measurement method applies to Clause 58, Clause 59, and Clause 60.

58.8 Environmental, safety, and labeling

58.8.1 General safety

All equipment meeting this standard shall conform to IEC 60950-1.

58.8.2 Laser safety

100BASE-LX10 and 100BASE-BX10 optical transceivers shall conform to Hazard Level 1 laser requirements as defined in IEC 60825-1 and IEC 60825-2, under any condition of operation. This includes single fault conditions whether coupled into a fiber or out of an open bore. Conformance to additional laser safety standards may be required for operation within specific geographical regions.

Laser safety standards and regulations require that the manufacturer of a laser product provide information about the product's laser, safety features, labeling, use, maintenance, and service. This documentation shall explicitly define requirements and usage restrictions on the host system necessary to meet these safety certifications.

58.8.3 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulation, be followed in every instance in which such practices are applicable.

58.8.4 Environment

Two optional temperature ranges are defined in Table 58–14. Implementations shall be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

Table 58–14—Component case temperature classes

Class	Low temperature (°C)	High temperature (°C)
Warm extended	–5	+85
Cool extended	–40	+60
Universal extended	–40	+85

Reference Annex 67A for additional environmental information.

58.8.5 PMD labeling requirements

It is recommended that each PHY (and supporting documentation) be labeled in a manner visible to the user, with at least the applicable safety warnings and the applicable port type designation (e.g., 100BASE-BX10-U).

Labeling requirements for Hazard Level 1 lasers are given in the laser safety standards referenced in 58.8.2.

Compliant systems and field pluggable components shall be clearly labeled with the operating temperature range over which their compliance is ensured.

58.9 Characteristics of the fiber optic cabling

The 100BASE-LX10 and 100BASE-BX10 fiber optic cabling shall meet the dispersion specifications of IEC 60793-2 and ITU-T G.652, or the requirements of Table 58–15 where they differ. The fiber cable attenuation is for information only; the end-to-end channel loss shall meet the requirements of Table 58–1. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together. The fiber optic cabling spans from one MDI to another MDI, as shown in Figure 58–12.

58.9.1 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 58–12.

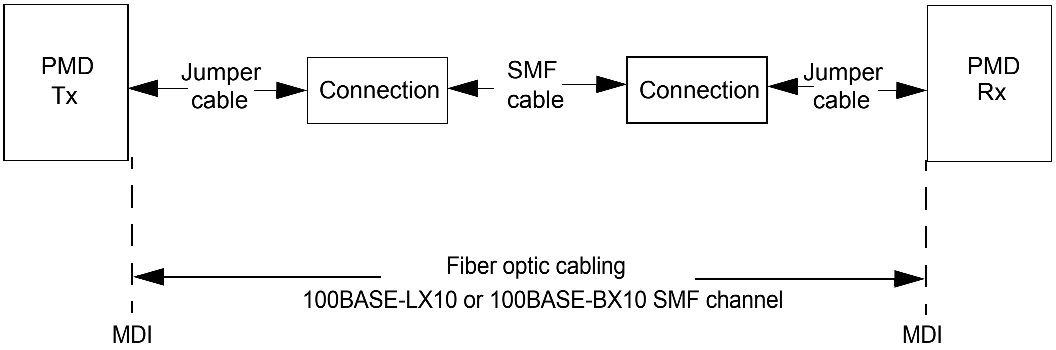

Figure 58–12—Fiber optic cabling model

The maximum channel insertion losses shall meet the requirements specified in Table 58–1. The minimum loss for 100BASE-LX10 and 100BASE-BX10 is zero. A channel may contain additional connectors or other optical elements as long as the optical characteristics of the channel, such as attenuation, dispersion and reflections, meet the specifications. Insertion loss measurements of installed fiber cables are made in accordance with ANSI/TIA/EIA-526-7 [B16], method A-1. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards.

NOTE—In extreme cases with minimum length links (less than 2 m), care may be taken to avoid excess optical power delivered through cladding modes to the receiver.

58.9.2 Optical fiber and cable

The fiber optic cable requirements are satisfied by the fibers specified in IEC 60793-2, Types B1.1 (dispersion un-shifted single-mode) and B1.3 (low water peak single-mode) and ITU-T G.652, or by the requirements of Table 58–15 where they differ.

Table 58–15—Optical fiber and cable characteristics

Description[a]	B1.1, B1.3 SMF		Unit
Nominal fiber specification wavelength[b]	1310	1550	nm
Cabled optical fiber attenuation (max)[c]	0.4	0.35	dB/km
Zero dispersion wavelength (λ_0)[d]	$1300 \le \lambda_0 \le 1324$		nm
Dispersion slope (max) (S_0)	0.093		ps/nm^{2}km

[a] The fiber dispersion values are normative, all other values in the table are informative.
[b] Wavelength specified is the nominal fiber specification wavelength which is the typical measurement wavelength. Power penalties at other wavelengths are accounted for.
[c] Attenuation values are informative not normative. Attenuation for single-mode optical fiber cables is defined in ITU-T G.652.
[d] See IEC 60793 or G.652 for correct use of zero dispersion wavelength and dispersion slope.

58.9.3 Optical fiber connection

The maximum link distances for single-mode fiber are calculated based on an allocation of 2 dB total connection and splice loss. Connections with different loss characteristics may be used provided the requirements of Table 58–1 are met.

The maximum discrete reflectance of e.g., a connection or splice shall be less than –26 dB.

58.9.4 Medium Dependent Interface (MDI)

The 100BASE-LX10, 100BASE-BX10-D or 100BASE-BX10-U PMD is coupled to the fiber optic cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” (as shown in Figure 58–12). Examples of an MDI include the following:

a) Connectorized fiber pigtail
b) PMD receptacle

The MDI carries the signal in both directions. For 100BASE-BX10 it couples a single fiber and for 100BASE-LX10 it couples dual fibers.

When the MDI is a remateable connection it shall meet the interface performance specifications of IEC 61753-1.

NOTE—Compliance testing is performed at TP2 and TP3 as defined in 58.2.1, not at the MDI.

58.10 Protocol implementation conformance statement (PICS) proforma for Clause 58, Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 (Long Wavelength) and 100BASE-BX10 (BiDirectional Long Wavelength)[6]

58.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 58, Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 and 100BASE-BX10, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

58.10.2 Identification

58.10.2.1 Implementation identification

Supplier[1]	
Contact point for inquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1, 3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

58.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 58, Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 and 100BASE-BX10
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[6] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

58.10.2.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
HT	High temperature operation	58.8.4	–5 °C to 85 °C	O	Yes [ ] No [ ]
LT	Low temperature operation	58.8.4	–40 °C to 60 °C	O	Yes [ ] No [ ]
*LX	100BASE-LX10 PMD	58.3	Device supports long wavelength (1310 nm) over dual single-mode fiber operation	O/1	Yes [ ] No [ ]
*BD	100BASE-BX10-D	58.4	Device operates with one single single-mode fiber and transmits at downstream wavelength (1550 nm)	O/1	Yes [ ] No [ ]
*BU	100BASE-BX10-U	58.4	Device operates with one single single-mode fiber and transmits at upstream wavelength (1310 nm)	O/1	Yes [ ] No [ ]
*INS	Installation / Cable	58.9	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer	O	Yes [ ] No [ ]

58.10.3 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 and 100BASE-BX10

58.10.3.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FN1	Transmit function	58.2.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FN2	Transmitter optical signal	58.2.2	Higher optical power transmitted is a logic 1	O	Yes [ ] No [ ]
FN3	Receive function	58.2.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FN4	Receiver optical signal	58.2.3	Higher optical power received is a logic 1	O	Yes [ ] No [ ]
FN5	Signal detect function	58.2.4	Mapping to PMD service interface	M	Yes [ ]
FN6	Signal detect behavior	58.2.4	Generated according to Table 58–2	M	Yes [ ]

58.10.3.2 PMD to MDI optical specifications for 100BASE-LX10

Item	Feature	Subclause	Value/Comment	Status	Support
LX1	100BASE-LX10 transmitter	58.3.1	Meets specifications in Table 58–3	LX:M	Yes [ ] N/A [ ]
LX2	100BASE-LX10 receiver	58.3.2	Meets specifications in Table 58–4	LX:M	Yes [ ] N/A [ ]
LX3	100BASE-LX10 stressed receiver sensitivity	58.3.2	Meets specification in Table 58–4	LX:O	Yes [ ] No [ ] N/A [ ]

58.10.3.3 PMD to MDI optical specifications for 100BASE-BX10-D

Item	Feature	Subclause	Value/Comment	Status	Support
BD1	100BASE-BX10 transmitter	58.4.1	Meets specifications in Table 58–5	BD:M	Yes [ ] N/A [ ]
BD2	100BASE-BX10 receiver	58.4.2	Meets specifications in Table 58–6	BD:M	Yes [ ] N/A [ ]
BD3	100BASE-BX10 stressed receiver sensitivity	58.4.2	Meets specification in Table 58–6	BD:O	Yes [ ] No [ ] N/A [ ]

58.10.3.4 PMD to MDI optical specifications for 100BASE-BX10-U

Item	Feature	Subclause	Value/Comment	Status	Support
BU1	100BASE-BX10 transmitter	58.4.1	Meets specifications in Table 58–5	BU:M	Yes [ ] N/A [ ]
BU2	100BASE-BX10 receiver	58.4.2	Meets specifications in Table 58–6	BU:M	Yes [ ] N/A [ ]
BU3	100BASE-BX10 stressed receiver sensitivity	58.4.2	Meets specification in Table 58–6	BU:O	Yes [ ] No [ ] N/A [ ]

58.10.3.5 Optical measurement requirements

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Measurement cable	58.7	2 m to 5 m in length	M	Yes [ ]
OM2	Test pattern	58.7.1, 58.7.8, 58.7.10	For eye, sensitivity, TDP, stressed sensitivity, jitter	M	Yes [ ]
OM3	Wavelength and spectral width	58.7.2	Per TIA-455-127-A under modulated conditions	M	Yes [ ]
OM4	Average optical power	58.7.3	Per TIA/EIA-455-95	M	Yes [ ]
OM5	Extinction ratio	58.7.4	Per IEC 61280-2-2	M	Yes [ ]
OM6	Transmit eye	58.7.8	Per 58.7.8 with specified test pattern	M	Yes [ ]
OM7	Receiver sensitivity	58.7.10	With specified pattern	M	Yes [ ]
OM8	Transmitter and dispersion penalty	58.7.9	With dispersion, reflection and decision timing offsets	M	Yes [ ]
OM9	Stressed receiver conformance test	58.7.11	According to 58.7.11.1, 58.7.11.2, and 58.7.11.3	O	Yes [ ] No [ ]

58.10.3.6 Environmental specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	58.8.1	Conforms to IEC-60950-1	M	Yes [ ]
ES2	Laser safety —IEC Hazard Level 1	58.8.2	Conform to Hazard Level 1 laser requirements defined in IEC 60825-1 and IEC 60825-2.	M	Yes [ ]
ES3	Documentation	58.8.2	Explicitly defines requirements and usage restrictions to meet safety certifications	M	Yes [ ]
ES4	Operating temperature range labeling	58.8.5	If required	M	Yes [ ] N/A [ ]

58.10.3.7 Characteristics of the fiber optic cabling and MDI

Item	Feature	Subclause	Value/Comment	Status	Support
FO1	Fiber optic cabling	58.9	Dispersion specifications of Table 58–15	INS:M	Yes [ ] N/A [ ]
FO2	End-to-end channel loss	58.1, 58.9	Meet the requirements of Table 58–1	INS:M	Yes [ ] N/A [ ]
FO3	Maximum discrete reflectance	58.9.3	Less than –26 dB	INS:M	Yes [ ] N/A [ ]
FO4	MDI requirements	58.9.4	IEC 61753-1 if remateable	INS:O	Yes [ ] No [ ] N/A [ ]

59. Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-LX10 (Long Wavelength) and 1000BASE-BX10 (BiDirectional Long Wavelength)

59.1 Overview

The 1000BASE-LX10 and 1000BASE-BX10 PMD sublayers provide point-to-point (P2P) 1000BASE-X links over a pair of fibers or a single fiber, respectively, up to 10 km.

This clause specifies the 1000BASE-LX10 PMD for both single-mode and multimode fiber, and the 1000BASE-BX10 PMD for single-mode fiber. A PMD is connected to the 1000BASE-X PMA of 66.2, and to the medium through the MDI. A PMD is optionally combined with the management functions that may be accessible through the management interface defined in Clause 22 or by other means.

Table 59–1 shows the primary attributes of each PMD type.

Table 59–1—Classification of 1000BASE-LX10 and 1000BASE-BX10 PMDs

Description	1000BASE-LX10		1000BASE-BX10-D	1000BASE-BX10-U	Unit
Fiber type[a]	B1.1, B1.3 SMF	50, 62.5 µm MMF	B1.1, B1.3 SMF		
Number of fibers	2	2	1		
Typical transmit direction	N/A		Downstream	Upstream	
Nominal transmit wavelength	1310	1310	1490	1310	nm
Minimum range	0.5 m to 10 km	0.5 m to 550 m[b]	0.5 m to 10 km		
Maximum channel insertion loss[c]	6.0	2.4	5.5	6.0	dB

[a] Per IEC 60793-2.
[b] See Table 59–16 for fiber and cable characteristics.
[c] At the nominal operating wavelength

A 1000BASE-LX10 link uses 1000BASE-LX10 PMDs at each end while a 1000BASE-BX10 link uses a 1000BASE-BX10-D PMD at one end and a 1000BASE-BX10-U PMD at the other. Typically the 1490 nm band is used to transmit away from the center of the network (“downstream”) and the 1310 nm band towards the center (“upstream”), although this arrangement, or the notion of hierarchy, is not required. The suffixes “D” and “U” indicate the PMDs at each end of a link that transmit in these directions and receive in the opposite directions.

1000BASE-LX10 is interoperable with 1000BASE-LX (see Clause 38). If used on single-mode fiber, operation is not ensured by this standard beyond the reach given in Table 38–6.

Two optional temperature ranges are defined; see 59.8.4 for further details. Implementations may be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

59.1.1 Goals and objectives

The following are the objectives of 1000BASE-LX10 and 1000BASE-BX10:

a) Point-to-point on optical fiber
b) 1000BASE-LX extended temperature range optics
c) 1000BASE-X up to 10km over SM fiber
d) BER better than or equal to 10^{-12} at the PHY service interface

59.1.2 Positioning of 1000BASE-LX10 and 1000BASE-BX10 PMDs within the IEEE 802.3 architecture

Figure 59–1 depicts the relationships of the PMD (shown shaded) with other sublayers and the ISO/IEC Open System Interconnection (OSI) reference model.

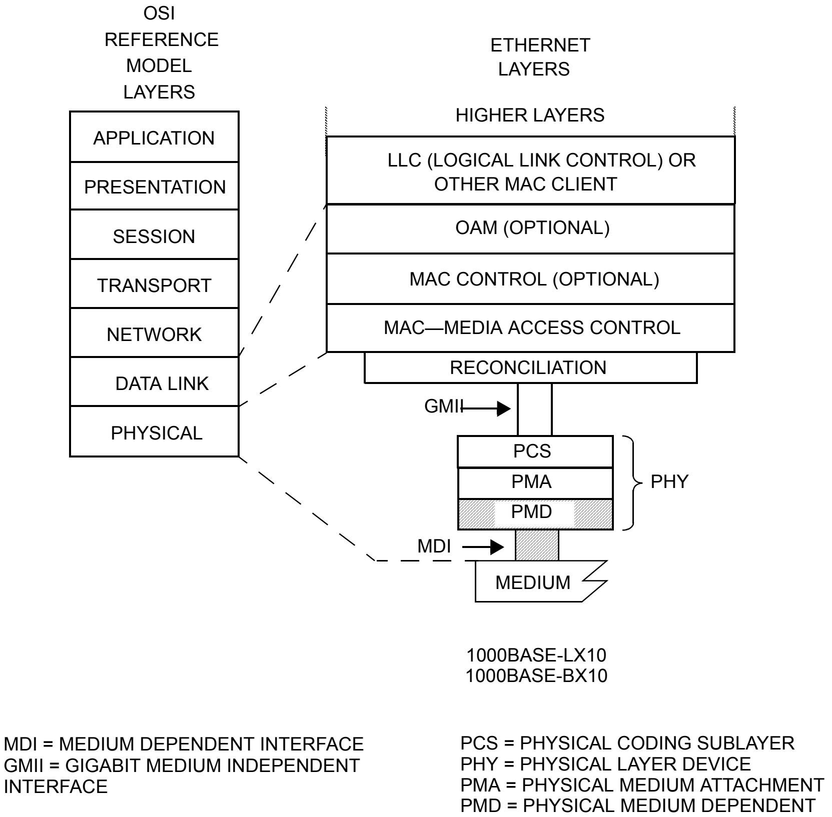

Figure 59–1—1000BASE-LX10 and 1000BASE-BX10 PMDs relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

59.1.3 Terminology and conventions

The following list contains references to terminology and conventions used in this clause:

Basic terminology and conventions, see 1.1 and 1.2.

Normative references, see 1.3.

Definitions, see 1.4.

Abbreviations, see 1.5.

Informative references, see Annex A.

Introduction to 1000 Mb/s baseband networks, see Clause 34.

Introduction to Ethernet for subscriber access networks, see Clause 56.

59.1.4 Physical Medium Dependent (PMD) sublayer service interface

The following specifies the services provided by the 1000BASE-LX10 and 1000BASE-BX10 PMDs. These PMD sublayers are described in an abstract manner and do not imply any particular implementation. The PMD service interface supports the exchange of encoded 8B/10B code-groups between the PMA and PMD entities. The PMD translates the serialized data of the PMA to and from signals suitable for the specified medium.

The following primitives are defined:

PMD_UNITDATA.request
PMD_UNITDATA.indication
PMD_SIGNAL.indication

59.1.5 Delay constraints

Delay requirements from the MDI to the GMII which include the PMD layer are specified in Clause 36. Of the budget, up to 20 ns is reserved for each of the transmit and receive functions of the PMD to account for those cases where the PMD includes a pigtail.

59.1.5.1 PMD_UNITDATA.request

This primitive defines the transfer of a serial data stream from the PMA to the PMD.

The semantics of the service primitive are PMD_UNITDATA.request(tx_bit). The data conveyed by PMD_UNITDATA.request is a continuous stream of bits where the tx_bit parameter can take one of two values: ONE or ZERO. The PMA continuously sends the appropriate stream of bits to the PMD for transmission on the medium, at a nominal 1.25 GBd signaling speed. Upon receipt of this primitive, the PMD converts the specified stream of bits into the appropriate signals at the MDI.

59.1.5.2 PMD_UNITDATA.indication

This primitive defines the transfer of data from the PMD to the PMA.

The semantics of the service primitive are PMD_UNITDATA.indication(rx_bit). The data conveyed by PMD_UNITDATA.indication is a continuous stream of bits where the rx_bit parameter can take one of two values: ONE or ZERO. The PMD continuously sends a stream of bits to the PMA corresponding to the signals received from the MDI.

59.1.5.3 PMD_SIGNAL.indication

This primitive is generated by the PMD to indicate the status of the signal being received from the MDI.

The semantics of the service primitive are PMD_SIGNAL.indication(SIGNAL_DETECT). The SIGNAL_DETECT parameter can take on one of two values: OK or FAIL, indicating whether the PMD is detecting light at the receiver (OK) or not (FAIL). When SIGNAL_DETECT = FAIL, PMD_UNITDATA.indication(rx_bit) is undefined. The PMD generates this primitive to indicate a change in the value of SIGNAL_DETECT.

SIGNAL_DETECT = OK does not guarantee that PMD_UNITDATA.indication(rx_bit) is known good. It is possible for a poor quality link to provide sufficient light for a SIGNAL_DETECT = OK indication and still not meet the specified bit error ratio.

59.2 PMD functional specifications

The 1000BASE-X PMDs perform the transmit and receive functions that convey data between the PMD service interface and the MDI.

59.2.1 PMD block diagram

The PMD sublayer is defined at the four reference points shown in Figure 59–2. Two points, TP2 and TP3, are compliance points. TP1 and TP4 are reference points for use by implementers. The optical transmit signal is defined at the output end of a patch cord (TP2), between 2 m and 5 m in length, of a fiber type consistent with the link type connected to the transmitter. If a single-mode fiber offset-launch mode-conditioning patch cord is used, the optical transmit signal is defined at the end of this single-mode fiber offset-launch mode-conditioning patch cord at TP2. Unless specified otherwise, all transmitter measurements and tests defined in 59.7 are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3) connected to the receiver. Unless specified otherwise, all receiver measurements and tests defined in 59.7 are made at TP3.

The electrical specifications of the PMD service interface (TP1 and TP4) are not system compliance points (these are not readily testable in a system implementation). It is expected that in many implementations, TP1 and TP4 will be common between 1000BASE-X PMD types.

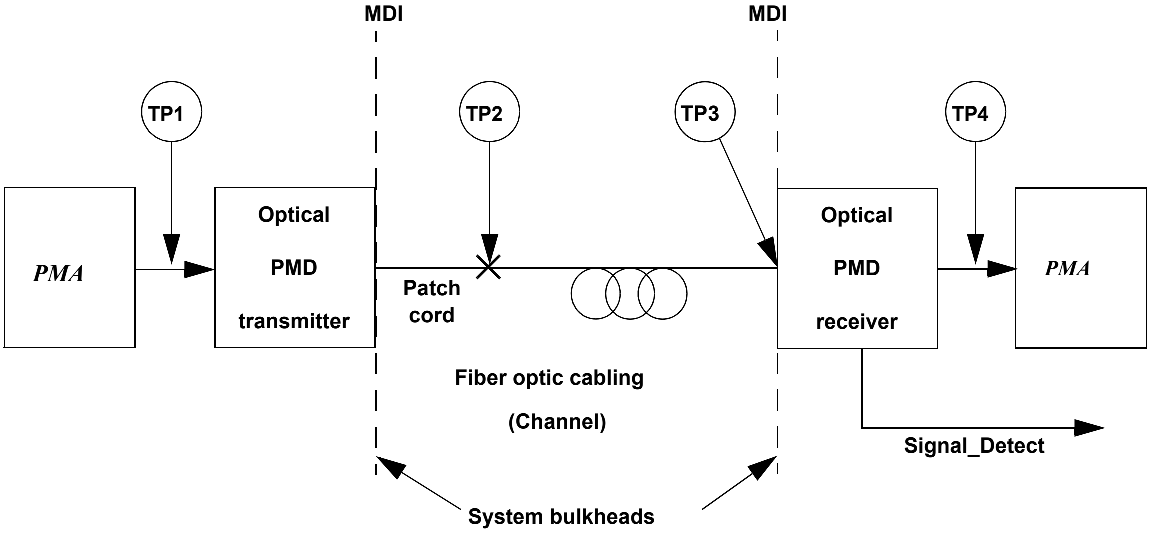

Figure 59–2—1000BASE-X block diagram

59.2.2 PMD transmit function

The PMD Transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the optical specifications in this clause. The higher optical power level shall correspond to tx_bit =ONE.

59.2.3 PMD receive function

The PMD receive function shall convey the bits received from the MDI according to the optical specifications in this clause to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). The higher optical power level shall correspond to rx_bit =ONE.

59.2.4 PMD signal detect function

The PMD signal detect function shall report to the PMD service interface using the message PMD_SIGNAL.indication(SIGNAL DETECT) which is signaled continuously. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence.

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 59–2. The PMD receiver is not required to verify whether a compliant 1000BASE-X signal is being received. This standard imposes no response time requirements on the generation of the SIGNAL_DETECT parameter.

As an unavoidable consequence of the requirements for the setting of the SIGNAL_DETECT parameter, implementations must provide adequate margin between the input optical power level at which the SIGNAL_DETECT parameter is set to OK, and the inherent noise level of the PMD due to cross talk, power supply noise, etc.

Various implementations of the Signal Detect function are permitted by this standard, including implementations which generate the SIGNAL_DETECT parameter values in response to the amplitude of the 8B/10B modulation of the optical signal and implementations which respond to the average optical power of the 8B/10B modulated optical signal.

Table 59–2—1000BASE-LX10 and 1000BASE-BX10 SIGNAL_DETECT value definition

Receive conditions		Signal_detect value
1000BASE-LX10	**1000BASE-BX10**	
Average input optical power ≤ signal detect threshold (min) in Table 59–5	Average input optical power ≤ signal detect threshold (min) in Table 59–7	FAIL
Average input optical power ≥ receiver sensitivity (max) in Table 59–5 with a compliant 1000BASE-LX or 1000BASE-LX10 signal input	Average input optical power ≥ receiver sensitivity (max) in Table 59–7 with a compliant 1000BASE-BX10 signal input at the specified receiver wavelength	OK
All other conditions		Unspecified

59.3 PMD to MDI optical specifications for 1000BASE-LX10

The operating range for 1000BASE-LX10 is defined in Table 59–1. A 1000BASE-LX10 compliant transceiver operates over the media types listed in Table 59–1 according to the specifications described in 59.9. A transceiver that exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

NOTE—In this subclause and Table 59–5, the specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is explained in 58.7.6.

59.3.1 Transmitter optical specifications

The 1000BASE-LX10 transmitter's signaling speed, operating wavelength, spectral width, average launch power, extinction ratio, return loss tolerance, OMA, eye and TDP shall meet the specifications defined in Table 59–3 per measurement techniques described in 59.7. Its RIN$_{12}$OMA should meet the value listed in Table 59–3 per measurement techniques described in 58.7.7. To ensure that the specifications of Table 59–3 are met with MMF links, the 1000BASE-LX10 transmitter output shall be coupled through a single-mode fiber offset-launch mode-conditioning patch cord, as defined in 59.9.5.The maximum RMS spectral width vs. center wavelength for 1000BASE-LX10 is shown in Table 59–4 and Figure 59–3. The equation used to generate these values is included in 59.7.2. The values in bold are normative, the others informative.

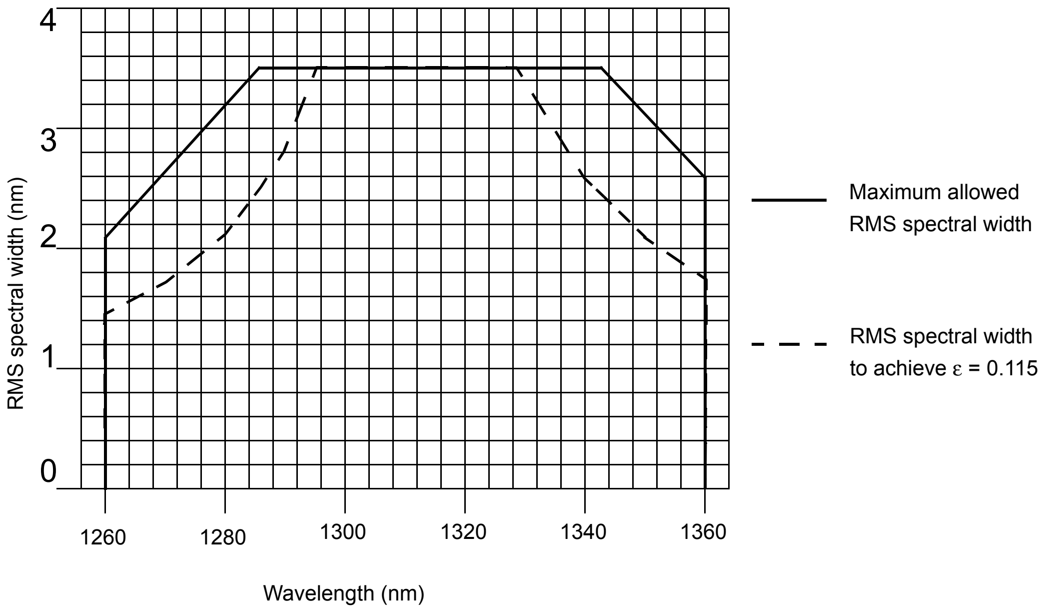

Figure 59–3—1000BASE-LX-10 Transmitter spectral limits

Table 59–3—1000BASE-LX10 transmit characteristics

Description	SMF	50 µm MMF	62.5 µm MMF	Unit
Nominal transmitter type[a]	Longwave Laser			
Signaling speed (range)	1.25 ± 100 ppm			GBd
Operating wavelength range[b]	1260 to 1360			nm
T rise /T fall (max, 20–80% response time)	0.30			ns
RMS spectral width (max)	See Table 59–4			nm
Average launch power (max)	–3			dBm
Average launch power (min)	–9	–11.0	–11.0	dBm
Average launch power of OFF transmitter (max)	–45			dBm
Extinction ratio (min)	6			dB
RIN$_{12}$OMA (max)	–113			dB/Hz
Optical return loss tolerance (max)	12			dB
Launch OMA (min)	–8.7 (130)	–10.2 (100)	–10.2 (100)	dBm (µW)
Transmitter eye mask definition {X1, X2, Y1, Y2, Y3}	0.22, 0.375, 0.20, 0.20, 0.30			UI

Table 59–3—1000BASE-LX10 transmit characteristics *(continued)*

Description	SMF	50 µm MMF	62.5 µm MMF	Unit
Decision timing offsets for transmitter and dispersion penalty (min)	±80			ps
Transmitter reflectance (max)	–6			dB
Transmitter and dispersion penalty, TDP (max)	3.3	3.5		dB
Differential delay, reference receiver for TDP (min)[c]	NA	367		ps

[a] The nominal device type is not intended to be a requirement on the source type, and any device meeting the transmitter characteristics specified may be substituted for the nominal device type.

[b] The great majority of the transmitted spectrum must fall within the operating wavelength range. The allowable range of central wavelengths is narrower than the operating wavelength range by the actual RMS spectral width at each extreme.

[c] Delay is calculated as Td = L/(3.BWf) where BWf is defined to –3 dB (optical). 1000BASE-LX is rated for 550 m of 500 MHz.km fiber while 1000BASE-LX also covered 550 m of 400 MHz.km fiber, but this is now seen as a historical bandwidth requirement.

Table 59–4—1000BASE-LX10 and 1000BASE-BX10 transmitter spectral limits

Center wavelength	RMS spectral width (max)[a]	RMS spectral width to achieve $\varepsilon \le 0.115$ (informative)
nm	nm	nm
1260	**2.09**	1.43
1270	**2.52**	1.72
1280	**3.13**	2.14
1286	**3.50**	2.49
1290		2.80
1297		3.50
1329		
1340		2.59
1343		2.41
1350	**3.06**	2.09
1360	**2.58**	1.76
1480 to 1500	**0.88**	0.60

[a] These limits for the 1000BASE-LX10 transmitter are illustrated in Figure 59–3. Limits at intermediate wavelengths may be found by interpolation.

59.3.2 Receiver optical specifications

The 1000BASE-LX10 receiver's signaling speed, operating wavelength, damage, overload, sensitivity, stressed receive characteristics, reflectance, and signal detect shall meet the specifications defined in Table 59–5 per measurement techniques defined in 59.7.

Table 59–5—1000BASE-LX10 receive characteristics

Description	Value	Unit
Signaling speed (range)	1.25 ± 100 ppm	GBd
Wavelength (range)	1260 to 1360	nm
Average receive power (max)	–3	dBm
Receive sensitivity (max)	–19.5	dBm
Receiver sensitivity as OMA (max)	–18.7 (13.4)	dBm (μW)
Bit error ratio (max)	10^{-12}	
Receiver reflectance (max)[a]	–12	dB
Stressed receive sensitivity (max)	–15.4	dBm
Stressed receiver sensitivity as OMA (max)	–14.6 (35)	dBm (μW)
Vertical eye-closure penalty (min)	3.6	dB
Receive electrical 3 dB upper cutoff frequency (max)	1500	MHz
Signal detect threshold (min)	–45	dBm
Stressed eye jitter (min)[b]	0.3	UI pk-pk
Jitter corner frequency	637	kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	0.05, 0.15	UI

[a] See 1.4 for definition of reflectance.

[b] Vertical eye closure penalty and jitter specifications are test conditions for measuring stressed receiver sensitivity. They are not required characteristics of the receiver.

59.4 PMD to MDI optical specifications for 1000BASE-BX10-D and 1000BASE-BX10-U

The operating range for 1000BASE-BX10-D and 1000BASE-BX10-U is defined in Table 59–1. A 1000BASE-BX10 compliant transceiver operates over all single-mode fibers listed in Table 59–1. A transceiver that exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

NOTE—In this subclause and 59.3, the specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is explained in 58.7.6.

59.4.1 Transmit optical specifications

The 1000BASE-BX10-D and 1000BASE-BX10-U transmitter's signaling speed, operating wavelength, spectral width, average launch power, extinction ratio, return loss tolerance, OMA, eye and TDP shall meet the specifications defined in Table 59–6 per measurement techniques described in 59.7. Its $RIN_{12}OMA$ should meet the value listed in Table 59–6 per measurement techniques described in 59.7.7.

Table 59–6—1000BASE-BX10-D and 1000BASE-BX10-U transmit characteristics

Description	1000BASE-BX10-D	1000BASE-BX10-U	Unit
Nominal transmitter type[a]	Longwave Laser		
Signaling speed (range)	1.25 ± 100 ppm		GBd
Operating wavelength range[b]	1480 to 1500	1260 to 1360	nm
RMS spectral width (max)	See Table 59–4		nm
Average launch power (max)	–3		dBm
Average launch power (min)	–9		dBm
Average launch power of OFF transmitter (max)	–45		dBm
Extinction ratio (min)	6		dB
$RIN_{12}OMA$ (max)	–113		dB/Hz
Optical return loss tolerance (max)	12		dB
Launch OMA	–8.2 (151)		dBm (μW)
Transmitter eye mask definition {X1, X2, Y1, Y2, Y3}	0.22, 0.375, 0.20, 0.20, 0.30		UI
Transmitter reflectance (max)	–10	–6	dB
Transmitter and dispersion penalty, TDP (max)	3.3		dB
Decision timing offsets for transmitter and dispersion penalty (min)	± 80		ps

[a] The nominal device type is not intended to be a requirement on the source type, and any device meeting the transmitter characteristics specified may be substituted for the nominal device type.

[b] The great majority of the transmitted spectrum must fall within the operating wavelength range. The allowable range of central wavelengths is narrower than the operating wavelength range by the actual RMS spectral width at each extreme.

59.4.2 Receiver optical specifications

The 1000BASE-BX10-D and 1000BASE-BX10-U receiver's signaling speed, operating wavelength, damage, overload, sensitivity, reflectance and signal detect shall meet the specifications defined in Table 59–7 per measurement techniques defined in 59.7. Its stressed receive characteristics should meet the values listed in Table 59–7 per measurement techniques described in 59.7.11.

Table 59–7—1000BASE-BX10-D and 1000BASE-BX10-U receive characteristics

Description	1000BASE-BX10-D	1000BASE-BX10-U	Unit
Signaling speed (range)	1.25 ± 100 ppm		GBd
Wavelength (range)	1260 to 1360	1480 to 1500	nm
Bit error ratio (max)	10^{-12}		
Average receive power (max)	–3		dBm
Receive sensitivity (max)	–19.5		dBm
Receiver sensitivity as OMA (max)	–18.7 (13.4)		dBm (μW)
Receiver reflectance (max)	–12		dB
Stressed receive sensitivity (max)[a]	–15.4		dBm
Stressed receiver sensitivity as OMA (max)	–14.6 (35)		dBm (μW)
Vertical eye-closure penalty (min)[b]	2.6		dB
Receive electrical 3 dB upper cutoff frequency (max)	1500		MHz
Signal detect threshold (min)	–45		dBm
Stressed eye jitter (min)	0.3		UI pk-pk
Jitter corner frequency	637		kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	0.05, 0.15		UI

[a] The stressed receiver sensitivity is optional.

[b] Vertical eye closure penalty and jitter specifications are test conditions for measuring stressed receiver sensitivity. They are not required characteristics of the receiver.

59.5 Illustrative 1000BASE-LX10 and 1000BASE-BX10 channels and penalties (informative)

The illustrative channel and penalties for 1000BASE-LX10 and 1000BASE-BX10 PMDs are shown in Table 59–8.

NOTE—The budgets include an allowance for –12 dB reflection at the receiver.

59.6 Jitter specifications

The entries for the 1000BASE-LX10 jitter budget on MMF in Table 59–9 and the 1000BASE-LX10 and 1000BASE-BX10 jitter budget on SMF in Table 59–10 represent high-frequency jitter (above 637 kHz) and do not include low frequency jitter or wander. All values are informative.

W is similar but not necessarily identical to deterministic jitter (DJ). A jitter measurement procedure is described in 58.7.12. Other jitter measurements are described in 59.7.12 and 59.7.13. Jitter at TP2 or TP3 is defined with a receiver of the same bandwidth as specified for the transmitted eye.

Table 59–8—Illustrative 1000BASE-LX10 and 1000BASE-BX10 channel and penalties

PMD type	1000BASE-LX10		1000BASE-BX10-D	1000BASE-BX10-U	Unit
Fiber type	B1.1, B1.3 SMF	50µm, 62.5µm MMF	B1.1, B1.3 SMF		
Measurement wavelength for fiber	1310	1300	1550	1310	nm
Nominal distance	10	0.55	10		km
Available power budget	10.5	8.5	10.5		dB
Maximum channel insertion loss[a]	6.0	2.4	5.5	6.0	dB
Allocation for penalties[b]	4.5	6.1	5.0	4.5	dB

[a] The maximum channel insertion loss is based on the cable attenuation at the target distance and nominal measurement wavelength. The channel insertion loss also includes the loss for connectors, splices and other passive components.

[b] The allocation for penalties is the difference between the available power budget and the channel insertion loss; insertion loss difference between nominal and worse case operating wavelength is considered a penalty.

Table 59–9—1000BASE-LX10 jitter budget on MMF (informative)

	Total jitter		*W*	
Reference point	UI	ps	UI	ps
TP1	0.240	192	0.100	80
TP1 to TP2	0.284	227	0.100	80
TP2	0.431	345	0.200	160
TP2 to TP3	0.170	136	0.050	40
TP3	0.510	408	0.250	200
TP3 to TP4	0.332	266	0.212	170
TP4	0.749	599	0.462	370

Table 59–10—1000BASE-LX10 and 1000BASE-BX10 jitter budget on SMF (informative)

	Total jitter		*W*	
Reference point	UI	ps	UI	ps
TP1	0.240	192	0.100	80
TP1 to TP2	0.334	267	0.150	120
TP2	0.481	385	0.250	200
TP2 to TP3	0.119	95	0	0
TP3	0.510	408	0.250	200
TP3 to TP4	0.332	266	0.212	170
TP4	0.749	599	0.462	370

NOTE—Informative jitter values are chosen to be compatible with the limits for eye mask and TDP (see 58.7.9). A margin between the total jitter at TP4 and the eye opening imposed by the decision point offsets for TDP is intended to allow for the performance of test equipment used for TDP measurement, to avoid very involved jitter calibrations.

Total jitter in this table is defined at 10^{-12} BER. In a commonly used model,

$$TJ = 14.1\sigma + DJ \text{ at } 10^{-12} \tag{59–1}$$

59.7 Optical measurement requirements

All optical measurements, except TDP and RIN, shall be made through a short patch cable, between 2 m and 5 m in length.

The following sections describe definitive patterns and test procedures for certain PMDs of this standard. implementers using alternative verification methods must ensure adequate correlation and allow adequate margin such that specifications are met by reference to the definitive methods.

59.7.1 Test patterns

The frame-based test patterns defined here are suitable for testing all Clause 59 and Clause 60 PMDs. Further information on frame-based testing in included in Annex 58A. The test suite and the patterns are shown in Table 59–11.

Table 59–11—List of test patterns and tests

Test pattern	Tests	Related subclauses
Any valid 8B/10B encoded signal	Eye mask Optical power Central wavelength Spectral width	59.7.8 59.7.3 59.7.2 59.7.2
Idles	Extinction ratio RIN_{12}OMA OMA	59.7.4 59.7.7
Random pattern test frame	Receiver sensitivity Stressed receiver sensitivity Receiver 3dB upper cutoff frequency TDP	59.7.11 59.7.14 59.7.15 59.7.10
Jitter pattern test frame	All jitter tests	59.7.12

The following test patterns are intended for frame-based testing of the 1000BASE-X PMDs of Clause 59 and Clause 60. They are compliant Ethernet packets with adequate user defined fields to allow them to be routed through a system to the point of the test. The common portions of the frames are given in Table 59–12.

Table 59–12—Common portion of frame-based test pattern

Field	Number of octets	Hexadecimal	8B/10B encoded binary[a]	
			Starting disparity +	Starting disparity–
SPD (/S/)	1	N/A[b]	N/A[c]	110110 1000
Remainder of preamble	6	55	N/A[c]	101010 0101
SFD	1	D5	N/A[c]	101010 0110
Destination address	6	User defined	User defined	User defined
Source address	6	User defined	User defined	User defined
Length/Type	2	User defined	User defined	User defined
First portion of MAC client data	32	User defined	User defined	User defined
Second portion of MAC client data	456	See Table 59–13 or Table 59–14	See Table 59–13 or Table 59–14	See Table 59–13 or Table 59–14
Frame check sequence[d]	4	As required by frame	As required by frame	As required by frame

Table 59–12—Common portion of frame-based test pattern *(continued)*

Field	Number of octets	Hexadecimal	8B/10B encoded binary[a]	
			Starting disparity +	Starting disparity–
EPD (/T/R/)[e]	2	N/A[b]	010001 0111 000101 0111	101110 1000 111010 1000
Idle (/I1/ or /I2/)[e]	2	N/A[b]	110000 0101 101001 0110	001111 1010 100100 0101
Idle (/I2/)[e]	10	N/A[b]	N/A[f]	001111 1010 100100 0101

[a] The binary bits are transmitted left most bit first.

[b] The SPD, EPD, and Idle code-groups are generated by the PCS and their hexadecimal octet values have no meaning without relation to the signals transmitted across the GMII.

[c] Except when operating in a half-duplex mode, it is not possible to transmit an SPD with a positive starting disparity. The first code-group that could begin with a positive running disparity would be the second octet of the destination address.

[d] The frame check sequence may be calculated using the method described in 3.2.9.

[e] The first row precedes the second row.

[f] The first idle code-group following the frame will be an /I1/ if the running disparity is positive and an /I2/ if the running disparity is negative. All subsequent idle code-groups will be /I2/.

NOTE—Users are advised to take care that the system under test is not connected to a network in service.

Two payloads are defined. The first, which emulates a random pattern with broad spectral content and minimal peaking, is shown in Table 59–13.

Table 59–13—Payload for random pattern test frame

Number of octets	Hexadecimal	8B/10B encoded binary	
		Starting disparity +	Starting disparity –
Repeat 19 times for 228 bytes	BE	100001 1010	011110 1010
	D7	111010 0110	000101 0110
	23	110001 1001	110001 1001
	47	000111 0101	111000 0101
	6B	110100 0011	110100 1100
	8F	101000 1101	010111 0010
	B3	110010 1010	110010 1010
	14	001011 0100	001011 1011
	5E	011110 0101	100001 0101
	FB	001001 1110	110110 0001
	35	101010 1001	101010 1001
	59	100110 0101	100110 0101
Transmit once for 12 bytes	BC	001110 1010	001110 1010
	D7	000101 0110	111010 0110
	23	110001 1001	110001 1001
	47	111000 0101	000111 0101
	6B	110100 1100	110100 0011
	8F	010111 0010	101000 1101
	B3	110010 1010	110010 1010
	14	001011 1011	001011 0100
	5E	100001 0101	011110 0101
	FB	110110 0001	001001 1110
	35	101010 1001	101010 1001
	59	100110 0101	100110 0101
Repeat 18 times for 216 bytes	BE	011110 1010	100001 1010
	D7	000101 0110	111010 0110
	23	110001 1001	110001 1001
	47	111000 0101	000111 0101
	6B	110100 1100	110100 0011
	8F	010111 0010	101000 1101
	B3	110010 1010	110010 1010
	14	001011 1011	001011 0100
	5E	100001 0101	011110 0101
	FB	110110 0001	001001 1110
	35	101010 1001	101010 1001
	59	100110 0101	100110 0101

The payload for the second pattern is shown in Table 59–14.

Table 59–14—Payload for jitter test frame

Field	Hexadecimal	8B/10B encoded binary	
		Starting disparity +	Starting disparity –
Low Transition Density, Repeat 96 times for 192 bytes	7E	100001 1100	011110 0011
	7E	011110 0011	100001 1100
Phase Jump, Repeat one time for 8 bytes	F4	001011 0001	001011 0111
	EB	110100 1110	110100 1000
	F4	001011 0001	001011 0111
	EB	110100 1110	110100 1000
	F4	001011 0001	001011 0111
	EB	110100 1110	110100 1000
	F4	001011 0001	001011 0111
	AB	110100 1010	110100 1010
High Transition Density, Repeat 20 times for 20 bytes	B5	101010 1010	101010 1010
Phase Jump, Repeat 4 times for 8 bytes	EB	110100 1110	110100 1000
	F4	001011 0001	001011 0111
Low Transition Density, Repeat 96 times for 192 bytes	7E	011110 0011	100001 1100
	7E	100001 1100	011110 0011
Phase Jump, Repeat one time for 8 bytes	F4	001011 0111	001011 0001
	EB	110100 1000	110100 1110
	F4	001011 0111	001011 0001
	EB	110100 1000	110100 1110
	F4	001011 0111	001011 0001
	EB	110100 1000	110100 1110
	F4	001011 0111	001011 0001
	AB	110100 1010	110100 1010
High Transition Density, Repeat 20 times for 20 bytes	B5	101010 1010	101010 1010
Phase Jump, Repeat 4 times for 8 bytes	EB	110100 1000	110100 1110
	F4	001011 0111	001011 0001

This pattern has areas of high and low transition density to aggravate jitter susceptibility.

Frames are separated by a near minimum interpacket gap (IPG) of 14 octets.

59.7.2 Wavelength and spectral width measurements

The wavelength and spectral width (RMS) shall meet the specifications according to TIA-455-127-A, under modulated conditions using a valid 1000BASE-X signal.

NOTE 1—The great majority of the transmitted spectrum must fall within the operating range. The allowable range of central wavelengths is narrower than the operating wavelength range by the actual RMS spectral width at each extreme.

NOTE 2—The 20 dB width for SLM lasers is taken as 6.07 times the RMS width.

The interaction between the transmitter and the chromatic dispersion of the fiber is accounted for by a parameter ε (epsilon), which is defined as the product of 10^{-3} times the signaling speed (in GBd) times the path dispersion (in ps/nm) times the RMS spectral width (in nm).

$$\varepsilon = \text{dispersion} \times \text{length} \times \text{RMS spectral width} \times \text{signaling speed} \times 10^{-3} \tag{59–2}$$

A maximum ε close to 0.168 is imposed by column 2 of Table 59–5. If the spectral width is kept below the limits of column 3, ε will not exceed 0.115, and the chromatic dispersion penalty is expected to be below 2 dB. The chromatic dispersion penalty is a component of transmitter and dispersion penalty (TDP) which is specified in Table 59–3, Table 59–6 and described in 58.7.9.

59.7.3 Optical power measurements

Optical power shall meet specifications according to the methods specified in ANSI/EIA-455-95. A measurement may be made with the port transmitting any valid encoded 8B/10B data stream.

59.7.4 Extinction ratio measurements

Extinction ratio shall meet specifications according to IEC 61280-2-2 with the port transmitting a repeating idle pattern /I2/ ordered set (see 36.2.4.12) that may be interspersed with OAM packets per 57A.2, and with minimal back reflections into the transmitter, lower than –20 dB. The /I2/ ordered set is defined in Clause 36, and is coded as /K28.5/D16.2/, which is binary 001111 1010 100100 0101 within idles. The extinction ratio is expected to be similar for other valid 8B/10B bit streams. The test receiver has the frequency response as specified for the transmitter optical waveform measurement.

59.7.5 OMA measurements (informative)

58.7.5 provides a reference technique for performing OMA measurements.

59.7.6 OMA relationship to extinction ratio and power measurements (informative)

The normative way of measuring transmitter characteristics is extinction ratio and mean power. Clause 58 provides information on how OMA, extinction ratio, and mean power, are related to each other (see 58.7.6).

59.7.7 Relative intensity noise optical modulation amplitude ($\mathrm{RIN}_{12}\mathrm{OMA}$)

$\mathrm{RIN}_{12}\mathrm{OMA}$ is the ratio of noise to modulated optical signal in the presence of a back reflection. The measurement procedure is described in 58.7.7.

59.7.8 Transmitter optical waveform (transmit eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 59–4.

The measurement procedure is described in 58.7.8 and references therein.

The eye shall comply to the mask of the eye using a fourth-order Bessel-Thomson receiver response with f_r= 0.9375 GHz, and where the relative response vs. relative frequency is defined in ITU-T G.957, Table B.2 (STM-16 values), along with the allowed tolerances for its physical implementation.

NOTE 1—This Bessel-Thomson filter is not intended to represent the noise filter used within an optical receiver, but is intended to provide uniform measurement conditions on the transmitter.

NOTE 2—The fourth order Bessel-Thomson filter is reactive. In order to suppress reflections, a 6 dB attenuator may be required at the filter input and/or output.

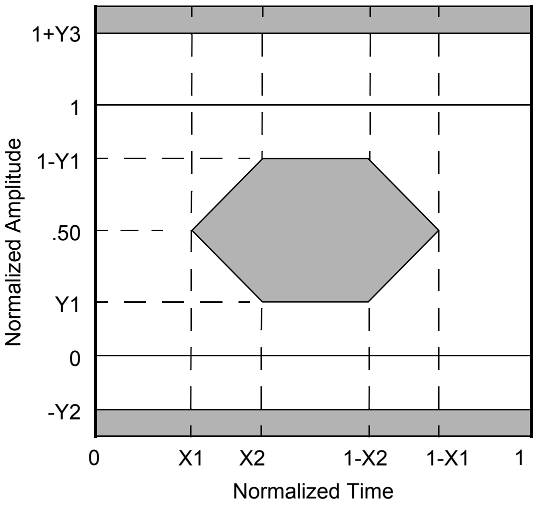

Figure 59–4—Transmitter eye mask definition

59.7.9 Transmit rise/fall characteristics

Optical response time specifications are based on unfiltered waveforms. Some lasers have overshoot and ringing on the optical waveforms, which, if unfiltered, reduce the accuracy of the 20–80% response times. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask defined in 59.7.8. If a filter is needed to conform to the mask, the filter response should be removed using Equation (59–3):

$$T_{\text{rise, fall}} = \sqrt{(T_{\text{rise, fall, measured}})^2 - (T_{\text{rise, fall, filter}})^2} \tag{59–3}$$

where the filter may be different for rise and fall. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson filter. The fourth order Bessel-Thomson filter describe in 59.7.8 may be a convenient filter for this measurement, however its low bandwidth adversely impacts the accuracy of the rise and fall time measurements.

59.7.10 Transmitter and dispersion penalty (TDP)

This measurement tests for transmitter impairments with modal (not chromatic) dispersion effects for a transmitter to be used with multimode fiber, and for transmitter impairments with chromatic effects for a transmitter to be used with single-mode fiber. Possible causes of impairment include intersymbol interference, jitter, RIN and mode partition noise. Meeting the separate requirements (e.g., eye mask, spectral characteristics) does not in itself guarantee the transmitter and dispersion penalty (TDP). The TDP limit shall be met. See 59.7.9 for details of the measurement.

59.7.11 Receive sensitivity measurements

Receiver sensitivity is defined for the random pattern test frame (see 59.7.1) and an ideal input signal quality with the specified extinction ratio. The measurement procedure is described in 58.7.10. The sensitivity shall be met for the bit error ratio defined in Table 59–5 or Table 59–7 as appropriate. Stressed sensitivity is described in 59.7.14 and 58.7.11.

59.7.12 Total jitter measurements (informative)

Total jitter measurements may be made according to the method in ANSI X3.230 [B21](FC-PH), Annex A, A.4.2, or according to 58.7.12. Total jitter at TP2 should be measured utilizing a BERT (bit error ratio tester). References to use of the Bessel-Thomson filter should substitute use of the Bessel-Thomson filter defined in this clause (see 59.7.8). The test should utilize the mixed frequency test pattern specified in 59.7.1.

Total jitter at TP4 should be measured using the conformance test signal at TP3, as specified in 59.7.14. The optical power should be at the stressed receive sensitivity level in Table 59–5 for 1000BASE-LX10 and in Table 59–7 for 1000BASE-BX10. This power level should be corrected if the extinction ratio differs from the specified extinction ratio (minimum). Measurements at TP4 should be taken directly without additional Bessel-Thomson filters.

Jitter measurement may use a clock recovery unit (commonly referred to in the industry as a “golden PLL”) to remove low-frequency jitter from the measurement as shown in Figure 59–5. The clock recovery unit has a low-pass filter with 20 dB/decade rolloff with –3 dB point of 637 kHz. For this measurement, the recovered clock will run at the signaling speed. The golden PLL is used to approximate the PLL in the deserializer function of the PMA. The PMA deserializer is able to track a large amount of low-frequency jitter (such as drift or wander) below its bandwidth. This low-frequency jitter would create a large measurement penalty, but does not affect operation of the link.

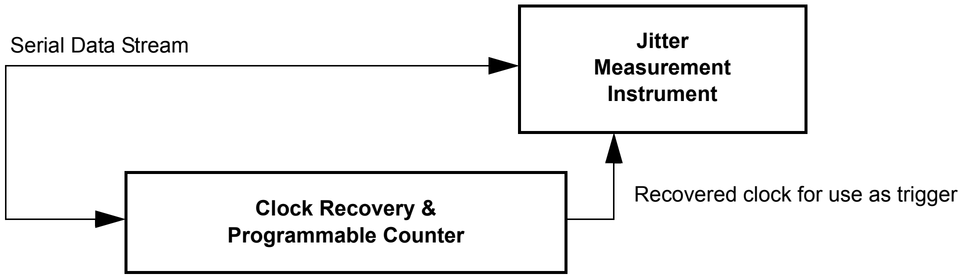

Figure 59–5—Utilization of clock recovery unit during measurement

59.7.13 Deterministic or high probability jitter measurement (informative)

Deterministic jitter may be measured according to ANSI X3.230-1994 [B21] (FC-PH), Annex A, A.4.3, DJ Measurement or high probability jitter may be measured according to 58.7.12. The test utilizes the mixed frequency test pattern specified in 36A.3. This method utilizes a digital sampling scope to measure actual vs. predicted arrival of bit transitions of the 36A.3 data pattern (alternating K28.5 code-groups).

It is convenient to use the clock recovery unit described in 59.7.12 for purposes of generating a trigger for the test equipment. This recovered clock should have a frequency equivalent to 1/20th of the signaling speed.

Measurements at TP2 and TP3 use the filter specified in 59.7.8, measurements at TP1 and TP4 do not use this filter.

59.7.14 Stressed receiver conformance test

The stressed receiver conformance test is intended to screen against receivers with poor frequency response or timing characteristics which could cause errors when combined with a distorted but compliant signal at TP3. Modal (MMF) or chromatic (SMF) dispersion can cause distortion. The conformance test signal uses the random pattern test frame and is conditioned by applying deterministic jitter and intersymbol interference. If the option for stressed receiver compliance is chosen, the receiver shall meet the specified bit error ratio at the power level and signal quality defined in Table 59–5 and Table 59–7 as appropriate, according to the measurement procedures of 58.7.11.

59.7.15 Measurement of the receiver 3 dB electrical upper cutoff frequency

The receiver 3 dB electrical upper cutoff frequency shall meet specifications according to the methods specified below. The test setup is shown in Figure 59–6. The test is performed with a laser that is suitable for analog signal transmission. The laser is modulated by a digital data signal. In addition to the digital modulation, the laser is modulated with an analog signal. The analog and digital signals should be asynchronous. The data pattern to be used for this test is the random pattern test frame defined in 59.7.1. The frequency response of the laser must be sufficient to allow it to respond to both the digital modulation and the analog modulation. The laser should be biased so that it remains linear when driven by the combined signals. Alternatively the two signals may be combined in the optical domain.

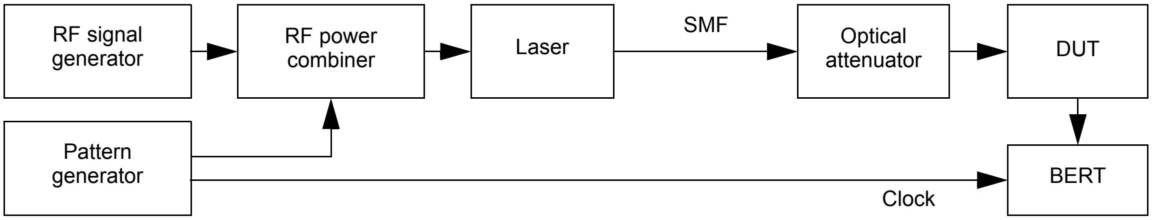

Figure 59–6—Test setup for receiver bandwidth measurement

The 3 dB upper cutoff frequency is measured using the following steps a) through e):

a) Calibrate the frequency response characteristics of the test equipment including the analog radio frequency (RF) signal generator, RF power combiner, and laser source. Measure the laser's extinction ratio according to 59.7.4. With the exception of extinction ratio, the optical source shall meet the requirements of Clause 59.
b) Configure the test equipment as shown in Figure 59–6. Take care to minimize changes to the signal path that could affect the system frequency response after the calibration in step a. Connect the laser output with no RF modulation applied to the receiver under test through an optical attenuator and taking into account the extinction ratio of the source, set the optical power to a level that approximates the stressed receive sensitivity level in Table 59–5 for 1000BASE-LX10 and in Table 59–7 for 1000BASE-BX10.
c) Locate the center of the eye with the BERT. Turn on the RF modulation while maintaining the same average optical power established in step b).
d) Measure the necessary RF modulation amplitude (in dBm) required to achieve a constant BER (e.g., 10^{-8}) for a number of frequencies.
e) The receiver 3 dB electrical upper cutoff frequency is that frequency where the corrected RF modulation amplitude (the measured amplitude in step d) corrected with the calibration data in step a) increases by 3 dB (electrical). If necessary, interpolate between the measured response values.

59.8 Environmental, safety, and labeling specifications

59.8.1 General safety

All equipment meeting this standard shall conform to IEC 60950-1.

59.8.2 Laser safety

1000BASE-BX10 and 1000BASE-LX10 optical transceivers shall conform to Hazard Level 1 laser requirements as defined in IEC 60825-1 and IEC 60825-2, under any condition of operation. This includes single fault conditions whether coupled into a fiber or out of an open bore. Conformance to additional laser safety standards may be required for operation within specific geographical regions.

Laser safety standards and regulations require that the manufacturer of a laser product provide information about the product's laser, safety features, labeling, use, maintenance and service. This documentation shall explicitly define requirements and usage restrictions on the host system necessary to meet these safety certifications.

59.8.3 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulations, be followed in every instance in which such practices are applicable.

59.8.4 Environment

Reference Annex 67A for additional environmental information.

Two optional temperature ranges are defined in Table 59–15. Implementations shall be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

Table 59–15—Component case temperature classes

Class	Low temperature (°C)	High temperature (°C)
Warm extended	–5	+85
Cool extended	–40	+60
Universal extended	–40	+85

59.8.5 PMD labeling requirements

It is recommended that each PHY (and supporting documentation) be labeled in a manner visible to the user, with at least the applicable safety warnings and the applicable port type designation (e.g., 1000BASE-BX10-U).

Labeling requirements for Hazard Level 1 lasers are given in the laser safety standards referenced in 59.8.2.

Compliant systems and field pluggable components shall be clearly labeled with the operating temperature range over which their compliance is ensured.

59.9 Characteristics of the fiber optic cabling

The 1000BASE-BX10 and 1000BASE-LX10 fiber optic cabling shall meet the dispersion and modal bandwidth specifications defined in IEC 60793-2 and ITU-T G.652, or the requirements of Table 59–16 where they differ. The fiber cable attenuation is shown for information only; the end-to-end channel loss shall meet the requirements of Table 59–1. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together. The fiber optic cabling spans from one MDI to another MDI, as shown in Figure 59–7.

59.9.1 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 59–7.

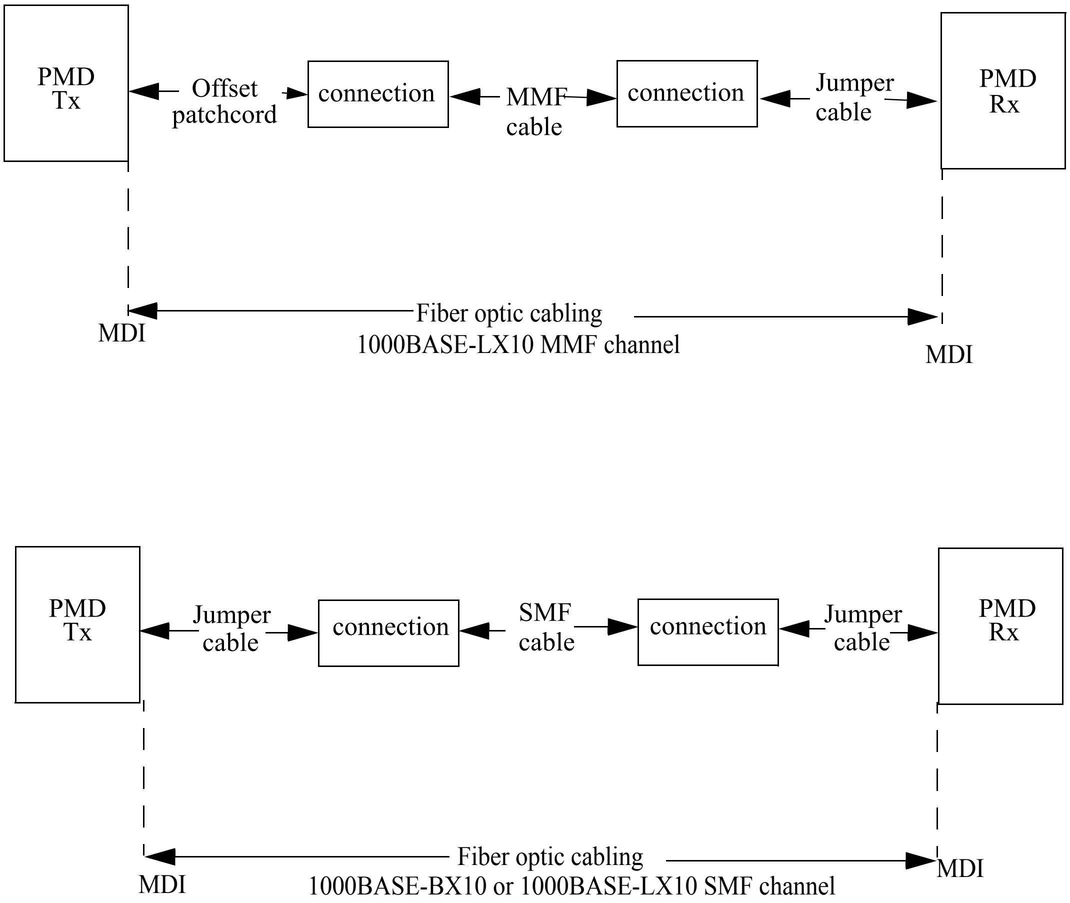

Figure 59–7—Fiber optic cable model

The maximum channel insertion loss shall meet the requirements specified in Table 59–1. The minimum loss for 1000BASE-BX10 and 100BASE-LX10 is zero. A channel may contain additional connectors or other optical elements as long as the optical characteristics of the channel, such as attenuation, dispersion and reflections, meet the specifications. Insertion loss measurements of installed fiber cables are made in accordance with ANSI/TIA/EIA-526-14A [B15], method B for multimode cabling and ANSI/TIA/EIA-526-7 [B16], method A-1 for single-mode cabling. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards.

59.9.2 Optical fiber and cable

The fiber optic cable requirements are satisfied by the fibers specified in IEC 60793-2 Type B1.1 (dispersion un-shifted single-mode fiber) and Type B1.3 (low water peak single-mode fiber) and ITU-T G.652, or by the requirements of Table 59–16 where they differ.

Table 59–16—Optical fiber and cable characteristics

Description[a]	B1.1, B1.3 SMF		50 µm MMF	62.5 µm MMF	Unit
Nominal fiber specification wavelength[b]	1310	1550	1300		nm
Cabled optical fiber attenuation (max)[c]	0.4	0.35	1.5		dB/km
Modal Bandwidth (min; overfilled launch)	N/A		500[d]		MHz· km
Zero dispersion wavelength[e]	$1300 \le \lambda_0 \le 1324$		$1295 \le \lambda_0 \le 1320$	$1320 \le \lambda_0 \le 1365$	nm
Dispersion slope (max)	0.093		0.11 for $1300 \le \lambda_0 \le 1320$ and $0.001(\lambda_0-1190)$ for $1295 \le \lambda_0 \le 1300$	0.11 for $1320 \le \lambda_0 \le 1348$ and $0.001(1458-\lambda_0)$ for $1348 \le \lambda_0 \le 1365$	ps /nm^2 · km

[a] The fiber dispersion values are normative, all other values in the table are informative.
[b] The wavelength specified is the nominal fiber specification wavelength which is the typical measurement wavelength. Power penalties at other wavelengths are accounted for.
[c] Attenuation values are informative. Attenuation for single-mode optical fiber cables is defined in ITU-T G.652 and for multimode fiber cables is defined in ISO/IEC 11801.
[d] 1000BASE-LX10 is rated for 550 m of 500 MHz·km fiber, while 1000BASE-LX also covered 550 m of 400 MHz·km, but this now seen as a historical bandwidth requirement.
[e] See IEC 60793 or G.652 for correct use of zero dispersion wavelength and dispersion slope.

59.9.3 Optical fiber connection

The maximum link distances for multimode fiber are calculated based on the allocation of 1.5 dB total connection and splice loss. Connections with different loss characteristics may be used provided the requirements of Table 59–1 are met.

The maximum link distances for single-mode fiber are calculated based on the allocation of 2 dB total connection and splice loss for 1000BASE-LX10 and 1000BASE-BX10. Connections with different loss characteristics may be used provided the requirements of Table 59–1 are met.

The maximum discrete reflectance for multimode connections shall be less than –20 dB.

The maximum discrete reflectance for single-mode connections shall be less than –26 dB.

59.9.4 Medium Dependent Interface (MDI)

The 1000BASE-LX10 or 1000BASE-BX10 PMD is coupled to the fiber cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” as shown in Figure 59–7. Examples of an MDI include the following:

a) Connectorized fiber pigtail
b) PMD receptacle

When the MDI is a remateable connection, it shall meet the interface performance specifications of IEC 61753-1. The MDI carries the signal in both directions. For 1000BASE-BX10 it couples a single fiber and for 1000BASE-LX10 it couples dual fibers.

NOTE—Compliance testing is performed at TP2 and TP3 as defined in 59.2.1, not at the MDI.

59.9.5 Single-mode fiber offset-launch mode-conditioning patch cord for MMF operation of 1000BASE-LX10

This subclause specifies an example embodiment of a mode conditioner for 1000BASE-LX10 operation with MMF cabling. The mode conditioner consists of a single-mode fiber permanently coupled off-center to a graded index fiber. This example embodiment of a patch cord is not intended to exclude other physical implementations of offset-launch mode conditioners. However, any implementation of an offset-launch mode conditioner used for 1000BASE-LX10 shall meet the specifications of Table 59–17. The offset launch shall be contained within the patch cord assembly and is not adjustable by the user.

NOTE—The single-mode fiber offset-launch mode-conditioning patch cord described in Clause 38 may be used, although its labeling and coloring requirements are not mandatory here. See 38.11.4.

Table 59–17—Single-mode fiber offset-launch mode conditioner specifications

Description	62.5 µm MMF	50 µm MMF	Unit
Maximum insertion loss	0.5	0.5	dB
Coupled power ratio (CPR)	28 < CPR < 40	12 < CPR < 20	dB
Optical center offset between SMF and MMF	17 < Offset < 23	10 < Offset < 16	µm
Maximum angular offset	1	1	degree

Patch cord connectors and ferrules for the single-mode-to-multimode offset launch shall have single-mode tolerances, float, and other mechanical requirements according to IEC 61754-1.

The single-mode fiber used in the construction of the single-mode fiber offset-launch mode conditioner shall meet the requirements of 59.9.2. The multimode fiber used in the construction of the single-mode fiber offset-launch mode conditioner shall be of the same type as the cabling over which the 1000BASE-LX10 link is to be operated. If the cabling is 62.5 µm MMF then the MMF used in the construction of the mode conditioner is of type 62.5 µm MMF. If the cabling is 50 µm MMF, then the MMF used in the construction of the mode conditioner is of type 50 µm MMF.

Figure 59–8 shows an example of an embodiment of the single-mode fiber offset-launch mode-conditioning patch cord. This patch cord consists of duplex fibers including a single-mode-to-multimode offset launch fiber connected to the transmitter MDI and a second conventional graded index MMF connected to the receiver MDI. The preferred configuration is a plug-to-plug patch cord since it maximizes the power budget margin of the 1000BASE-LX10 link. The single-mode end of the patch cord is labeled “To Equipment”. The multimode end of the patch cord is labeled “To Cable”. The recommended color identifier of the single-mode fiber connector is blue. The recommended color identifier of all multimode fiber connector plugs is beige. The patch cord assembly is labeled “Offset-launch mode-conditioning patch cord assembly”. Labeling identifies which size multimode fiber is used in the construction of the patch cord. The keying of this duplex optical plug ensures that the single-mode fiber end is automatically aligned to the transmitter MDI.

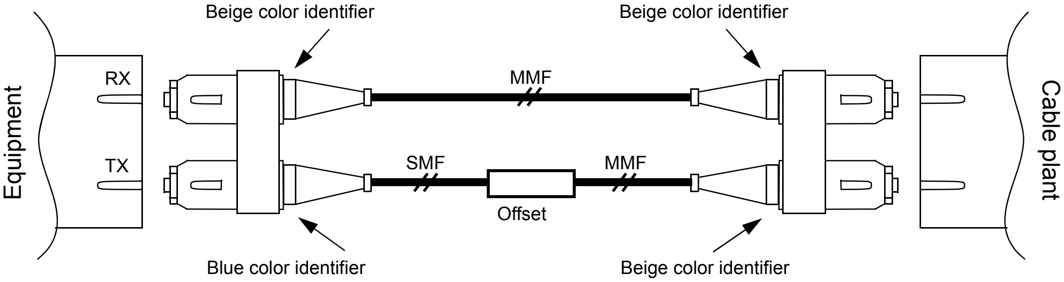

Figure 59–8—1000BASE-LX10 single-mode fiber offset-launch mode-conditioning patch cord assembly

59.10 Protocol implementation conformance statement (PICS) proforma for Clause 59, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-LX10 (Long Wavelength) and 1000BASE-BX10 (BiDirectional Long Wavelength)[7]

59.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 59, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-LX10 and type 1000BASE-LX10, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

59.10.2 Identification

59.10.2.1 Implementation identification

Supplier[1]	
Contact point for inquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1, 3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

59.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 59, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-LX10 and 1000BASE-BX10
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[7] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

59.10.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
HT	High temperature operation	59.8.4	–5 to 85°C	O	Yes [ ] No [ ]
LT	Low temperature operation	59.8.4	–40 to 60°C	O	Yes [ ] No [ ]
*LX	1000BASE-LX10 PMD	59.3	Device supports long wavelength (1310 nm) over dual multimode and single-mode fibers.	O/1	Yes [ ] No [ ]
*BXD	1000BASE-BX10-D PMD	Table 59–6	Device operates with one single single-mode fiber and transmits at downstream wavelength (1490 nm).	O/1	Yes [ ] No [ ]
*BXU	1000BASE-BX10-U PMD	Table 59–6	Device operates with one single single-mode fiber and transmits upstream wavelength (1310 nm).	O/1	Yes [ ] No [ ]
*INS	Installation / cable	59.9	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer.	O	Yes [ ] No [ ]
*OFP	Single-mode offset-launch mode-conditioning patch cord	59.9.5	Items marked with OFP include installation practices and cable specifications not applicable to a PHY manufacturer.	O	Yes [ ] No [ ]

59.10.3.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FN1	Transmit function	59.2.2	Convey bits requested by PMD_UNITDATA.request() to the MDI.	M	Yes [ ]
FN2	Transmitter optical signal	59.2.2	Higher optical power is a logical 1.	M	Yes [ ]
FN3	Receive function	59.2.3	Convey bits received from the MDI to PMD_UNITDATA.indication().	M	Yes [ ]
FN4	Receiver optical signal	59.2.3	Higher optical power is a logical 1.	M	Yes [ ]
FN5	Signal detect function	59.2.4	Mapping to PMD interface.	M	Yes [ ]
FN6	Signal detect behavior	59.2.4	Generated according to Table 59–2.	M	Yes [ ]

59.10.3.2 PMD to MDI optical specifications for 1000BASE-LX10

Item	Feature	Subclause	Value/Comment	Status	Support
LX1	1000BASE-LX10 transmitter	59.3.1	Transmitter meets specifications in Table 59–3.	LX:M	Yes [ ] N/A [ ]
LX2	Offset-launch mode-conditioning patch cord	59.3.1	Required for LX10 multimode operation.	OFP:M	Yes [ ] N/A [ ]
LX3	1000BASE-LX10 receiver	59.3.2	Receiver meets mandatory specifications in Table 59–5.	LX:M	Yes [ ] N/A [ ]
LX4	1000BASE-LX10 stressed receiver sensitivity	59.3.2	Receiver meets mandatory specifications in Table 59–5.	LX:M	Yes [ ] N/A [ ]

59.10.3.3 PMD to MDI optical specifications for 1000BASE-BX10-D

Item	Feature	Subclause	Value/Comment	Status	Support
BXD1	1000BASE-BX10-D transmitter	59.4.1	Transmitter meets specifications in Table 59–6.	BXD:M	Yes [ ] N/A [ ]
BXD2	1000BASE-BX10-D receiver	59.4.2	Receiver meets mandatory specifications in Table 59–7.	BXD:M	Yes [ ] N/A [ ]
BXD3	1000BASE-BX10-D stressed receiver sensitivity	59.4.2	Receiver meets specifications in Table 59–7.	BXD:O	Yes [ ] No [ ] N/A [ ]

59.10.3.4 PMD to MDI optical specifications for 1000BASE-BX10-U

Item	Feature	Subclause	Value/Comment	Status	Support
BXU1	1000BASE-BX10-U transmitter	59.4.1	Transmitter meets specifications in Table 59–6.	BXU:M	Yes [ ] N/A [ ]
BXU2	1000BASE-BX10-U receiver	59.4.2	Receiver meets mandatory specifications in Table 59–7.	BXU:M	Yes [ ] N/A [ ]
BXU3	1000BASE-BX10-U stressed receiver sensitivity	59.4.2	Receiver meets specifications in Table 59–7.	BXU:O	Yes [ ] No [ ] N/A [ ]

59.10.3.5 Optical Measurement requirements

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Measurement cable		2 m to 5 m in length.	M	Yes [ ]
OM2	Test patterns	59.7.1	See Table 59–11.	M	Yes [ ]
OM3	Wavelength and spectral width	59.7.2	Per TIA-455-127-A under modulated conditions.	M	Yes [ ]
OM4	Average optical power	59.7.3	Per TIA/EIA-455-95.	M	Yes [ ]
OM5	Extinction ratio	59.7.4	Per IEC 61280-2-2 with minimal back reflections and fourth-order Bessel-Thomson receiver.	M	Yes [ ]
OM6	$\mathrm{RIN}_{12}\mathrm{OMA}$	58.7.7	As described in 58.7.7.	M	Yes [ ]
OM7	Transmit optical waveform (transmit eye)	59.7.8	Per ANSI/TIA/EIA-526-4A with test pattern and fourth-order Bessel-Thomson receiver.	M	Yes [ ]
OM8	Transmit rise/fall characteristics	59.7.9	Waveforms conform to mask in Figure 59–4, measure from 20% to 80%, using patch cable per 59.7.	LX:M	Yes [ ]
OM9	Transmitter and dispersion penalty	59.7.10	As described in 58.7.9.	M	Yes [ ]
OM10	Receive sensitivity	59.7.11	With specified pattern.	M	Yes [ ]
*OM11	Stressed receiver conformance	59.7.14	As described in 59.7.14.	O	Yes [ ] N/A[ ]
OM12	Receiver 3dB electrical upper cutoff frequency	59.7.15	As described in 59.7.15.	M	Yes [ ]

59.10.3.6 Environmental, safety, and labeling specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	59.8.1	Conforms to IEC 60950-1.	M	Yes [ ]
ES2	Laser safety—IEC Hazard Level 1	59.8.2	Conform to Hazard Level 1 laser requirements defined in IEC 60825-1 and IEC 60825-2.	M	Yes [ ]
ES3	Documentation	59.8.2	Explicitly define requirements and usage restrictions to meet safety certifications.	M	Yes [ ]
ES4	Operating temperature range labeling	59.8.5	If required, label range over which compliance is ensured.	M	Yes [ ] N/A[ ]

59.10.3.7 Characteristics of the fiber optic cabling

Item	Feature	Subclause	Value/Comment	Status	Support
FO1	Fiber optic cabling	59.9	Meets specifications in Table 59–16.	INS:M	Yes [ ] N/A [ ]
FO2	End-to-end channel loss	59.9.1	Meet the requirements specified in Table 59–1.	INS:M	Yes [ ] N/A [ ]
FO3	Maximum discrete reflectance for multimode connections	59.9.3	Less than –20 dB.	INS:M	Yes [ ] N/A [ ]
FO4	Maximum discrete reflectance for single-mode connections	59.9.3	Less than –26 dB.	INS:M	Yes [ ] N/A [ ]
FO5	MDI requirements	59.9.4	Meet the interface performance specifications of IEC 61753-1, if remateable.	INS:O	Yes [ ] No[ ] N/A [ ]

59.10.3.8 Offset-launch mode-conditioning patch cord

Item	Feature	Subclause	Value/Comment	Status	Support
LPC1	Offset-launch mode-conditioning patch cord	59.9.5	Meet conditions of 59.9.5.	OFP:M	Yes [ ] N/A [ ]
LPC2	Single-mode mechanics in offset-launch mode-conditioning patch cords	59.9.5	IEC 61754-1:1997 [B39] grade 1 ferrule.	OFP:M	Yes [ ] N/A [ ]
LPC3	Single-mode fiber in offset-launch mode-conditioning patch cords	59.9.5	Per 59.9.5.	OFP:M	Yes [ ] N/A [ ]
LPC4	Multimode fiber in offset-launch mode-conditioning patch cords	59.9.5	Same type as used in cable plant.	OFP:M	Yes [ ] N/A [ ]

60. Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks)

60.1 Overview

The 1000BASE-PX10, 1000BASE-PX20, 1000BASE-PX30, and 1000BASE-PX40 PMD sublayers provide point-to-multipoint (P2MP) 1000BASE-X connections over passive optical networks (PONs). The 1000BASE-PX10 PMD sublayers support a reach of at least 10 km whereas the 1000BASE-PX20, 1000BASE-PX30, and 1000BASE-PX40 PMD sublayers support a reach of at least 20 km. The 1000BASE-PX10 and 1000BASE-PX20 PMD sublayers support a typical split ratio of 1:16. The 1000BASE-PX30 PMD sublayers support a typical split ratio of 1:32. The 1000BASE-PX40 PMD sublayers support a typical split ratio of 1:64. In an Ethernet PON, a single downstream (D) PMD broadcasts to multiple upstream (U) PMDs and receives bursts from each “U” PMD over a single branched topology, single-mode fiber network. The same fibers are used simultaneously in both directions. This clause specifies a single-mode fiber medium and the following PMDs (including MDI): 1000BASE-PX10-D, 1000BASE-PX10-U, 1000BASE-PX20-D, 1000BASE-PX20-U, 1000BASE-PX30-D, 1000BASE-PX30-U, 1000BASE-PX40-D, and 1000BASE-PX40-U. A 1000BASE-PX-U PMD or a 1000BASE-PX-D PMD is connected to the appropriate 1000BASE-X PMA of Clause 65, and to the medium through the MDI. A PMD is optionally combined with the management functions that may be accessible through the management interface defined in Clause 22 or by other means.

A 1000BASE-PX10 link uses a 1000BASE-PX10-U PMD at one end and a 1000BASE-PX10-D PMD at the other. A 1000BASE-PX20 link uses a 1000BASE-PX20-U PMD at one end and a 1000BASE-PX20-D PMD at the other. A 1000BASE-PX30 link uses a 1000BASE-PX30-U PMD at one end and a 1000BASE-PX30-D PMD at the other. A 1000BASE-PX40 link uses a 1000BASE-PX40-U PMD at one end and a 1000BASE-PX40-D PMD at the other. A 1000BASE-PX20-D PMD is interoperable with a 1000BASE-PX10-U PMD. This allows certain upgrade possibilities from 10 km to 20 km PONs.

Two optional temperature ranges are defined; see 60.10.4 for further details. Implementations may be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

Table 60–1 shows the primary attributes of each PMD type.

60.1.1 Goals and objectives

All 1000BASE-PX PMDs share the objectives of:

a) Point-to-multipoint on optical fiber.
b) BER better than or equal to 10^{-12} at the PHY service interface.
c) 1000 Mb/s on one single-mode fiber.

1000BASE-PX10 has an objective of operating at the distance of at least of 10 km and at a split ratio of at least of 1:16. 1000BASE-PX20 has an objective of operating at the distance of at least of 20 km and at a split ratio of at least of 1:16. 1000BASE-PX30 has an objective of operating at the distance of at least of 20 km and at a split ratio of at least of 1:32. 1000BASE-PX40 has an objective of operating at the distance of at least of 20 km and at a split ratio of at least of 1:64.

60.1.2 Positioning of this PMD set within the IEEE 802.3 architecture

Figure 60–1 depicts the relationships of the PMD (shown shaded) with other sublayers and the ISO/IEC Open System Interconnection (OSI) reference model.

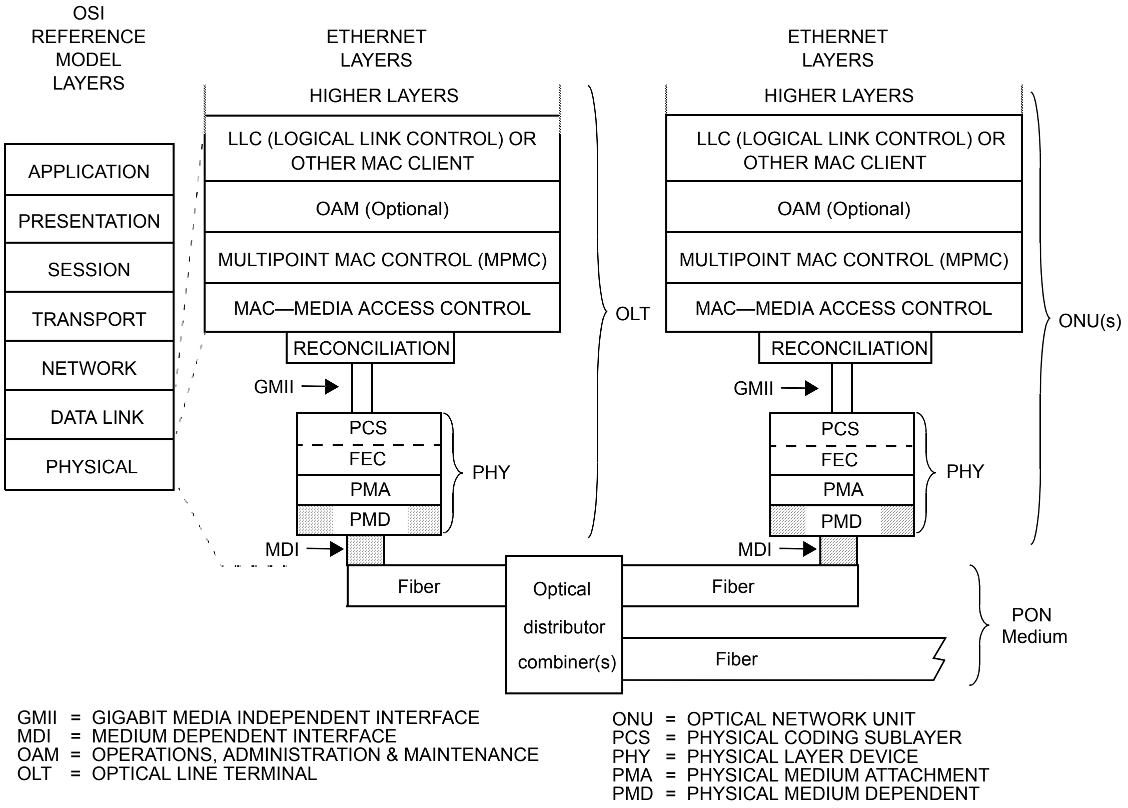

Figure 60–1—P2MP PMDs relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

60.1.3 Terminology and conventions

The following list contains references to terminology and conventions used in this clause:

Basic terminology and conventions, see 1.1 and 1.2.

Normative references, see 1.3.

Definitions, see 1.4.

Abbreviations, see 1.5.

Informative references, see Annex A.

Introduction to 1000 Mb/s baseband networks, see Clause 34.

Introduction to Ethernet for subscriber access networks, see Clause 56.

60.1.4 Physical Medium Dependent (PMD) sublayer service interface

The following specifies the services provided by the 1000BASE-PX10, 1000BASE-PX20, 1000BASE-PX30, and 1000BASE-PX40 PMDs.

These PMD sublayer service interfaces are described in an abstract manner and do not imply any particular implementation. The PMD Service Interface supports the exchange of 8B/10B code-groups between the PMA and PMD entities. The PMD translates the serialized data of the PMA to and from signals suitable for the specified medium. The following primitives are defined:

PMD_UNITDATA.request

PMD_UNITDATA.indication

PMD_SIGNAL.request

PMD_SIGNAL.indication

Table 60–1—PMD types specified in this clause

Description	1000BASE-PX10-U	1000BASE-PX10-D	1000BASE-PX20-U	1000BASE-PX20-D	1000BASE-PX30-U	1000BASE-PX30-D	1000BASE-PX40-U	1000BASE-PX40-D	Unit
Fiber type	IEC 60793–2 B1.1, B1.3 SMF				IEC 60793–2 B1.1, B1.3 SMF ITU–T G.652, G.657 SMF				
Number of fibers	1				1				
Nominal transmit wavelength	1310	1490	1310	1490	1310	1490	1310	1490	nm
Transmit direction[a]	US	DS	US	DS	US	DS	US	DS	
Minimum range[b]	0.5 m to 10 km		0.5 m to 20 km						
Maximum channel insertion loss[c]	20	19.5	24	23.5	29		33		dB
Minimum channel insertion loss[d]	5		10		15		18		dB

[a] US stands for Upstream, DS stands for Downstream.

[b] In an FEC enabled link, the minimum range may be increased, or, links with a higher channel insertion loss may be used.

[c] At nominal transmit wavelength.

[d] The differential insertion loss for a link is the difference between the maximum and minimum channel insertion loss, and not applicable to 1000BASE-PX30 and 1000BASE-PX40.

60.1.5 Delay constraints

Delay requirements from the MDI to the GMII which include the PMD layer are specified in Clause 36. Of the budget, up to 20 ns is reserved for each of the transmit and receive functions of the PMD to account for those cases where the PMD includes a pigtail.

60.1.5.1 PMD_UNITDATA.request

This primitive defines the transfer of a serial data stream from the PMA to the PMD.

The semantics of the service primitive are PMD_UNITDATA.request(tx_bit). The data conveyed by PMD_UNITDATA.request is a continuous stream of bits. The tx_bit parameter can take one of two values: ONE or ZERO. The PMA continuously sends the appropriate stream of bits to the PMD for transmission on the medium, at a nominal 1.25 GBd signaling speed. Upon receipt of this primitive, the PMD converts the specified stream of bits into the appropriate signals at the MDI.

60.1.5.2 PMD_UNITDATA.indication

This primitive defines the transfer of data from the PMD to the PMA.

The semantics of the service primitive are PMD_UNITDATA.indication(rx_bit). The data conveyed by PMD_UNITDATA.indication is a continuous stream of bits. The rx_bit parameter can take one of two values: ONE or ZERO. The PMD continuously sends a stream of bits to the PMA corresponding to the signals received from the MDI.

60.1.5.3 PMD_SIGNAL.request

In the upstream direction, this primitive is generated by the PCS to turn on and off the transmitter according to the granted time. A signal for laser control is generated in 65.3.1.1.

The semantics of the service primitive are PMD_SIGNAL.request(tx_enable). The tx_enable parameter can take on one of two values: ENABLE or DISABLE, determining whether the PMD transmitter is on (enabled) or off (disabled). The PCS generates this primitive to indicate a change in the value of tx_enable. Upon receipt of this primitive, the PMD turns the transmitter on or off as appropriate.

60.1.5.4 PMD_SIGNAL.indication

This primitive is generated by the PMD to indicate the status of the signal being received from the MDI.

The semantics of the service primitive are PMD_SIGNAL.indication(SIGNAL_DETECT). The SIGNAL_DETECT parameter can take on one of two values: OK or FAIL, indicating whether the PMD is detecting light at the receiver (OK) or not (FAIL). When SIGNAL_DETECT = FAIL, PMD_UNITDATA.indication(rx_bit) is undefined. The PMD generates this primitive to indicate a change in the value of SIGNAL_DETECT. If the MDIO interface is implemented, then PMD_global_signal_detect shall be continuously set to the value of SIGNAL_DETECT.

NOTE—SIGNAL_DETECT = OK does not guarantee that PMD_UNITDATA.indication(rx_bit) is known good. It is possible for a poor quality link to provide sufficient light for a SIGNAL_DETECT = OK indication and still not meet the specified bit error ratio. PMD_SIGNAL.indication(SIGNAL_DETECT) has different characteristics for upstream and downstream links, see 60.2.4.

60.2 PMD functional specifications

The 1000BASE-PX PMDs perform the transmit and receive functions that convey data between the PMD service interface and the MDI.

60.2.1 PMD block diagram

The PMD sublayer is defined at the four reference points shown in Figure 60–2 where the first digit represents the downstream direction and the second the upstream. Two points, TP2 and TP3, are compliance points. TP1 and TP4 are reference points for use by implementers. The optical transmit signal is defined at the output end of a patch cord (TP2), between 2 m and 5 m in length, of a fiber type consistent with the link type connected to the transmitter. Unless specified otherwise, all transmitter measurements and tests defined in 60.9 are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3) connected to the receiver. Unless specified otherwise, all receiver measurements and tests defined in 60.9 are made at TP3.

The electrical specifications of the PMD service interface (TP1 and TP4) are not system compliance points (these are not readily testable in a system implementation). It is expected that in many implementations, TP1 and TP4 will be common between 1000BASE-PX PMDs.

60.2.2 PMD transmit function

The PMD Transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the optical specifications in this clause. The higher optical power level shall correspond to tx_bit = ONE.

In the upstream direction, the flow of bits is interrupted according to PMD_SIGNAL.request(tx_enable). This implies three optical levels, 1, 0, and dark, the latter corresponding to the transmitter being in the OFF state.

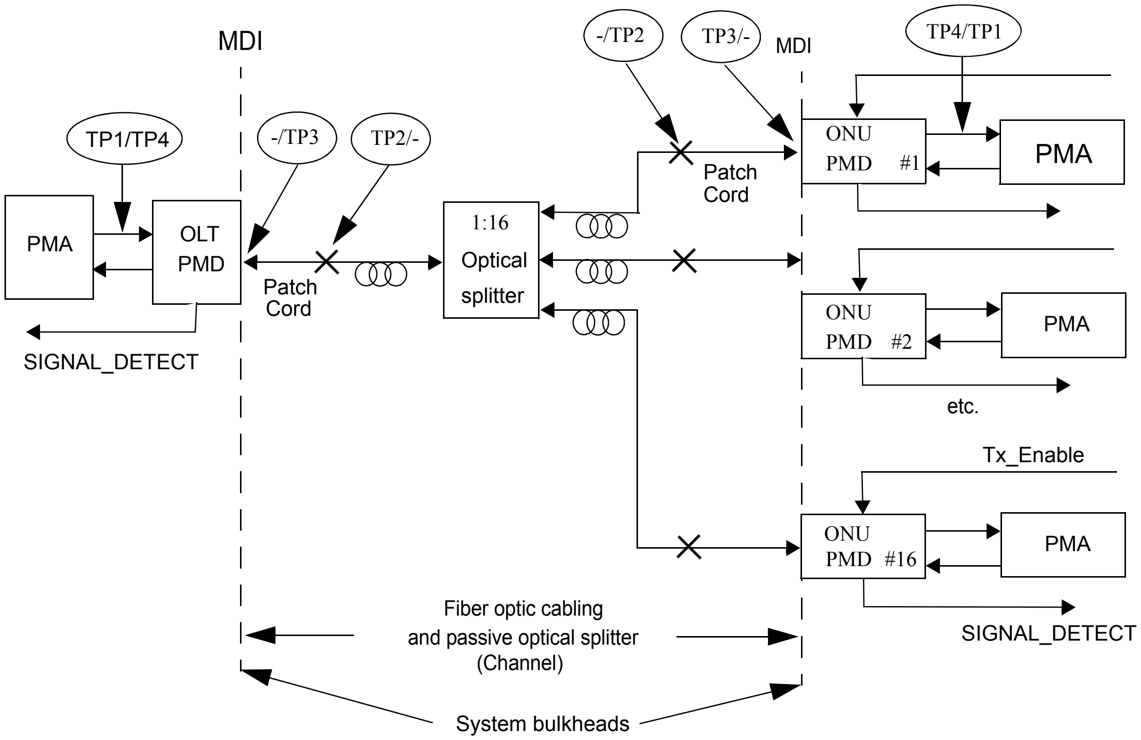

Figure 60–2—1000BASE-PX block diagram

60.2.3 PMD receive function

The PMD Receive function shall convey the bits received from the MDI according to the optical specifications in this clause to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). The higher optical power level shall correspond to rx_bit = ONE.

60.2.4 PMD signal detect function

60.2.4.1 ONU PMD signal detect (downstream)

The PMD Signal Detect function for the continuous mode downstream signal shall report to the PMD service interface, using the message PMD_SIGNAL.indication(SIGNAL_DETECT), which is signaled continuously. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence.

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 60–2 for 1000BASE-PX. The PMD receiver is not required to verify whether a compliant 1000BASE-PX signal is being received.

60.2.4.2 OLT PMD signal detect (upstream)

The response time for the PMD Signal Detect function for the burst mode upstream signal may be longer or shorter than a burst length, thus, it may not fulfill the traditional requirements placed on Signal Detect. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence. The signal detect function in the OLT may be realized in the PMD or PMA layer.

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 60–2 for 1000BASE-PX. The PMD receiver is not required to verify whether a compliant 1000BASE-PX signal is being received.

60.2.4.3 1000BASE-PX Signal detect functions

The Signal Detect value definitions for the 1000BASE-PX PMDs are shown in Table 60–2.

Table 60–2—1000BASE-PX SIGNAL_DETECT value definition

PMD type	Receive conditions	SIGNAL_DETECT value
1000BASE-PX10	Average input optical power ≤ Signal Detect Threshold (min) in Table 60–5 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 60–5 with a compliant 1000BASE-X signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified
1000BASE-PX20	Average input optical power ≤ Signal Detect Threshold (min) in Table 60–8 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 60–8 with a compliant 1000BASE-X signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified
1000BASE-PX30	Average input optical power ≤ Signal Detect Threshold (min) in Table 60–9 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 60–9 with a compliant 1000BASE-X signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified
1000BASE-PX40	Average input optical power ≤ Signal Detect Threshold (min) in Table 60–12 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 60–12 with a compliant 1000BASE-X signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified

60.2.5 PMD transmit enable function for ONU

PMD_SIGNAL.request(tx_enable) is defined for the two ONU PMDs. PMD_SIGNAL.request(tx_enable) is asserted prior to data transmission by the ONU PMDs.

60.3 PMD to MDI optical specifications for 1000BASE-PX10-D and 1000BASE-PX10-U

The operating range for 1000BASE-PX10 is defined in Table 60–1. A 1000BASE-PX10 compliant transceiver supports all media types listed in Table 60–19 according to the specifications described in 60.11. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant (e.g., a single-mode solution operating at 10.5 km meets the minimum range requirement of 0.5 m to 10 km for 1000BASE-PX10).

NOTE—The specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is defined in 58.7.6.

60.3.1 Transmitter optical specifications

The 1000BASE-PX10-D and 1000BASE-PX10-U transmitter's specifications described in Table 60–3 are normative requirements, per measurement techniques described in 60.9, with the exception of $\text{RIN}_{15}\text{OMA}$ which is an optional requirement per measurement techniques described in 60.9.7.

Table 60–3—1000BASE-PX10-D and 1000BASE-PX10-U transmit characteristics

Description	1000BASE-PX10-D	1000BASE-PX10-U	Unit
Nominal transmitter type[a]	Longwave Laser	Longwave Laser	
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength[b] (range)	1480 to 1500	1260 to 1360	nm
RMS spectral width (max)	see Table 60–4		nm
Average launch power (max)	+2	+4	dBm
Average launch power (min)	–3	–1	dBm
Average launch power of OFF transmitter (max)	–39	–45	dBm
Extinction ratio (min)	6	6	dB
$RIN_{15}OMA$ (max)	–118	–113	dB/Hz
Launch OMA (min)	–2.2 (0.6)	–0.22 (0.95)	dBm (mW)
Transmitter eye mask definition {X1, X2, Y1, Y2, Y3}	{0.22, 0.375, 0.2, 0.2, 0.3}	{0.22, 0.375, 0.2, 0.2, 0.3}	UI
T_{on} (max)	N/A	512	ns
T_{off} (max)	N/A	512	ns
Optical return loss tolerance (max)	15	15	dB
Optical return loss of ODN (min)	20	20	dB
Transmitter reflectance (max)	–10	–6	dB
Transmitter and dispersion penalty (max)	1.3	2.8	dB
Decision timing offset for transmitter and dispersion penalty (min)	± 0.1	± 0.125	UI

[a] The nominal transmitter type is not intended to be a requirement on the source type, and any device meeting the transmitter characteristics specified may be substituted for the nominal transmitter type.
[b] This represents the range of centre wavelength $\pm 1\sigma$ of the rms spectral width.

The maximum RMS spectral width vs. wavelength for 1000BASE-PX10 is shown in Table 60–4 and for 1000BASE-PX10-U in Figure 60–3. The equation used to generate these values is included in 60.9.2. The central column values are normative, the right hand column is informative.

Table 60–4—1000BASE-PX10-D and 1000BASE-PX10-U transmitter spectral limits

Center Wavelength	RMS spectral width (max)[a]	RMS spectral width to achieve epsilon $\varepsilon \leq 0.115$ (informative)
nm	nm	nm
1260	**2.09**	1.43
1270	**2.52**	1.72
1280	**3.13**	2.14

Table 60–4—1000BASE-PX10-D and 1000BASE-PX10-U transmitter spectral limits *(continued)*

Center Wavelength	RMS spectral width (max)[a]	RMS spectral width to achieve epsilon ε ≤ 0.115 (informative)
nm	nm	nm
1286	**3.50**	2.49
1290		2.80
1297		3.50
1329		
1340		2.59
1343		2.41
1350	**3.06**	2.09
1360	**2.58**	1.76
1480 to 1500	**0.88**	0.60

[a] These limits for the 1000BASE-PX10-U transmitter are illustrated in Figure 60–3. The equation used to calculate these values is detailed in 60.9.2. Limits at intermediate wavelengths may be found by interpolation.

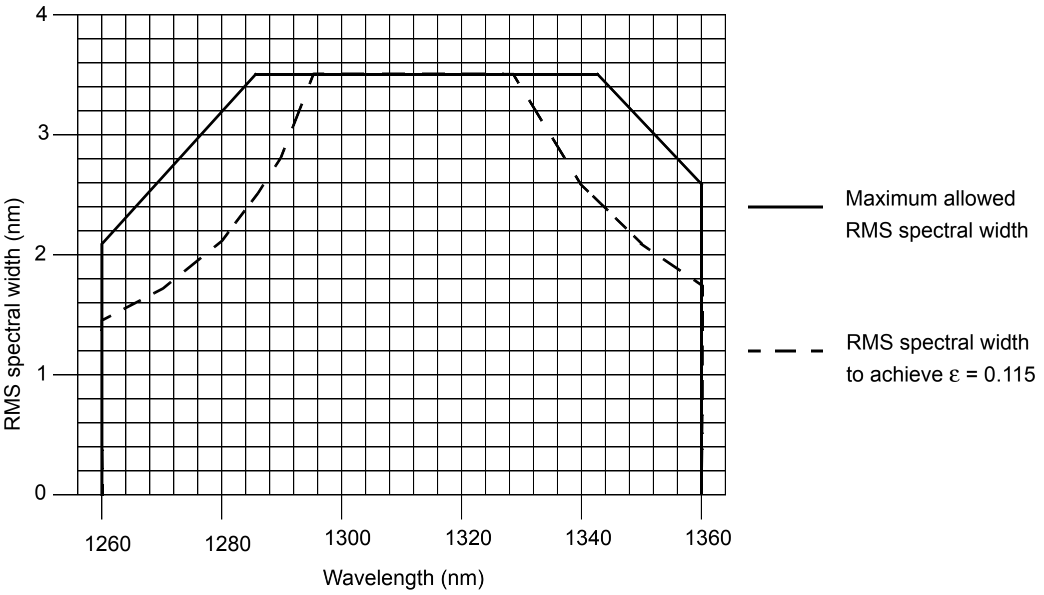

Figure 60–3—1000BASE-PX10-U transmitter spectral limits

60.3.2 Receiver optical specifications

The 1000BASE-PX10-D and 1000BASE-PX10-U receiver shall meet the specifications defined in Table 60–5 per measurement techniques defined in 60.9.10 with the following exceptions. The stressed receive sensitivity (OMA) should meet the values listed in Table 60–5 per measurement techniques described in 60.9.11. Either the damage threshold included in Table 60–5 shall be met, or, the receiver shall be labeled to indicate the maximum optical input power level to which it can be continuously exposed without damage. The vertical eye-closure penalty, the stressed eye jitter, the jitter corner frequency, and the sinusoidal jitter limits are test conditions for measuring stressed receiver sensitivity and are not required characteristics of the receiver.

Table 60–5—1000BASE-PX10-D and 1000BASE-PX10-U receive characteristics

Description	1000BASE-PX10-D	1000BASE-PX10-U	Unit
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength (range)	1260 to 1360	1480 to 1500	nm
Bit error ratio (max)	10^{-12}		
Average receive power (max)	–1	–3	dBm
Damage threshold (max)	+4	+2	dBm
Receiver sensitivity (max)	–24	–24	dBm
Receiver sensitivity OMA (max)	–23.2 (5)	–23.2 (5)	dBm (μW)
Signal detect threshold (min)	–45	–44	dBm
Receiver reflectance (max)	–12	–12	dB
Stressed receive sensitivity (max)	–22.3	–21.4	dBm
Stressed receive sensitivity OMA (max)	–21.5 (7)	–20.7 (8.6)	dBm (μW)
Vertical eye-closure penalty (min)	1.2	2.2	dB
$T_{receiver\_settling}$ (max)	400	N/A	ns
Stressed eye jitter (min)	0.25	0.25	UI pk-pk
Jitter corner frequency	637	637	kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	(0.05, 0.15)	(0.05, 0.15)	UI

60.4 PMD to MDI optical specifications for 1000BASE-PX20-D and 1000BASE-PX20-U

The operating range for 1000BASE-PX20 is defined in Table 60–1. A 1000BASE-PX20 compliant transceiver supports all media types listed in Table 60–19 according to the specifications described in 60.11.2. A transceiver that exceeds the operational range requirement while meeting all other optical specifications is considered compliant (e.g., a single-mode solution operating at 20.5 km meets the minimum range requirement of 0.5 m to 20 km for 1000BASE-PX20).

NOTE—The specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is explained in 58.7.6.

60.4.1 Transmitter optical specifications

The 1000BASE-PX20-D and 1000BASE-PX20-U transmitter's specifications described in Table 60–6 are normative requirements, per measurement techniques described in 60.9, with the exception of $\text{RIN}_{15}\text{OMA}$ which is an optional requirement per measurement techniques described in 60.9.7.

Table 60–6—1000BASE-PX20-D and 1000BASE-PX20-U transmit characteristics

Description	1000BASE-PX20-D	1000BASE-PX20-U	Unit
Nominal transmitter type[a]	Longwave Laser	Longwave Laser	
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength[b] (range)	1480 to 1500	1260 to 1360	nm
RMS spectral width (max)	see Table 60–7		nm
Average launch power (max)	+7	+4	dBm
Average launch power (min)	+2	–1	dBm
Average launch power of OFF transmitter (max)	–39	–45	dBm
Extinction ratio (min)	6	6	dB
$\text{RIN}_{15}\text{OMA}$ (max)	–115	–115	dB/Hz
Launch OMA (min)	2.8 (1.9)	–0.22 (0.95)	dBm (mW)
Transmitter eye mask definition {X1, X2, Y1, Y2, Y3}	{0.22, 0.375, 0.2, 0.2, 0.3}	{0.22, 0.375, 0.2, 0.2, 0.3}	UI
T_{on} (max)	N/A	512	ns
T_{off} (max)	N/A	512	ns
Optical return loss tolerance (max)	15	15	dB
Optical return loss of ODN (min)	20	20	dB
Transmitter reflectance (max)	–10	–10	dB
Transmitter and dispersion penalty (max)	2.3	1.8	dB
Decision timing offset for transmitter and dispersion penalty (min)	± 0.1	± 0.125	UI

[a] The nominal transmitter type is not intended to be a requirement on the source type, and any device meeting the transmitter characteristics specified may be substituted for the nominal transmitter type.
[b] This represents the range of centre wavelength ±1σ of the rms spectral width.

The maximum RMS spectral width vs. wavelength for 1000BASE-PX20 is shown in Table 60–7 and for 1000BASE-PX20-U in Figure 60–4. The equation used to generate these values is included in 60.9.2. The central column values are normative, the right hand column is informative.

60.4.2 Receiver optical specifications

The 1000BASE-PX20-D and 1000BASE-PX20-U receiver shall meet the specifications defined in Table 60–8 per measurement techniques defined in 60.9.10 with the following exceptions. The stressed receive sensitivity (OMA) should meet the values listed in Table 60–8 per measurement techniques described in

Table 60–7—1000BASE-PX20-D and 1000BASE-PX20-U transmitter spectral limits

Center Wavelength	RMS spectral width (max) [a]	RMS spectral width to achieve epsilon $\varepsilon \leq 0.10$ (informative)
nm	nm	nm
1260	**0.72**	0.62
1270	**0.86**	0.75
1280	**1.07**	0.93
1290	**1.40**	1.22
1300	**2.00**	1.74
1304	**2.5**	2.42
1305	**2.55**	2.5
1308	**3.00**	
1317		
1320	**2.53**	2.2
1321	**2.41**	
1330	**1.71**	1.48
1340	**1.29**	1.12
1350	**1.05**	0.91
1360	**0.88**	0.77
1480 to 1500	**0.44**	0.30

[a] These limits for the 1000BASE-PX20-U are illustrated in Figure 60–4. The equation used to calculate these values is detailed in 60.9.2. Limits at intermediate wavelengths may be found by interpolation.

60.9.11. Either the damage threshold included in Table 60–8 shall be met, or, the receiver shall be labeled to indicate the maximum optical input power level to which it can be continuously exposed without damage. The vertical eye-closure penalty, the stressed eye jitter, the jitter corner frequency, and the sinusoidal jitter limits are test conditions for measuring stressed receiver sensitivity and are not required characteristics of the receiver.

Table 60–8—1000BASE-PX20-D and 1000BASE-PX20-U receive characteristics

Description	1000BASE-PX20-D	1000BASE-PX20-U	Unit
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength (range)	1260 to 1360	1480 to 1500	nm
Bit error ratio (max)	10^{-12}		
Average receive power (max)	–6	–3	dBm
Damage threshold (max)	+4	+7	dBm
Receive sensitivity (max)	–27	–24	dBm
Receiver sensitivity OMA (max)	–26.2 (2.4)	–23.2 (5)	dBm (μW)

Table 60–8—1000BASE-PX20-D and 1000BASE-PX20-U receive characteristics *(continued)*

Description	1000BASE-PX20-D	1000BASE-PX20-U	Unit
Signal detect threshold (min)	–45	–44	dBm
Receiver reflectance (max)	–12	–12	dB
Stressed receive sensitivity (max)	–24.4	–22.1	dBm
Stressed receive sensitivity OMA (max)	–23.6 (4.3)	–21.3 (7.4)	dBm (μW)
Vertical eye-closure penalty (min)	2.2	1.5	dB
$T_{receiver\_settling}$ (max)	400	N/A	ns
Stressed eye jitter (min)	0.28	0.25	UI pk-pk
Jitter corner frequency	637	637	kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	(0.05, 0.15)	(0.05, 0.15)	UI

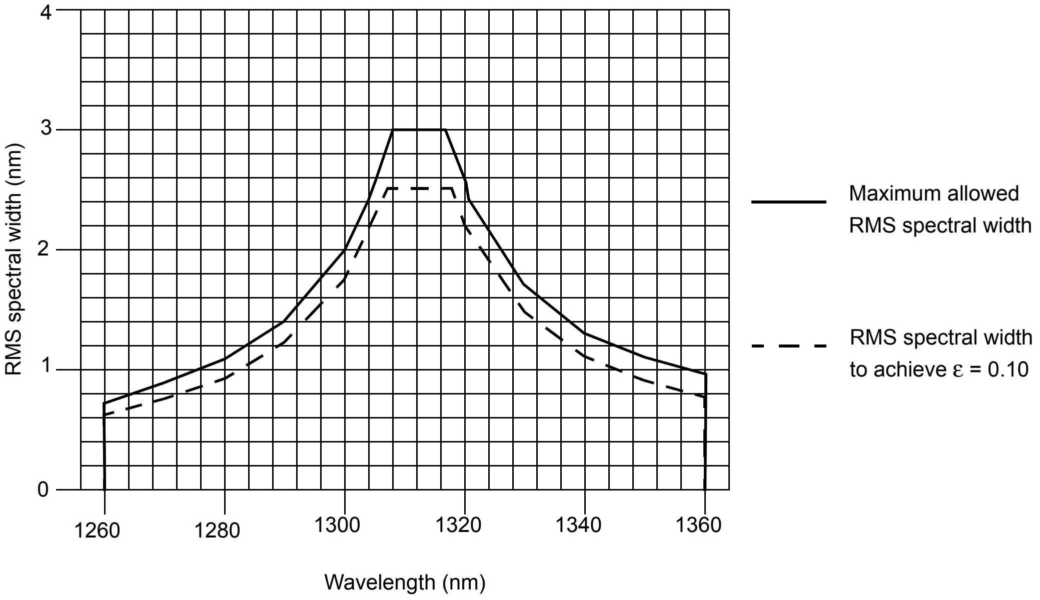

Figure 60–4—1000BASE-PX20-U transmitter spectral limits

60.5 PMD to MDI optical specifications for 1000BASE-PX30-D and 1000BASE-PX30-U

The operating range for 1000BASE-PX30 is defined in Table 60–1. A 1000BASE-PX30 compliant transceiver supports all media types listed in Table 75–14 according to the specifications described in 75.9. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant (e.g., a single-mode solution operating at 20.5 km meets the minimum range requirement of 0.5 m to 20 km for 1000BASE-PX30).

NOTE—The specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is defined in 58.7.6.

60.5.1 Transmitter optical specifications

The 1000BASE-PX30-D and 1000BASE-PX30-U transmitter's specifications described in Table 60–9 are normative requirements, per measurement techniques described in 60.8, with the exception of $\text{RIN}_{15}\text{OMA}$ which is an optional requirement, per measurement techniques described in 60.9.7.

The maximum RMS spectral width vs. wavelength for 1000BASE-PX30 is shown in Table 60–10 and for 1000BASE-PX30-U in Figure 60–5. 1000BASE-PX30-D transmitter uses a DFB laser, and 1000BASE-PX30-U transmitter can use either a DFB or Fabry-Perot laser. If 1000BASE-PX30-U PMD employs a DFB laser, Side Mode Suppression Ratio requirement shown in Table 60–9 is mandatory. If 1000BASE-PX30-U PMD employs a Fabry-Perot laser, RMS spectral width requirement shown in Table 60–10 and Figure 60–5 is mandatory. The equation used to generate these values is included in 60.9.2. The central column values are normative, the right hand column is informative.

Table 60–9—1000BASE-PX30-D and 1000BASE-PX30-U transmit characteristics

Description	1000BASE-PX30-D	1000BASE-PX30-U	Unit
Nominal transmitter type[a]	Longwave Laser	Longwave Laser	
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength[b] (range)	1480 to 1500	1260 to 1360	nm
Side Mode Suppression Ratio	30	30[c]	dB
RMS spectral width (max)	N/A	see Table 60–10[c]	nm
Average launch power (max)	7	5.62	dBm
Average launch power (min)	3	0.62	dBm
Average launch power of OFF transmitter (max)	–39	–45	dBm
Extinction ratio (min)	6	6	dB
$\text{RIN}_{15}\text{OMA}$ (max)	–115	–115	dB/Hz
Launch OMA (min)	3.78 (2.39)	1.4 (1.38)	dBm (mW)
Transmitter eye mask definition {X1, X2, Y1, Y2, Y3}	{0.22, 0.375, 0.2, 0.2, 0.3}	{0.22, 0.375, 0.2, 0.2, 0.3}	UI
T_{on} (max)	N/A	512	ns
T_{off} (max)	N/A	512	ns
Optical return loss tolerance (max)	15	15	dB
Optical return loss of ODN (min)	20	20	dB
Transmitter reflectance (max)	–10	–10	dB
Transmitter and dispersion penalty (max)	1	1.4	dB
Decision timing offset for transmitter and dispersion penalty (min)	±0.1	±0.125	UI

[a] The nominal transmitter type is not intended to be a requirement on the source type, and any device meeting the transmitter characteristics specified may be substituted for the nominal transmitter type.

[b] This represents the range of centre wavelength $\pm 1\sigma$ of the rms spectral width.

[c] If 1000BASE-PX30-U PMD employs a DFB laser, Side Mode Suppression Ratio is mandatory. If it employs a Fabry-Perot laser, RMS spectral width requirement is mandatory.

Table 60–10—1000BASE-PX30-U transmitter spectral limits

Center wavelength	RMS spectral width (max)[a]	RMS spectral width to achieve epsilon ε ≤ 0.08 (informative)
nm	nm	nm
1260	0.59	0.5
1270	0.7	0.59
1280	0.87	0.74
1290	1.14	0.97
1300	1.64	1.39
1304	1.98	1.67
1305	2.09	1.77
1308	2.4	2
1317	2.4	2
1320	2.07	1.75
1321	1.98	1.67
1330	1.4	1.18
1340	1.06	0.89
1350	0.86	0.72
1360	0.72	0.61
1480 to 1500	0.25	0.21

[a] These limits for the 1000BASE–PX30–U transmitter are illustrated in Figure 60–5. The equation used to calculate these values is detailed in 60.9.2. Limits at intermediate wavelengths may be found by interpolation.

60.5.2 Receiver optical specifications

The 1000BASE-PX30-D and 1000BASE-PX30-U receiver shall meet the specifications defined in Table 60–11 per measurement techniques defined in 60.9.10 with the following exceptions. The stressed receive sensitivity OMA (max) should meet the value listed in Table 60–11 per measurement techniques described in 60.9.11. Either the damage threshold included in Table 60–11 shall be met, or, the receiver shall be labeled to indicate the maximum optical input power level to which it can be continuously exposed without damage. The vertical eye-closure penalty, the stressed eye jitter, the jitter corner frequency, and the sinusoidal jitter limits are test conditions for measuring stressed receiver sensitivity and are not required characteristics of the receiver.

60.6 PMD to MDI optical specifications for 1000BASE-PX40-D and 1000BASE-PX40-U

The operating range for 1000BASE-PX40 is defined in Table 60–1. A 1000BASE-PX40 compliant transceiver supports all media types listed in Table 75–14 according to the specifications described in 75.9. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant (e.g., a single-mode solution operating at 20.5 km meets the minimum range requirement of 0.5 m to 20 km for 1000BASE-PX40).

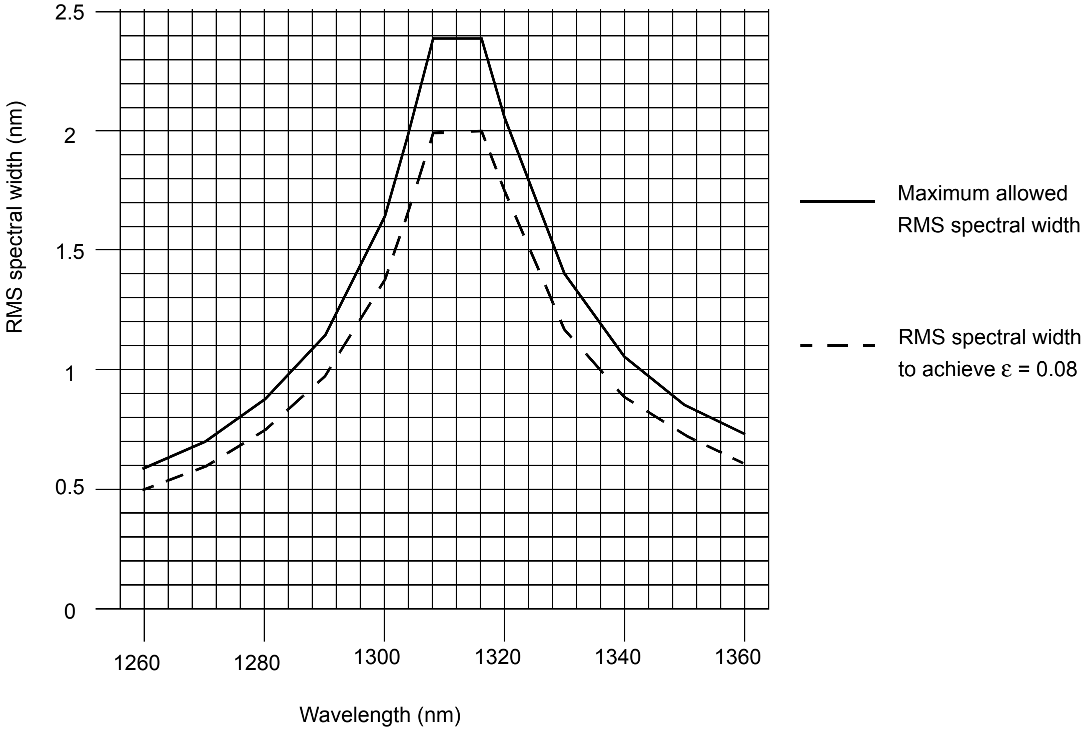

Figure 60–5—1000BASE-PX30-U transmitter spectral limits

Table 60–11—1000BASE-PX30-D and 1000BASE-PX30-U receive characteristics

Description	1000BASE-PX30-D	1000BASE-PX30-U	Unit
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength (range)	1260 to 1360	1480 to 1500	nm
Bit error ratio (max)	10^{-12}		
Average receive power (max)	–9.38	–8	dBm
Damage threshold (max)[a]	–5	+4	dBm
Receiver sensitivity (max)	–29.78	–27	dBm
Receiver sensitivity OMA (max)	–29 (1.26)	–26.22 (2.39)	dBm (µW)
Signal detect threshold (min)	–45	–44	dBm
Receiver reflectance (max)	–12	–12	dB
Stressed receive sensitivity (max)	–28.38	–26	dBm
Stressed receive sensitivity OMA (max)	–27.6 (1.74)	–25.22 (3.01)	dBm (µW)
Vertical eye-closure penalty (min)	1.4	1.5	dB

Table 60–11—1000BASE-PX30-D and 1000BASE-PX30-U receive characteristics *(continued)*

Description	1000BASE-PX30-D	1000BASE-PX30-U	Unit
$T_{receiver\_settling}$ (max)[b]	400	N/A	ns
Stressed eye jitter (min)	0.28	0.25	UI pk-pk
Jitter corner frequency	637	637	kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	(0.05, 0.15)	(0.05, 0.15)	UI

[a] Direct ONU–OLT connection may result in damage of the receiver.

[b] $T_{receiver\_settling}$ represents an upper bound. Optics with better performance may be used in compliant implementations, since the OLT notifies the ONUs of its requirements in terms of the $T_{receiver\_settling}$ time via the syncTime parameter.

NOTE—The specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is defined in 58.7.6.

60.6.1 Transmitter optical specifications

The 1000BASE-PX40-D and 1000BASE-PX40-U transmitter's specifications described in Table 60–12 are normative requirements, per measurement techniques described in 60.9, with the exception of $RIN_{15}OMA$ which is an optional requirement, per measurement techniques described in 60.9.7.

Table 60–12—1000BASE-PX40-D and 1000BASE-PX40-U transmit characteristics

Description	1000BASE-PX40-D	1000BASE-PX40-U	Unit
Nominal transmitter type[a]	Longwave Laser	Longwave Laser	
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength (range)	1480 to 1500	1290 to 1330	nm
Side Mode Suppression Ratio (min)[b]	30		dB
Average launch power (max)	10	6	dBm
Average launch power (min)	4	2	dBm
Average launch power of OFF transmitter (max)	–39	–45	dBm
Extinction ratio (min)	6	6	dB
$RIN_{15}OMA$ (max)	–115	–115	dB/Hz
Launch OMA (min)	4.78 (3.01)	2.78 (1.9)	dBm (mW)
Transmitter eye mask definition {X1, X2, Y1, Y2, Y3}	{0.22, 0.375, 0.2, 0.2, 0.3}	{0.22, 0.375, 0.2, 0.2, 0.3}	UI
T_{on} (max)	N/A	512	ns
T_{off} (max)	N/A	512	ns
Optical return loss tolerance (max)	15	15	dB
Optical return loss of ODN (min)	20	20	dB
Transmitter reflectance (max)	–10	–10	dB
Transmitter and dispersion penalty (max)	1	1	dB
Decision timing offset for transmitter and dispersion penalty (min)	±0.1	±0.125	UI

[a] The nominal device type is not intended to be a requirement on the source type, and any device meeting the transmitter characteristics specified may be substituted for the nominal device type.

[b] Transmitter is a single longitudinal mode device. Chirp is allowed such that the total penalty does not exceed that found in Table 60–14.

60.6.2 Receiver optical specifications

The 1000BASE-PX40-D and 1000BASE-PX40-U receiver shall meet the specifications defined in Table 60–13 per measurement techniques defined in 60.9.10 with the following exceptions. The stressed receive sensitivity OMA (max) should meet the value listed in Table 60–13 per measurement techniques described in 60.9.11. Either the damage threshold included in Table 60–13 shall be met, or, the receiver shall be labeled to indicate the maximum optical input power level to which it can be continuously exposed without damage. The vertical eye-closure penalty, the stressed eye jitter, the jitter corner frequency, and the sinusoidal jitter limits are test conditions for measuring stressed receiver sensitivity and are not required characteristics of the receiver.

Table 60–13—1000BASE-PX40-D and 1000BASE-PX40-U receive characteristics

Description	1000BASE-PX40-D	1000BASE-PX40-U	Unit
Signaling speed (range)	1.25 ± 100 ppm	1.25 ± 100 ppm	GBd
Wavelength (range)	1260 to 1360	1480 to 1500	nm
Bit error ratio (max)	10^{-12}		
Average receive power (max)	–12	–8	dBm
Damage threshold (max)[a]	–6	–3	dBm
Receiver sensitivity (max)	–32	–30	dBm
Receiver sensitivity OMA (max)	–31.22 (0.76)	–29.22 (1.2)	dBm (μW)
Signal detect threshold (min)	–45	–44	dBm
Receiver reflectance (max)	–12	–12	dB
Stressed receive sensitivity (max)	–31	–29	dBm
Stressed receive sensitivity OMA (max)	–30.22 (0.95)	–28.22 (1.51)	dBm (μW)
Vertical eye-closure penalty (min)	2.2	1.5	dB
$T_{receiver\_settling}$ (max)[b]	400	N/A	ns
Stressed eye jitter (min)	0.28	0.25	UI pk-pk
Jitter corner frequency	637	637	kHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	(0.05, 0.15)	(0.05, 0.15)	UI

[a] Direct ONU–OLT connection may result in damage of the receiver.

[b] $T_{receiver\_settling}$ represents an upper bound. Optics with better performance may be used in compliant implementations, since the OLT notifies the ONUs of its requirements in terms of the $T_{receiver\_settling}$ time via the syncTime parameter.

60.7 Illustrative 1000BASE-PX channels and penalties (informative)

Illustrative power budget for 1000BASE-PX10, 1000BASE-PX20, 1000BASE-PX30, and 1000BASE-PX40 channels are shown in Table 60–14.

Table 60–14—Illustrative 1000BASE-PX channel insertion loss and penalties

Description[a]	1000BASE -PX10		1000BASE -PX20		1000BASE -PX30		1000BASE -PX40		Unit
	US	DS	US	DS	US	DS	US	DS	
Fiber type	IEC 60793–2 B1.1, B1.3 SMF				IEC 60793–2 B1.1, B1.3 SMF ITU-T G.652, G.657 SMF				
Measurement wavelength for fiber	1310	1550[b]	1310	1550[b]	1310	1550[b]	1310	1550[b]	nm
Nominal distance	10		20						km
Available power budget[c]	23	21	26	26	30.4	30	34	34	dB
Channel insertion loss (max)[d]	20	19.5	24	23.5	29		33		dB
Channel insertion loss (min)[e]	5		10		15		18		dB
Allocation for penalties[f]	3	1.5	2	2.5	1.4	1	1	1	dB
Optical return loss of ODN (min)	20								dB

[a] US stands for Upstream, DS stands for Downstream.
[b] The nominal transmit wavelength is 1490 nm.
[c] In an FEC enabled link, when not operating at the dispersion limit, the available power budget is increased by 2.5 dB.
[d] The channel insertion loss is based on the cable attenuation at the target distance and nominal measurement wavelength. The channel insertion loss also includes the loss for connectors, splices and other passive components such as splitters.
[e] The power budgets for PX10, PX20, PX30, and PX40 links are such that a minimum insertion loss is assumed between transmitter and receiver. This minimum attenuation is required for PMD testing.
[f] The allocation for penalties is the difference between the available power budget and the channel insertion loss; insertion loss difference between nominal and worst case operating wavelength is considered a penalty. This allocation may be used to compensate for transmission related penalties. Further details are given in 60.9.2.

NOTE—The budgets include an allowance for –12 dB reflection at the receiver.

60.8 Jitter at TP1 to TP4 for 1000BASE-PX (informative)

The entries in Table 60–15 and Table 60–16 represent high-frequency jitter (above 637 kHz) and do not include low frequency jitter or wander. They are two sided (peak-to-peak) measures. Table 60–15 applies to the downstream direction (D to U) while Table 60–16 applies to the upstream direction (U to D). All values are informative.

For the 1000BASE-PX upstream jitter budget, the jitter transfer function is defined by Equation (60-2) where the value is given in Figure 60–6 when input sinusoidal jitter according to the mask defined in 58.7.11.4 and values in Table 60–5, Table 60–8, Table 60–11, and Table 60–13 are applied to the receiver input of the ONU. Two sets of upstream jitter values are defined in Table 60–16, one set corresponds to testing the upstream link with no jitter on the downstream (jitter generation) and the other set with maximum jitter on the downstream (generated and transferred jitter).

Table 60–15—1000BASE-PX downstream jitter budget (informative)

	Total jitter		Deterministic jitter	
Reference point	**UI**	**ps**	**UI**	**ps**
TP1	0.24	192	0.10	80
TP1 to TP2	0.191	153	0.15	120
TP2	0.431	345	0.25	200
TP2 to TP3	0.009	7	0	0
TP3	0.44	352	0.25	200
TP3 to TP4	0.309	247	0.212	170
TP4	0.749	599	0.462	370

Table 60–16—1000BASE-PX upstream jitter budget (informative)

	No Jitter input to ONU				Jitter input to ONU			
	Total jitter		***W***		**Total jitter**		***W***	
Reference point	**UI**	**ps**	**UI**	**ps**	**UI**	**ps**	**UI**	**ps**
TP1	0.19	152	0.06	48	0.24	192	0.11	88
TP1 to TP2	0.16	128	0.14	112	0.16	128	0.14	112
TP2	0.35	280	0.2	160	0.4	320	0.25	200
TP2 to TP3	0.09	72	0.05	40	0.09	72	0.05	40
TP3	0.44	352	0.25	200	0.49	392	0.30	24
TP3 to TP4	0.18	144	0.15	120	0.18	144	0.15	120
TP4	0.62	496	0.4	320	0.67	536	0.45	360

NOTE—Informative jitter values are chosen to be compatible with the limits for eye mask and TDP (see 58.7.9).

Total jitter in this table is defined at 10^{-12} BER. In a commonly used model,

$$TJ = 14.1\sigma + DJ \text{ at } 10^{12} \tag{60–1}$$

W is similar but not necessarily identical to deterministic jitter (DJ). A jitter measurement procedure is described in 58.7.12. Other jitter measurements are described in 59.7.12 and 59.7.13. Jitter at TP2 or TP3 is defined with a receiver of the same bandwidth as specified for the transmitted eye.

$$\text{Jitter Transfer} = 20\log_{10}\left[\frac{\text{Jitter on upstream signal (UI)}}{\text{Jitter on downstream signal (UI)}}\right] \tag{60-2}$$

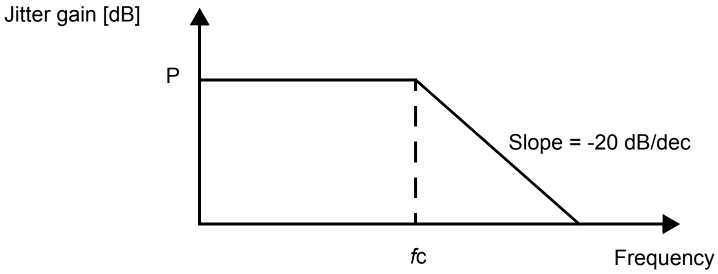

Figure 60–6—Jitter gain curve values for 1000BASE-PX10-U and 1000BASE-PX20-U

Table 60–17—Jitter gain curve values for 1000BASE-PX10-U and 1000BASE-PX20-U

	Value	Unit
P	0.3	dB
*f*c	1274	kHz

60.9 Optical measurement requirements

The following sections describe definitive patterns and test procedures for certain PMDs of this standard. implementers using alternative verification methods must ensure adequate correlation and allow adequate margin such that specifications are met by reference to the definitive methods. All optical measurements, except TDP and RIN_{15}OMA, shall be made through a short patch cable between 2 m and 5 m in length.

60.9.1 Frame-based test patterns

Subclause 59.7.1 provides suitable patterns for frame-based testing.

NOTE—Users are advised to take care that the system under test is not connected to a network in service.

60.9.2 Wavelength and spectral width measurements

The wavelength and spectral width (RMS) shall meet specifications according to TIA-455-127-A, under modulated conditions using a valid 1000BASE-X signal.

NOTE 1—The allowable range of central wavelengths is narrower than the operating wavelength range by the actual RMS spectral width at each extreme.

NOTE 2—The 20 dB width for SLM lasers is taken as 6.07 times the RMS width.

The interaction between the transmitter and the chromatic dispersion of the fiber is accounted for by a parameter ε (epsilon), which is defined as the product of 10^{-3} times the signaling speed (in GBd) times the path dispersion (in ps/nm) times the RMS spectral width (in nm).

$$\varepsilon = \text{dispersion} \times \text{length} \times \text{RMS spectral width} \times 10^{-3} \qquad (60\text{–}3)$$

For the 1000BASE-PX10-D and 1000BASE-PX10-U links, a maximum ε close to 0.168 is imposed by the middle column of Table 60–4. If the spectral width is kept below the limits of the right hand column, ε will not exceed 0.115, and the chromatic dispersion penalty is expected to be below 2 dB when all link parameters are simultaneously at worst case values. For the 1000BASE-PX20-D and 1000BASE-PX20-U links, a maximum ε close to 0.115 is imposed by the middle column of Table 60–7. If the spectral width is kept below the limits of the right hand column, ε will not exceed 0.10, and the chromatic dispersion penalty is expected to be below 1.5 dB when all link parameters are simultaneously at worst case values.

For the 1000BASE-PX30-D and 1000BASE-PX30-U links, a maximum ε close to 0.095 is imposed by the middle column of Table 60–10. If the spectral width is kept below the limits of the right hand column, ε will not exceed 0.08, and the chromatic dispersion penalty is expected to be below 0.9 dB when all link parameters are simultaneously at worst case values.

The chromatic dispersion penalty is a component of transmitter and dispersion penalty (TDP), which is specified in Table 60–3, Table 60–6, Table 60–9, and Table 60–12, and described in 58.7.9.

60.9.3 Optical power measurements

Optical power shall meet specifications according to the methods specified in ANSI/EIA-455-95. A measurement may be made with the port transmitting any valid encoded 8B/10B data stream.

60.9.4 Extinction ratio measurements

Extinction ratio shall meet specifications according to IEC 61280-2-2 with the port transmitting a repeating idle pattern /I2/ ordered set (see 36.2.4.12) that may be interspersed with OAM packets per 57A.2, and with minimal back reflections into the transmitter, lower than –20 dB. The /I2/ ordered set is defined in Clause 36, and is coded as /K28.5/D16.2/, which is binary 001111 1010 100100 0101 within idles. The extinction ratio is expected to be similar for other valid 8B/10B bit streams. The test receiver has the frequency response as specified for the transmitter optical waveform measurement.

60.9.5 OMA measurements (informative)

Subclause 58.7.5 provides a reference technique for performing OMA measurements.

60.9.6 OMA relationship to extinction ratio and power measurements (informative)

The normative way of measuring transmitter characteristics is extinction ratio and mean power. Clause 58 provides information on how OMA, extinction ratio and mean power are related to each other (see 58.7.6).

60.9.7 Relative intensity noise optical modulation amplitude ($RIN_{15}OMA$)

$RIN_{15}OMA$ is the ratio of noise to modulated optical signal in the presence of a back reflection. The measurement procedure is described in 58.7.7.

60.9.8 Transmitter optical waveform (transmit eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 60–7.

The measurement procedure is described in 58.7.8 and references therein.

The eye shall comply to the mask of the eye using a fourth-order Bessel-Thomson receiver response with f_r = 0.9375 GHz, and where the relative response vs. relative frequency is defined in ITU-T G.957, Table B.2 (STM-16 values), along with the allowed tolerances for its physical implementation.

NOTE 1—This Bessel-Thomson filter is not intended to represent the noise filter used within an optical receiver, but is intended to provide uniform measurement conditions on the transmitter.

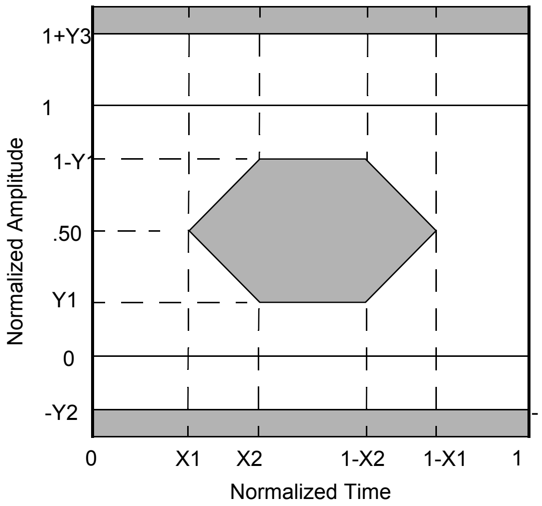

Figure 60–7—Transmitter eye mask definition

NOTE 2—The fourth order Bessel-Thomson filter is reactive. In order to suppress reflections, a 6 dB attenuator may be required at the filter input and/or output.

60.9.9 Transmitter and dispersion penalty (TDP)

TDP measurement tests for transmitter impairments with chromatic effects for a transmitter to be used with single-mode fiber. Possible causes of impairment include intersymbol interference, jitter, RIN and mode partition noise. Meeting the separate requirements (e.g., eye mask, spectral characteristics) does not in itself guarantee the transmitter and dispersion penalty (TDP). The TDP limit shall be met. See 58.7.9 for details of the measurement.

60.9.10 Receive sensitivity measurement

Receiver sensitivity is defined for the random pattern test frame and an ideal input signal quality with the specified extinction ratio. The measurement procedure is described in 58.7.10. The sensitivity shall be met for the bit error ratio defined in Table 60–5, Table 60–8, Table 60–11, or Table 60–13 as appropriate.

60.9.11 Stressed receive conformance test

The stressed receiver conformance test is intended to screen against receivers with poor frequency response or timing characteristics which could cause errors when combined with a distorted but compliant signal at TP3. Modal (MMF) or chromatic (SMF) dispersion can cause distortion. The conformance test signal uses the random pattern test frame and is conditioned by applying deterministic jitter and intersymbol interference. If the option for stressed receiver compliance is chosen, the receiver shall meet the specified bit error ratio at the power level and signal quality defined in Table 60–5, Table 60–8, Table 60–11, and Table 60–13 as appropriate, according to the measurement procedures of 58.7.11.

60.9.12 Jitter measurements (informative)

Jitter measurements for 1000 Mb/s are described in 58.7.12.

60.9.13 Other measurements

60.9.13.1 Laser On/Off timing measurement

T_{on} is defined in 60.9.13.1.1, value is less than 512 ns (defined in Table 60–3, Table 60–6, Table 60–9, and Table 60–12).

$T_{receiver\_settling}$ is defined in 60.9.13.2.1 (informative), value is less than 400 ns (defined in Table 60–5, Table 60–8, Table 60–11, and Table 60–13).

T_{CDR} is defined in 65.3.2.1, value is less than 400 ns (defined in 60.2.2).

$T_{code\_group\_align}$ is defined in 36.3.2.4, value is less than 4 ten-bit code-groups.

T_{off} is defined in 60.9.13.1.1, value is less than 512 ns (defined in Table 60–3, Table 60–6, Table 60–9, and Table 60–12).

60.9.13.1.1 Definitions

T_{on} is denoted as the time beginning from the falling edge of the Tx_Enable line to the ONU PMD and ending at the time that the optical signal at TP2 of the ONU PMD is within 15% of its steady state parameters (average launched power, wavelength, RMS spectral width, transmitter and dispersion penalty, optical return loss tolerance, jitter, $RIN_{15}OMA$, extinction ratio and eye mask opening) as defined in Table 60–3 for 1000BASE-PX10-U, Table 60–6 for 1000BASE-PX20-U, Table 60–9 for 1000BASE-PX30-U, and Table 60–12 for 1000BASE-PX40-U. T_{on} is presented in Figure 60–8. The data transmitted may be any valid 8B/10B symbols.

T_{off} is denoted as the time beginning from the rising edge of the Tx_Enable line to the ONU PMD and ending at the time that the optical signal at TP2 of the ONU PMD reaches the specified average launch power of off transmitter as defined in Table 60–3 for 1000BASE-PX10-U, Table 60–6 for 1000BASE-PX20-U, Table 60–9 for 1000BASE-PX30-U, and Table 60–12 for 1000BASE-PX40-U. T_{off} is presented in Figure 60–8. The data transmitted may be any valid 8B/10B symbols.

60.9.13.1.2 Test specification

The test setup for measuring T_{on} and T_{off} is described in Figure 60–9. An O/E converter is used to convert the optical signal at TP3 to an electrical signal at TP4 where it is assumed that the response time of the converter is considerably shorter that the T_{on} value under measurement. A scope, with a variable delay, can measure the time from the Tx_Enable trigger to the time the optical signal reaches all its specified conditions. The delay to the scope trigger is adjusted until the point that the received signal meets all its specified conditions. This is the T_{on} in question.

A non-rigorous way to describe this test setup would be: for a PMD with a declared T_{on} and T_{off}, measure all PMD optical parameter after T_{on} and T_{off} from the Tx_Enable trigger, reassuring conformance 15% of the steady state values. Notice that only the steady state optical OFF power must be conformed when measuring T_{off} time, since that is the only relevant parameter.

60.9.13.2 Receiver settling timing measurement (informative)

60.9.13.2.1 Definitions

$T_{receiver\_settling}$ is denoted as the time beginning from the time that the optical power in the receiver at TP3 reaches the conditions specified in 38.6.11, 58.7.11.2 and ending at the time that the electrical signal after the PMD at TP4, reaches within 15% of its steady state parameter, (average power, jitter), see Table 60–5,

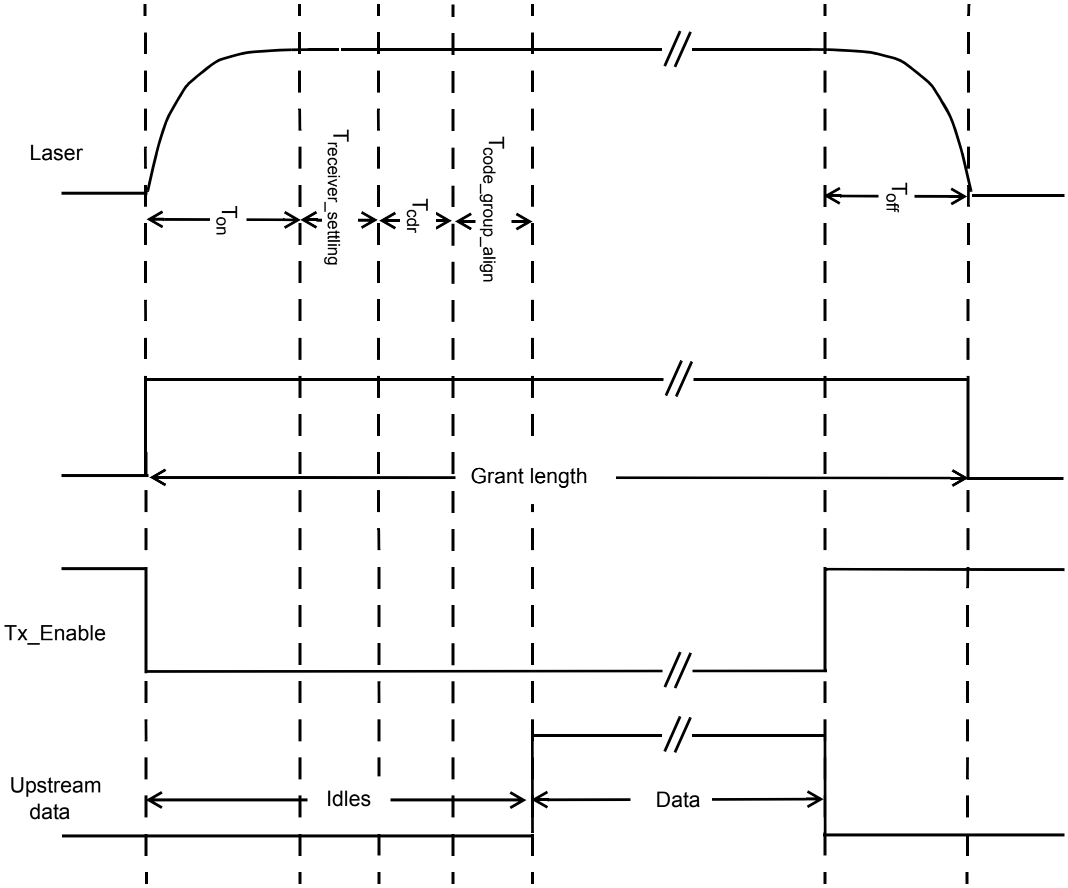

Figure 60–8—P2MP timing parameter definition

Table 60–8, Table 60–11, and Table 60–13. $T_{receiver\_settling}$ is presented in Figure 60–8. The data transmitted may be any valid 8B/10B symbols (or a specific power synchronization sequence). The optical signal at TP3, at the beginning of the locking, may have any valid 8B/10B pattern, optical power level, jitter, or frequency shift matching the standard specifications.

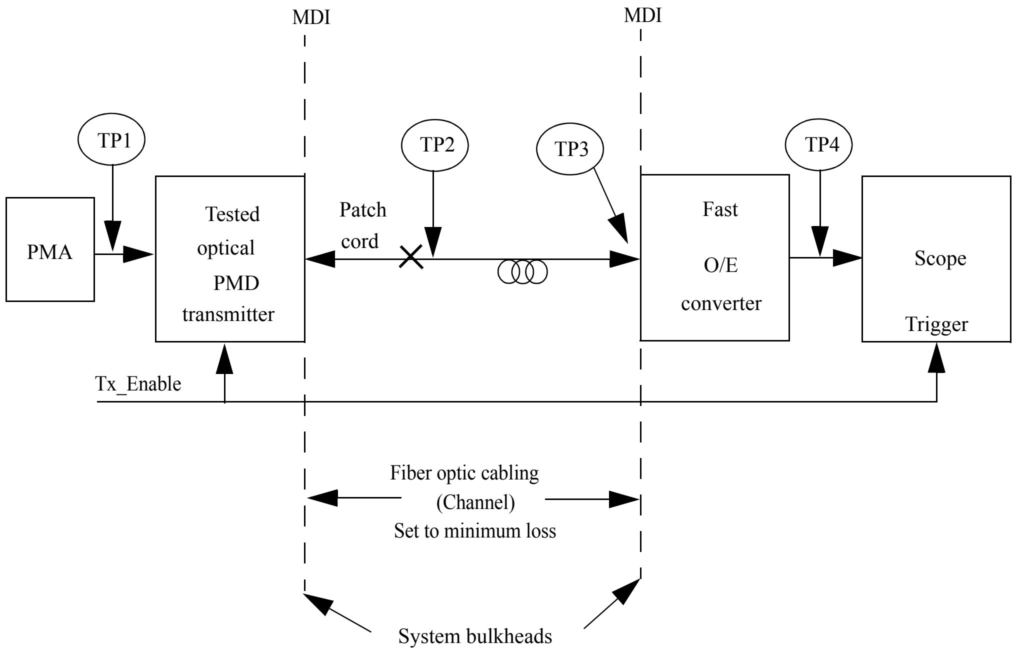

Figure 60–9—ONU PMD Laser on/off time measurement setup

60.9.13.2.2 Test specification

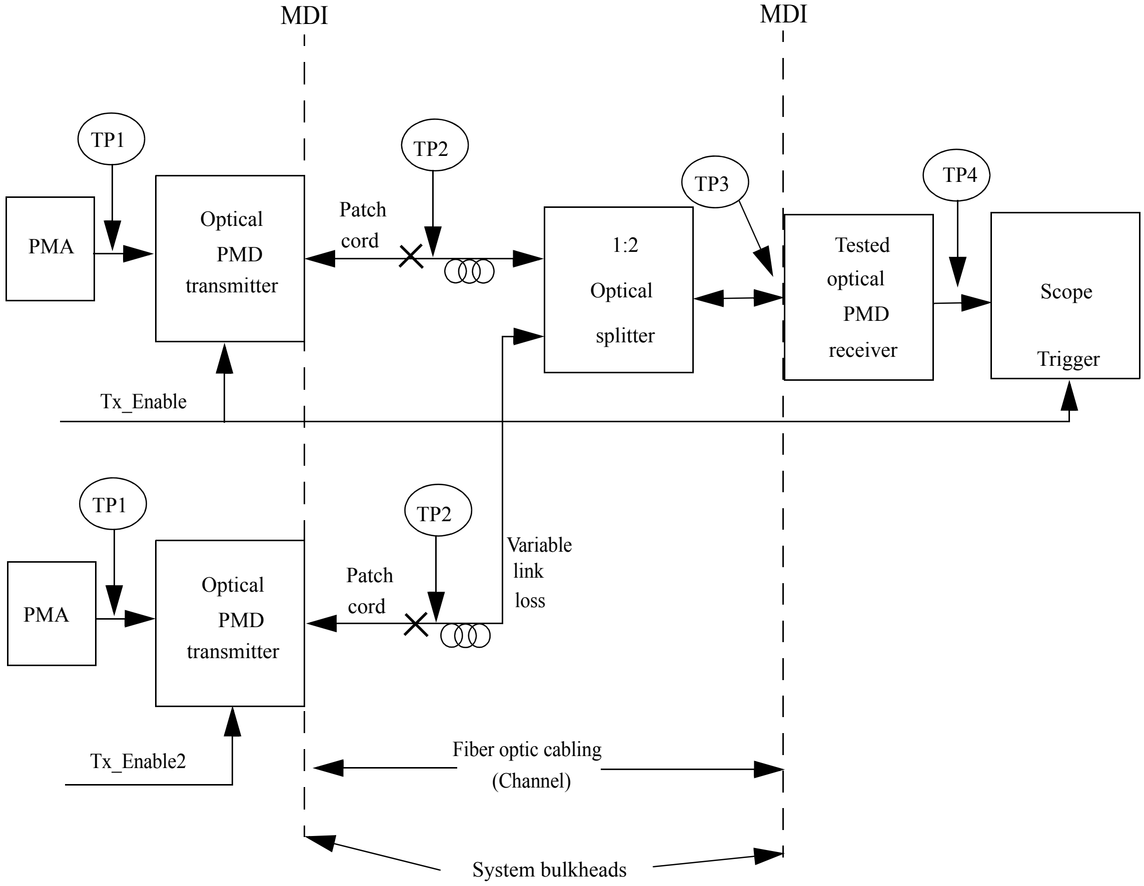

Figure 60–10—Receiver settling time measurement setup

Figure 60–10 illustrates the test setup for the OLT PMD receiver (upstream) $T_{receiver\_settling}$ time. The optical PMD transmitter has well-known parameters, with a fixed known T_{on} time. After T_{on} time the parameters of the reference transmitter, at TP2 and therefore at TP3, reach within 15% of its steady state values as specified in Table 60–3 for 1000BASE-PX10-U, Table 60–6 for 1000BASE-PX20-U, Table 60–9 for 1000BASE-PX30-U, and Table 60–12 for 1000BASE-PX40-U.

Define $T_{receiver\_settling}$ time as the time from the Tx_Enable assertion, minus the known T_{on} time, to the time the electrical signal at TP4 reaches within 15% of its steady state conditions.

Conformance should be assured for an optical signal at TP3 with any level of its specified parameters before the Tx_Enable assertion. Especially the $T_{receiver\_settling}$ time must be met in the following scenarios:

— Switching from a ‘weak’ (minimal received power at TP3) ONU to a ‘strong’ (maximal received power at TP3) ONU, with minimal guard band between.
— Switching from a ‘strong’ ONU to a ‘weak’ ONU, with minimal guard band between.
— Switching from noise level, with maximal duration interval, to ‘strong’ ONU power level.

A non-rigorous way to describe this test setup would be (using a transmitter with a known T_{on}).

For a tested PMD receiver with a declared $T_{receiver\_settling}$ time, measure all PMD receiver electrical parameters at TP4 after $T_{receiver\_settling}$ from the TX_ENABLE trigger minus the reference transmitter T_{on}, reassuring conformance to within 15% of its specified steady state values.

60.10 Environmental, safety, and labeling

60.10.1 General safety

All equipment meeting this standard shall conform to IEC 60950-1.

60.10.2 Laser safety

1000BASE-PX10, 1000BASE-PX20, 1000BASE-PX30, and 1000BASE-PX40 optical transceivers shall conform to Hazard Level 1 laser requirements as defined in IEC 60825-1 and IEC 60825-2, under any condition of operation. This includes single fault conditions whether coupled into a fiber or out of an open bore. Conformance to additional laser safety standards may be required for operation within specific geographic regions.

Laser safety standards and regulations require that the manufacturer of a laser product provide information about the product's laser, safety features, labeling, use, maintenance, and service. This documentation shall explicitly define requirements and usage restrictions on the host system necessary to meet these safety certifications.

60.10.3 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulation, be followed in every instance in which such practices are applicable.

60.10.4 Environment

Reference Annex 67A for additional environmental information.

Two optional temperature ranges are defined in Table 60–18. Implementations shall be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

Table 60–18—Component case temperature classes

Class	Low temperature (°C)	High temperature (°C)
Warm extended	–5	+85
Cool extended	–40	+60
Universal extended	–40	+85

60.10.5 PMD labeling requirements

It is recommended that each PHY (and supporting documentation) be labeled in a manner visible to the user, with at least the applicable safety warnings and the applicable port type designation (e.g., 1000BASE-PX10-U).

Labeling requirements for Hazard Level 1 lasers are given in the laser safety standards referenced in 60.10.2.

Each systems and field pluggable component shall be clearly labeled with its operating temperature range over which their compliance is ensured.

60.11 Characteristics of the fiber optic cabling

The 1000BASE-PX fiber optic cabling shall meet the dispersion specifications defined in IEC 60793-2 and ITU-T G.652, or the requirements of Table 60–19 where they differ. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together. It also includes a connector plug at each end to connect to the MDI. The fiber optic cabling spans from one MDI to another MDI, as shown in Figure 60–11.

60.11.1 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 60–11.

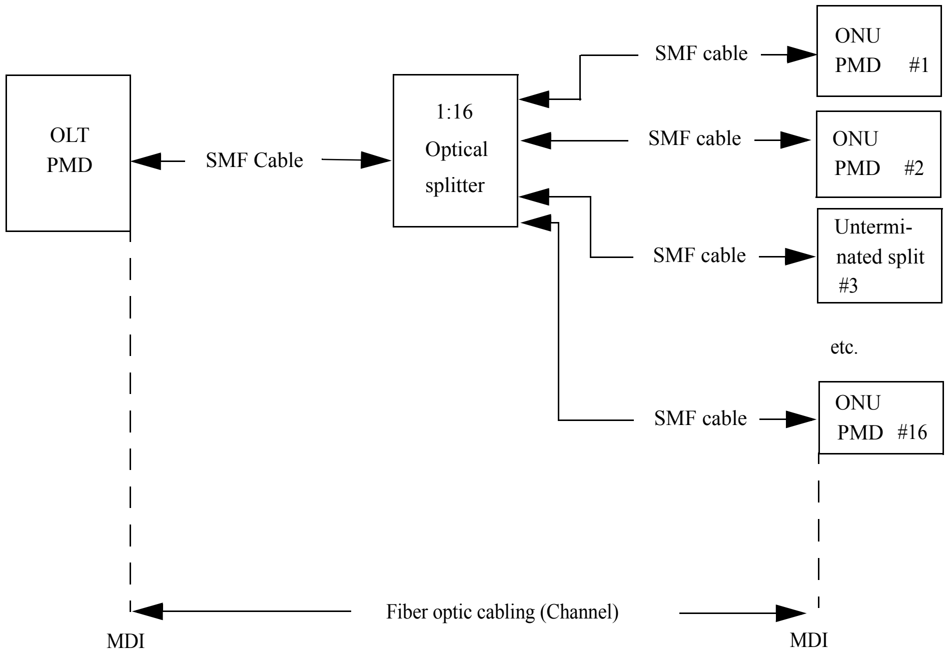

Figure 60–11—Fiber optic cable model

NOTE—The 1:16 optical splitter may be replaced by a number of smaller 1:n splitters such that a different topology may be implemented while preserving the link characteristics and power budget as defined in Table 60–14.

The maximum channel insertion losses shall meet the requirements specified in Table 60–1. Insertion loss measurements of installed fiber cables are made in accordance with ANSI/TIA/EIA-526-7 [B16], method A-1. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards.

60.11.2 Optical fiber and cable

The fiber optic cable requirements for 1000BASE-PX10 and 1000BASE-PX20 are satisfied by the fibers specified in IEC 60793-2 Type B1.1 (dispersion un-shifted single-mode fiber) and Type B1.3 (low water peak single-mode fiber) and ITU-T G.652, or by the requirements of Table 60–19 where they differ.

The fiber optic cable requirements for 1000BASE-PX30 and 1000BASE-PX40 are satisfied by the fibers specified in IEC 60793–2 Type B1.1 (dispersion un–shifted single-mode fiber), Type B1.3 (low water peak single-mode fiber), ITU-T G.652, and ITU-T G.657 (bend–insensitive single-mode fiber), or by the requirements of Table 75–14 where they differ.

60.11.3 Optical fiber connection

Table 60–19—Optical fiber and cable characteristics

Description[a]	Type B1.1, B1.3 SMF		Unit
Nominal wavelength[b]	1310	1550	nm
Cabled optical fiber attenuation (max)[c]	0.4	0.35	dB/km
Zero dispersion wavelength[d]	$1300 \le \lambda_0 \le 1324$		nm
Dispersion slope (max)	0.093		$ps / nm^2 \cdot km$

[a] The fiber dispersion values are normative, all other values in the table are informative.
[b] Wavelength specified is the nominal wavelength and typical measurement wavelength. Power penalties at other wavelengths are accounted for.
[c] Attenuation for single-mode optical fiber cables is defined in ITU-T G.652.
[d] See IEC 60793 or ITU-T G.652.

An optical fiber connection as shown in Figure 60–11 consists of a mated pair of optical connectors. The 1000BASE-PX is coupled to the fiber optic cabling through an optical connection and any optical splitters into the MDI optical receiver, as shown in Figure 60–11. The channel insertion loss includes the loss for connectors, splices and other passive components such as splitters, see Table 60–14.

The link attenuations have been calculated on the assumption of 14.5 dB for a 16:1 splitter; 3.5 dB, 4 dB, 7.5 dB, or 8 dB (at the appropriate measurement wavelength where these attenuations are a combination of the minimum range given in Table 60–1 and the values in Table 60–19) for cabled optical fiber attenuation and 1.5 dB for connectors and splices. For example, this allocation supports three connections with an average insertion loss equal to 0.5 dB (or less) per connection, or two connections with a maximum insertion loss of 0.75 dB. Other arrangements, such as a shorter link length and a higher split ratio in the case of 1000BASE-PX20, may be used provided the requirements of Table 60–1 are met.

The maximum discrete reflectance for single-mode connections shall be less than –26 dB.

60.11.4 Medium Dependent Interface (MDI)

The 1000BASE-PX10, 1000BASE-PX20, 1000BASE-PX30, or 1000BASE-PX40 PMD is coupled to the fiber cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” as shown in Figure 60–11. Examples of an MDI include the following:

a) Connectorized fiber pigtail
b) PMD receptacle

When the MDI is a remateable connection, it shall meet the interface performance specifications of IEC 61753-1. The MDI carries the signal in both directions for 1000BASE-PX10, 1000BASE-PX20, 1000BASE-PX30, and 1000BASE-PX40 and couples to a single fiber.

NOTE—Compliance testing is performed at TP2 and TP3 as defined in 60.2.1, not at the MDI.

60.12 Protocol implementation conformance statement (PICS) proforma for Clause 60, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks)[8]

60.12.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 60, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks), shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

60.12.2 Identification

60.12.2.1 Implementation identification

Supplier[1]	
Contact point for inquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1,3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTE 1—Required for all implementations. NOTE2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

60.12.2.2 Protocol Summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 60, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[8] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

60.12.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
HT	High temperature operation	60.10.4	–5 °C to 85 °C	O	Yes [ ] No [ ]
LT	Low temperature operation	60.10.4	–40 °C to 60 °C	O	Yes [ ] No [ ]
*PX10U	1000BASE-PX10-U-PHY or 1000BASE-PX10-U PMD	60.3	Device supports 10 km	O/1	Yes [ ] No [ ]
*PX10D	1000BASE-PX10-D-PHY or 1000BASE-PX10-D PMD	60.3	Device supports 10 km	O/1	Yes [ ] No [ ]
*PX20U	1000BASE-PX20-U-PHY or 1000BASE-PX20-U PMD	60.4	Device supports 20 km	O/1	Yes [ ] No [ ]
*PX20D	1000BASE-PX20-D-PHY or 1000BASE-PX20-D PMD	60.4	Device supports 20 km	O/1	Yes [ ] No [ ]
*PX30U	1000BASE-PX30-U-PHY or 1000BASE-PX30-U PMD	60.5	Device supports 20 km	O/1	Yes [] No []
*PX30D	1000BASE-PX30-D-PHY or 1000BASE-PX30-D PMD	60.5	Device supports 20 km	O/1	Yes [] No []
*PX40U	1000BASE-PX40-U-PHY or 1000BASE-PX40-U PMD	60.6	Device supports 20 km	O/1	Yes [] No []
*PX40D	1000BASE-PX40-D-PHY or 1000BASE-PX40-D PMD	60.6	Device supports 20 km	O/1	Yes [] No []
*INS	Installation / Cable	60.3.1	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer.	O	Yes [ ] No [ ]

60.12.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks)

60.12.4.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FN1	Transmit function	60.2.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FN2	Transmitter optical signal	60.2.2	Higher optical power transmitted is a logic 1	M	Yes [ ]
FN3	Receive function	60.2.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FN4	Receiver optical signal	60.2.3	Higher optical power received is a logic 1	M	Yes [ ]
FN5	Signal detect function (downstream)	60.2.4.1	Mapping to PMD service interface	M	Yes [ ]
FN6	Signal detect parameter (downstream)	60.2.4.1	Generated according to Table 60–2	M	Yes [ ]
FN7	Signal detect function (upstream)	60.2.4.2	Mapping to PMD service interface	O/2	Yes [ ]
FN7	Signal detect function (upstream)	60.2.4.2	Provided by higher layer	O/2	Yes [ ]
FN8	Signal detect parameter (upstream)	60.2.4.1	Generated according to Table 60–2	O	Yes [ ]

60.12.4.2 PMD to MDI optical specifications for 1000BASE-PX10-D

Item	Feature	Subclause	Value/Comment	Status	Support
PX10D1	1000BASE-PX10-D transmitter	60.3.1	Meets specifications in Table 60–3	PX10D:M	Yes [ ] N/A [ ]
PX10D2	1000BASE-PX10-D transmitter $RIN_{15}OMA$	60.3.1	Meets the $RIN_{15}OMA$ specification in Table 60–3	PX10D:O	Yes [ ] N/A [ ]
PX10D3	1000BASE-PX10-D receiver	60.3.2	Meets specifications in Table 60–5	PX10D:M	Yes [ ] N/A [ ]
PX10D4	1000BASE-PX10-D stressed receiver sensitivity	60.3.2	Meets specifications in Table 60–5	PX10D:O	Yes [ ] No [ ] N/A[ ]
PX10D5	1000BASE-PX10-D receiver damage threshold	60.3.2	If the receiver does not meet the damage requirements in Table 60–5 then label accordingly	PX10D:M	Yes [ ] N/A [ ]

60.12.4.3 PMD to MDI optical specifications for 1000BASE-PX10-U

Item	Feature	Subclause	Value/Comment	Status	Support
PX10U1	1000BASE-PX10-U transmitter	60.3.1	Meets specifications in Table 60–3	PX10U:M	Yes [ ] N/A [ ]
PX10U2	1000BASE-PX10-U transmitter $\text{RIN}_{15}\text{OMA}$	60.3.1	Meets the $\text{RIN}_{15}\text{OMA}$ specification in Table 60–3	PX10U:O	Yes [ ] N/A [ ]
PX10U3	1000BASE-PX10-U receiver	60.3.2	Meets specifications in Table 60–5	PX10U:M	Yes [ ] N/A [ ]
PX10U4	1000BASE-PX10-U stressed receiver sensitivity	60.3.2	Meets specifications in Table 60–5	PX10U:O	Yes [ ] No [ ] N/A[ ]
PX10U5	1000BASE-PX10-U receiver damage threshold	60.3.2	If the receiver does not meet the damage requirements in Table 60–5 then label accordingly	PX10U:M	Yes [ ] N/A [ ]

60.12.4.4 PMD to MDI optical specifications for 1000BASE-PX20-D

Item	Feature	Subclause	Value/Comment	Status	Support
PX20D1	1000BASE-PX20-D transmitter	60.4.1	Meets specifications in Table 60–6	PX20D:M	Yes [ ] N/A [ ]
PX20D2	1000BASE-PX20-D transmitter $\text{RIN}_{15}\text{OMA}$	60.4.1	Meets the $\text{RIN}_{15}\text{OMA}$ specification in Table 60–6	PX20D:O	Yes [ ] N/A [ ]
PX20D3	1000BASE-PX20-D receiver	60.4.2	Meets specifications in Table 60–8	PX20D:M	Yes [ ] N/A [ ]
PX20D4	1000BASE-PX20-D stressed receiver sensitivity	60.4.2	Meets specifications in Table 60–8	PX20D:O	Yes [ ] No [ ] N/A[ ]
PX20D5	1000BASE-PX20-D receiver damage threshold	60.4.2	If the receiver does not meet the damage requirements in Table 60–8 then label accordingly	PX20D:M	Yes [ ] N/A [ ]

60.12.4.5 PMD to MDI optical specifications for 1000BASE-PX20-U

Item	Feature	Subclause	Value/Comment	Status	Support
PX20U1	1000BASE-PX20-U transmitter	60.4.1	Meets specifications in Table 60–6	PX20U:M	Yes [ ] N/A [ ]
PX20U2	1000BASE-PX20-U transmitter $\text{RIN}_{15}\text{OMA}$	60.4.1	Meets the $\text{RIN}_{15}\text{OMA}$ specification in Table 60–6	PX20U:O	Yes [ ] N/A [ ]
PX20U3	1000BASE-PX20-U receiver	60.4.2	Meets specifications in Table 60–8	PX20U:M	Yes [ ] N/A [ ]
PX20U4	1000BASE-PX20-U stressed receiver sensitivity	60.4.2	Meets specifications in Table 60–8	PX20U:O	Yes[ ] No [ ] N/A[ ]
PX20U5	1000BASE-PX20-U receiver damage threshold	60.4.2	If the receiver does not meet the damage requirements in Table 60–8 then label accordingly	PX20U:M	Yes [ ] N/A [ ]

60.12.4.6 PMD to MDI optical specifications for 1000BASE-PX30-D

Item	Feature	Subclause	Value/Comment	Status	Support
PX30D1	1000BASE-PX30-D transmitter	60.5.1	Meets normative specifications in Table 60–9	PX30D:M	Yes [ ] N/A [ ]
PX30D2	1000BASE-PX30-D transmitter $\text{RIN}_{15}\text{OMA}$	60.5.1	Meets the $\text{RIN}_{15}\text{OMA}$ specification in Table 60–9	PX30D:O	Yes [ ] N/A [ ]
PX30D3	1000BASE-PX30-D receiver	60.5.2	Meets specifications in Table 60–11	PX30D:M	Yes [ ] N/A [ ]
PX30D4	1000BASE-PX30-D stressed receiver sensitivity	60.5.2	Meets specifications in Table 60–11	PX30D:O	Yes [ ] No [ ] N/A[ ]
PX30D5	1000BASE-PX30-D receiver damage threshold	60.5.2	If the receiver does not meet the damage requirements in Table 60–11 then label accordingly	PX30D:M	Yes [ ] N/A [ ]

60.12.4.7 PMD to MDI optical specifications for 1000BASE-PX30-U

Item	Feature	Subclause	Value/Comment	Status	Support
PX30U1	1000BASE-PX30-U transmitter	60.5.1	Meets specifications in Table 60–9	PX30U:M	Yes [ ] N/A [ ]
PX30U2	1000BASE-PX30-U transmitter $\text{RIN}_{15}\text{OMA}$	60.5.1	Meets the $\text{RIN}_{15}\text{OMA}$ specification in Table 60–9	PX30U:O	Yes [ ] N/A [ ]
PX30U3	1000BASE-PX30-U receiver	60.5.2	Meets specifications in Table 60–11	PX30U:M	Yes [ ] N/A [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
PX30U4	1000BASE-PX30-U stressed receiver sensitivity	60.5.2	Meets specifications in Table 60–11	PX30U:O	Yes [ ] No [ ] N/A[ ]
PX30U5	1000BASE-PX30-U receiver damage threshold	60.5.2	If the receiver does not meet the damage requirements in Table 60–11 then label accordingly	PX30U:M	Yes [ ] N/A [ ]

60.12.4.8 PMD to MDI optical specifications for 1000BASE-PX40-D

Item	Feature	Subclause	Value/Comment	Status	Support
PX40D1	1000BASE-PX40-D transmitter	60.6.1	Meets specifications in Table 60–12	PX40D:M	Yes [ ] N/A [ ]
PX40D2	1000BASE-PX40-D transmitter $RIN_{15}OMA$	60.6.1	Meets the $RIN_{15}OMA$ specification in Table 60–12	PX40D:O	Yes [ ] N/A [ ]
PX40D3	1000BASE-PX40-D receiver	60.6.2	Meets specifications in Table 60–13	PX40D:M	Yes [ ] N/A [ ]
PX40D4	1000BASE-PX40-D stressed receiver sensitivity	60.6.2	Meets specifications in Table 60–13	PX40D:O	Yes[ ] No [ ] N/A[ ]
PX40D5	1000BASE-PX40-D receiver damage threshold	60.6.2	If the receiver does not meet the damage requirements in Table 60–13 then label accordingly	PX40D:M	Yes [ ] N/A [ ]

60.12.4.9 PMD to MDI optical specifications for 1000BASE-PX40-U

Item	Feature	Subclause	Value/Comment	Status	Support
PX40U1	1000BASE-PX40-U transmitter	60.6.1	Meets specifications in Table 60–12	PX40U:M	Yes [ ] N/A [ ]
PX40U2	1000BASE-PX40-U transmitter $RIN_{15}OMA$	60.6.1	Meets the $RIN_{15}OMA$ specification in Table 60–12	PX40U:O	Yes [ ] N/A [ ]
PX40U2	1000BASE-PX40-U receiver	60.6.2	Meets specifications in Table 60–13	PX40U:M	Yes [ ] N/A [ ]
PX40U3	1000BASE-PX40-U stressed receiver sensitivity	60.6.2	Meets specifications in Table 60–13	PX40U:O	Yes[ ] No [ ] N/A[ ]
PX40U4	1000BASE-PX40-U receiver damage threshold	60.6.2	If the receiver does not meet the damage requirements in Table 60–13 then label accordingly	PX40U:M	Yes [ ] N/A [ ]

60.12.4.10 Optical measurement requirements

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Measurement cable	60.9	2 m to 5 m in length	M	Yes [ ]
OM2	Wavelength and spectral width measurement	60.9.2	Per TIA-455-127-A under modulated conditions	M	Yes [ ]
OM3	Average optical power	60.9.3	Per TIA/EIA-455-95	M	Yes [ ]
OM4	Extinction ratio	60.9.4	Per IEC 61280-2-2 with minimal back reflections and fourth-order Bessel-Thomson receiver	M	Yes [ ]
OM5	$\text{RIN}_{15}\text{OMA}$	60.9.7	As described in 58.7.7	M	Yes [ ]
OM6	Transmit optical waveform (transmit eye)	60.9.8	Per 58.7.8 and references therein	M	Yes [ ]
OM7	Transmitter and dispersion penalty measurements	60.9.9	As described in 58.7.9	M	Yes [ ]
OM8	Receive sensitivity	60.9.10	With specified pattern	M	Yes [ ]
*OM9	Stressed receiver conformance test	60.9.11	As described in 60.9.11	O	Yes[ ] N/A[ ]

60.12.4.11 Characteristics of the fiber optic cabling and MDI

Item	Feature	Subclause	Value/Comment	Status	Support
FO1	Fiber optic cabling	60.11	Specified in Table 60–19	INS:M	Yes [ ] N/A[ ]
F02	End-to-end channel loss	60.11	Meeting the requirements of Table 60–1	INS:M	Yes [ ] N/A[ ]
FO3	Maximum discrete reflectance - single-mode fiber	60.11.2	Less than –26 dB	INS:M	Yes [ ] N/A [ ]
FO4	MDI requirements	60.11.4	Meet the interface performance specifications of IEC 61753-1, if remateable	INS:O	Yes [ ] No [ ] N/A [ ]

60.12.4.12 Environmental specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	60.10.1	Conforms to IEC 60950-1	M	Yes [ ]
ES2	Laser safety —IEC Hazard Level 1	60.10.2	Conform to Hazard Level 1 laser requirements defined in IEC 60825-1 and IEC 60825-2.	M	Yes [ ]
ES3	Documentation	60.10.2	Explicitly defines requirements and usage restrictions to meet safety certifications	M	Yes [ ]
ES4	Operating temperature range labeling	60.10.5	If required	M	Yes [ ] N/A[ ]

61. Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications, type 10PASS-TS and type 2BASE-TL

61.1 Overview

This clause specifies the Physical Coding Sublayer (PCS), Transmission Convergence sublayer (TC), and handshaking mechanisms that are common to a family of Physical Layer implementations for Ethernet over voice-grade copper known as 10PASS-TS and 2BASE-TL. These PHYs deliver a minimum of 10 Mb/s over distances of up to 750 m, and a minimum of 2 Mb/s over distances of up to 2700 m, using a single copper pair. Optionally, transmission over multiple copper pairs is supported.

The copper category of EFM PHYs is based on Digital Subscriber Line (DSL) PMDs defined for use in the access network according to ATIS T1, ETSI, and ITU-T standards. These systems are intended to be used in public as well as private networks; therefore they shall be capable of compliance with appropriate regulatory, governmental and regional requirements.

Unlike the specified copper categories for 10BASE-T, 100BASE-T, and 1000BASE-T, existing common carrier voice-grade copper has channel characteristics that are very diverse. Therefore it is conventional to discuss the channel behavior only in terms of averages, standard deviations and percentage worst case.

The 10PASS-TS and 2BASE-TL EFM Copper PHYs, in conjunction with the MAC specified in Clause 4 and Annex 4A, are used for point-to-point communications on a subscriber access network, typically between centralized distribution equipment, such as a Central Office (CO), and equipment located at the subscriber premises [Customer Premises Equipment, (CPE)].

For the 10PASS-TS and 2BASE-TL EFM Copper PHYs, two subtypes are defined: 10PASS-TS-O and 10PASS-TS-R are the subtypes of 10PASS-TS; 2BASE-TL-O and 2BASE-TL-R are the subtypes of 2BASE-TL. A connection can only be established between a 10PASS-TS-O PHY on one end of the voice-grade copper line, and a 10PASS-TS-R PHY on the other end, or between a 2BASE-TL-O PHY on one end and a 2BASE-TL-R PHY on the other end. In public networks, a 10PASS-TS-O or 2BASE-TL-O PHY is used at a CO, a cabinet or other centralized distribution point; a 10PASS-TS-R or 2BASE-TL-R PHY is used as CPE. In private networks, the network administrator will designate one end of each link as the network end. In this clause, 10PASS-TS-O and 2BASE-TL-O are collectively referred to as "CO-subtypes"; 10PASS-TS-R and 2BASE-TL-R are collectively referred to as "CPE-subtypes". The CO and CPE subtypes of a 10PASS-TS or 2BASE-TL PHY may be implemented in a single physical device.

10PASS-TS and 2BASE-TL PHYs do not provide support for unidirectional links as described in 57.2.12. If a particular anomaly or failure occurs in either downstream or upstream, sublayer-specific signaling will alert the remote end of this condition. In the case of a sustained anomaly or failure, the link will reinitialize.

61.1.1 Scope

This clause defines the Physical Coding Sublayer (PCS) and Transmission Convergence (TC) sublayer for 2BASE-TL and 10PASS-TS. The PCS has similarities to other IEEE 802.3 PCS types, but also differs since new sublayers are added within the PCS sublayer to accommodate the operation of Ethernet over access network copper channels. The TC contains additional functions specific to the EFM Copper PHYs. This clause also defines the common startup and handshaking mechanism used by both PHYs. Parts of register 3.0, parts of register 3.4, and registers 3.60 through 3.73 specified in Clause 45 may be used to control the PCS specified in this clause. The remaining PCS registers defined in Clause 45 do not have any effect on the PCS specified in this clause. Parts of register 6.0 and registers 6.16 through 6.23 specified in Clause 45 may be used to control the TC sublayer specified in this clause.

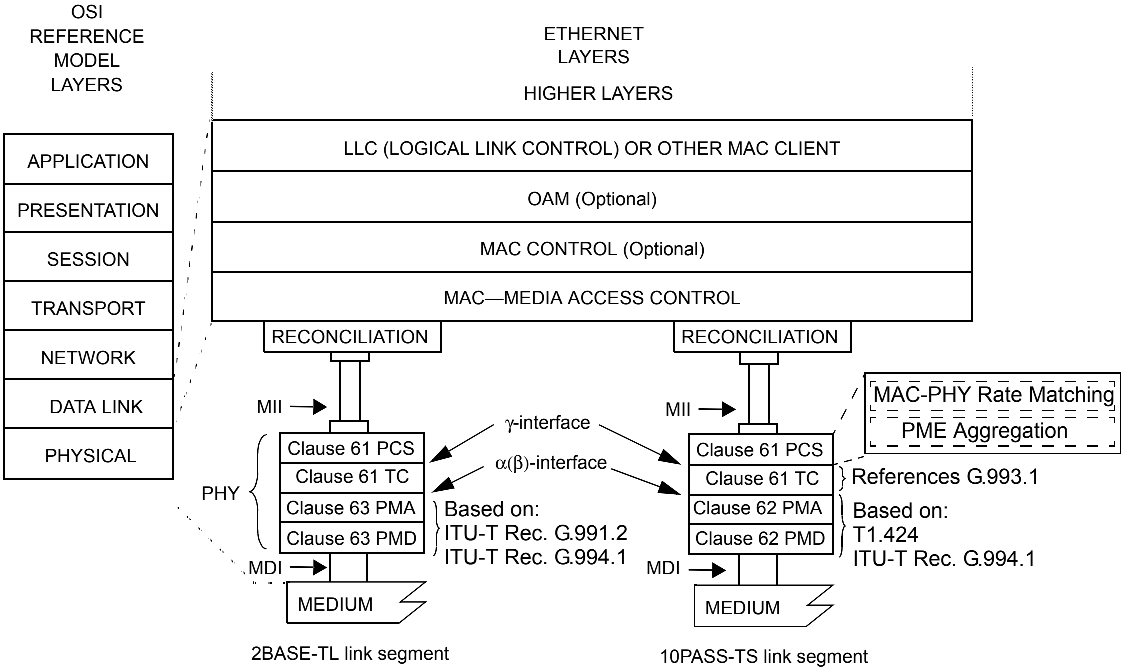
61.1.2 Objectives

The following are the objectives for 2BASE-TL and 10PASS-TS:

a) To provide 100 Mb/s burst data rate at the MII using Rate Matching.
b) To provide support for simultaneous transmission and reception without interference.
c) To provide for operating over unshielded voice grade twisted pair cable.
d) To provide a communication channel with a mean BER at the PMA service interface of less than 10^{-7} with a noise margin of 6 dB (10PASS-TS) or 5 dB (2BASE-TL).
e) To provide optional support for operation on multiple pairs.
f) To provide functional layering in the PCS which ensures compatibility with the layering and frame interfaces for xDSL systems, including a γ-interface based on that used for the PTM-TC sublayer as defined in ITU-T Recommendation G.993.1.

61.1.3 Relation of 2BASE-TL and 10PASS-TS to other standards

The relation of 2BASE-TL and 10PASS-TS to other standards is shown schematically in Figure 61–1.



MDI = MEDIUM DEPENDENT INTERFACE
MII = MEDIA INDEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION & MAINTENANCE
TC = TRANSMISSION CONVERGENCE

PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
PME = PHYSICAL MEDIUM ENTITY

Figure 61–1—Relation of this clause to other standards

NOTE—The PCS shown in the 2BASE-TL PHY and the PCS shown in the 10PASS-TS PHY are two instances of one unique PCS, specified in this clause. The TC shown in the 2BASE-TL PHY and the TC shown in the 10PASS-TS PHY are two instances of one unique TC, specified in this clause.

61.1.4 Summary

61.1.4.1 Summary of Physical Coding Sublayer (PCS) specification

The Physical Coding Sublayer (PCS) for 2BASE-TL and 10PASS-TS contains two functions: MAC-PHY rate matching and PME aggregation. The functional position of the PCS is shown in Figure 61–2.

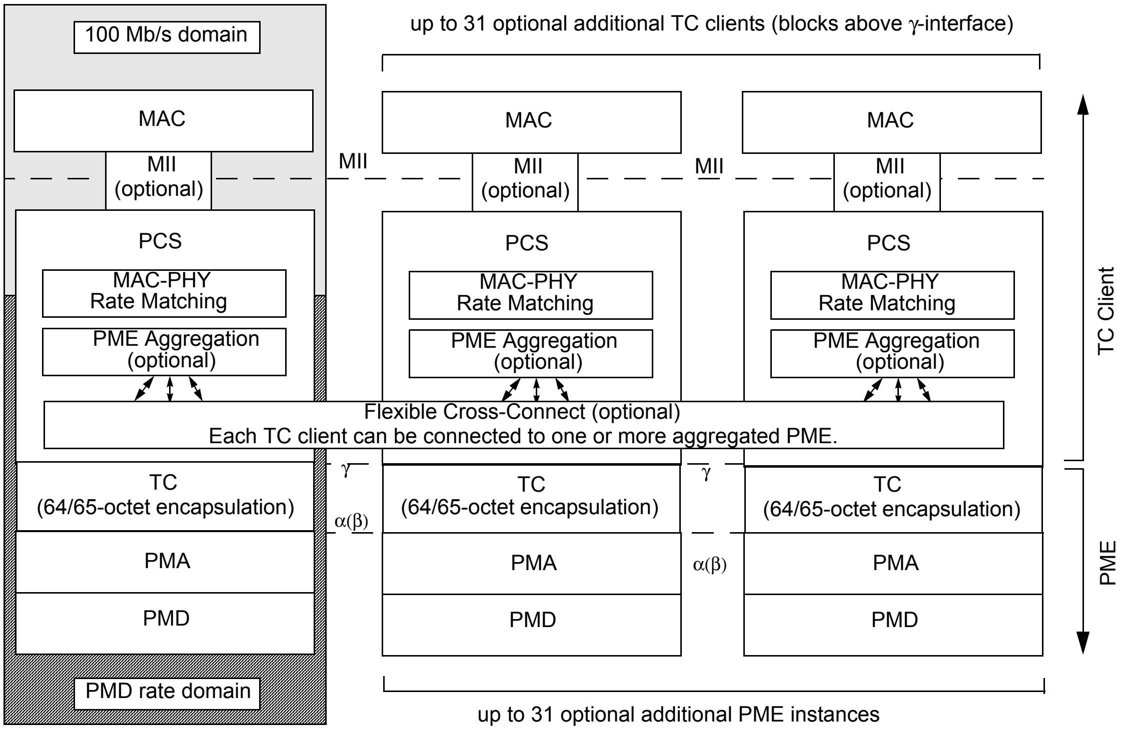


Figure 61–2—Overview of PCS functions

The γ-interface and α(β)-interface are specified in 61.3.1 and 61.3.2, respectively. They are generic interfaces used in various xDSL specifications, such as the ones referenced in Clause 62 and Clause 63. The α(β)-interface is a simple octet-synchronous data interface; the γ-interface adds protocol-awareness (in the case of the TC sublayer defined in this Clause, the γ-interface can signal packet boundaries).

The bit rates in the shaded area labeled "PMD rate domain" are derived from the DSL bit rates. Data is transferred across the γ-interface at the rate imposed by the lower layers. The bit rates in the shaded area labeled "100 Mb/s domain" are synchronous to the MII rate. Data is transferred across the MII at the rate of one nibble per MII clock cycle. The MAC-PHY rate matching function adjusts the inter packet gap so that the net data rate across these interface matches the sum of rates across the γ-interfaces.[9]

In the transmit direction, frames are transferred from the MAC to the PCS across the MII when the MAC-PHY rate matching function allows this. In the PCS, preamble and SFD octets are removed. If the optional PME aggregation function (PAF) is present, the MAC frame is fragmented by the PAF, and fragments are forwarded, optionally through a flexible cross-connect, towards each of the aggregated Physical Medium Entity (PME) instances via their γ-interfaces. If the PAF is not present, the data frame is forwarded to the TC sublayer via the γ-interface. The TC sublayer accepts data from the MAC-PHY rate matching function or the PAF, at the rate at which it can be processed by the TC sublayer, by asserting Tx_Enbl on the γ-interface.

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[9] Bit rate domains and physical clock domains do not necessarily coincide. The TC sublayer receives a clock signal from the PMA via the α(β)-interface, and a clock signal from the optional PAF or the MAC-PHY Rate Matching function via the γ-interface. The TC provides matching between these two clock domains.

In the receive direction the TC sublayer pushes data to the PAF (if present) or the MAC-PHY rate matching function by asserting Rx_Enbl on the γ-interface. If multiple links are aggregated, the PAF reassembles the received fragments into data frames. Preamble and SFD octets are generated and prepended to the data frame prior to passing it up to the MAC across the MII. The MAC-PHY Rate Matching function may delay the transfer of the frame to avoid simultaneous transfer of Transmit and Receive frames if required.

NOTE—The MAC_PHY rate matching function and PME Aggregation function both require some form of frame buffer for many implementations. It is recommended that these frame buffers should be sized to accommodate maximum length envelope frames (see 3.2.7).

61.1.4.1.1 Implementation of Media Independent Interface

10PASS-TS and 2BASE-TL specify the optional use of the MII electrical interface as defined in Clause 22 (see also 61.1.5.2). 10PASS-TS and 2BASE-TL do not utilize the MII management interface as described in 22.2.4. The use of the MDIO interface specified in Clause 45 or an equivalent management interface is recommended.

Notwithstanding the specifications in 22.2.2.9, CRS may be asserted by a full-duplex EFM Copper PHY to reduce the effective MAC rate to that of the PHY.

61.1.4.1.2 Summary of MAC-PHY Rate Matching specification

The 10PASS-TS and 2BASE-TL PCS is specified to work with a MAC operating at 100 Mb/s using the MII as defined in Clause 22. The PCS matches the MAC's rate of data transmission to the transmission data rate of the medium, if slower. This is achieved using deference as defined in Annex 4A.

The MAC transmits data at a rate of 100 Mb/s, which is buffered by the PCS before being transmitted onto the medium. Prior to transmission, the MAC checks the carrierSense variable (mapped from the MII signal CRS), and will not transmit another frame as long as carrierSense is asserted. In order to prevent the PCS's transmit buffer from overflowing, the PCS keeps CRS asserted until it has space to receive a maximum length frame. The PCS forces COL to logic zero to prevent the MAC from dropping the frame and performing a re-transmission.

The transmitter MAC-PHY Rate Matching function strips the Preamble and SFD fields from the MAC frame, and forwards the resulting data frame to the PME Aggregation Function or to the TC sublayer.

For reception the PHY buffers a complete frame, prepends the Preamble and SFD fields, and sends it to the MAC at 100 Mb/s.

It is recognized that some MAC implementations have to be configured for half duplex operation to support deference (according to 4.2.3.2.1), and that these may not allow the simultaneous transmission and reception of data while operating in half duplex mode. To permit operation with these MACs the PHY has an operating mode where MAC data transmission is deferred using CRS when received data is sent from the PHY to the MAC. This mode of operation is defined in Figure 61–8, which describes the MAC-PHY rate matching receive state diagram. This state diagram gives receive frames priority over transmitted frames to ensure the receive buffer does not overflow.

The definition of MAC-PHY rate matching is presented in 61.2.1.

61.1.4.1.3 Summary of PME Aggregation specification

An optional PME Aggregation Function (PAF) allows one or more PMEs to be combined together to form a single logical Ethernet link. The PAF is located in the PCS, between the MAC-PHY Rate Matching function and the TC sublayer. It interfaces with the PMEs across the γ-interface, and to the MAC-PHY Rate Matching function using an abstract interface. The definition of the PAF is presented in 61.2.2.

61.1.4.1.4 Overview of management

Ethernet OAM (Clause 57) runs over a MAC service which uses a PHY consisting of either a single physical link, or more than one physical 2BASE-TL or 10PASS-TS links, aggregated as described in 61.2.2. The Ethernet OAM operates as long as there is at least one PME in the PHY that is operational. The physical xDSL PMEs in Clause 62 and Clause 63 each have their own management channel that operates per loop (eoc, VOC and IB for 10PASS-TS; EOC and IB for 2BASE-TL).

61.1.4.2 Summary of Transmission Convergence (TC) specification

The Transmission Convergence sublayer (TC) resides between the γ-interface of the PCS and α(β)-interface of the PMA. It is intended to convert the data frame to be sent into the format suitable to be mapped into PMA, and to recognize the received frame at the other end of the link. Since PMA and MII clocks may be unequal, the TC also provides clock rate matching. The definition of the TC sublayer is presented in 61.3.

61.1.4.3 Summary of handshaking and PHY control specification

Both 2BASE-TL and 10PASS-TS use handshake procedures defined in ITU-T G.994.1 at startup. Devices implementing both 2BASE-TL and 10PASS-TS port types may use ITU-T G.994.1 to determine a common mode of operation.

61.1.5 Application of 2BASE-TL, 10PASS-TS

61.1.5.1 Compatibility considerations

The PCS, TC, PMA, and the MDI are defined to provide compatibility among devices designed by different manufacturers. Designers are free to implement circuitry within the PCS, TC, and PMA in an application-dependent manner provided the MDI and MII specifications are met.

61.1.5.2 Incorporating the 2BASE-TL, 10PASS-TS PHY into a DTE

When the PHY is incorporated within the physical bounds of a DTE, conformance to the MII is optional, provided that the observable behavior of the resulting system is identical to that of a system with a full MII implementation. For example, an integrated PHY may incorporate an interface between PCS and MAC that is logically equivalent to the MII, but does not have the full output current drive capability called for in the MII specification.

61.1.5.3 Application and examples of PME Aggregation

The PME Aggregation Function defined in 61.2.2 allows multiple PME instances to be aggregated together to form one logical link underneath one MII (or MAC). Additionally, the control mechanism allows multi-MAC devices to be built with flexible connections between the MACs and the PMEs. Clause 45 defines a mechanism for addressing and controlling this flexible connectivity. The relationship between the flexible connectivity and the other functions within the PCS is shown in Figure 61–2.

The connection relationship between the PCS instances (including MIIs) and the PME instances is defined in two registers: PME_Available_register (see 45.2.3.27) and PME_Aggregate_register (see 45.2.3.28). The PME_Available_register controls which PMEs may be aggregated into a particular PCS (and MII). This register value is limited by the physical connectivity in the device, may be further constrained by management, and is additionally constrained as PMEs are aggregated into other PCSs (which causes their bit to be cleared to zero in the PCS instances that they are not aggregated into). The register represents the potential for connectivity into this PCS at the particular point in time. The PME_Aggregate_register indicates the actual connectivity, i.e., which PMEs are being aggregated into the particular PCS.

NOTE—The addressing of PCS instances is independent of the addressing of PME instances in order to support the flexible connectivity. Each PCS consumes one of the 32 available port addresses.

Bits corresponding to the same PME may appear in multiple PME_Available_registers but the PME_Aggregate_register for each MII shall be set such that each PME is only actively connected to at most one MII. A particular bit set in one PME_Aggregate_register shall exclude the same corresponding bit in all other PME_Aggregate_registers for the same MDIO connected system.

61.1.5.3.1 Addressing PCS and PME instances

The addressing of the MDIO management interface is defined in 45.1. It is assumed that the reader is familiar with the definition of this interface. The examples here assume that only three MMDs are used: PCS (MMD = 3), TC (MMD = 6), and PMA/PMD (MMD = 1). The combination of TC, PMA and PMD is shown as PME in Figure 61–3. The difference between these examples and the example shown in 45.1 is that the PCS instances are addressed independently of the PME instances. Up to 32 PCS instances and up to 32 PME instances may be addressed by one MDIO bus. These instances may make up one or more aggregateable subdomains. The connection of the MDIO bus to the MMDs is shown in Figure 61–3.

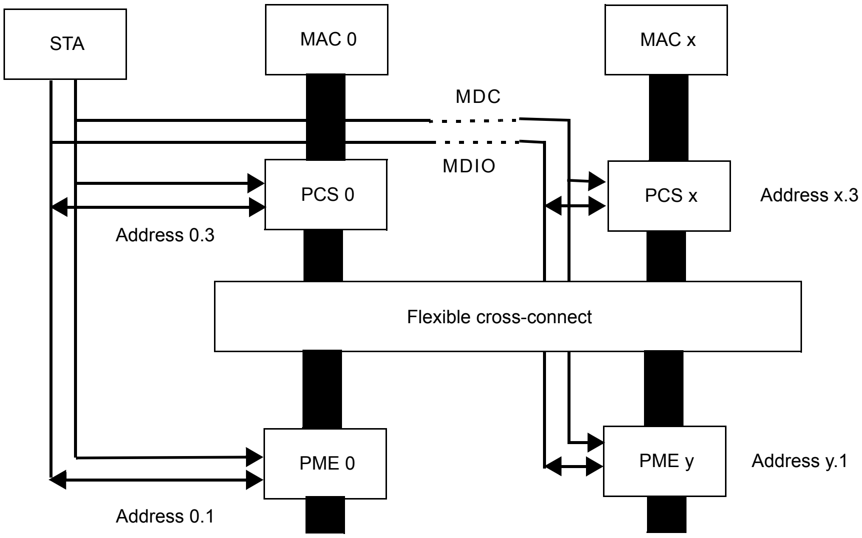


Figure 61–3—Connection of MDIO bus to MMD instances

In the example shown in Figure 61–3 there is no necessary connection between the PCS address and the PME address. The number of PCS instances may be different from the number of PME instances.

61.1.5.3.2 Indicating PME aggregation capability

The PME aggregation capability is indicated by the state of the PME_Available_register (see 45.2.3.27). An instance of this register is readable for each PAF instance *x* at register addresses *x*.3.62 and *x*.3.63. (Device address 3 of every port *x* is assigned to the PCS. The PAF specific registers reside under the *x*.3 register tree, because the PAF is part of the PCS as shown in Figure 61–2.) A bit is set in this register corresponding to the PME address for each PME which can be aggregated through the PAF in that PCS. Some examples are given that show register contents and connectivity for some popular configurations:

a) Simple two PME per MII connections, 32 PMEs are available for aggregation into 16 MIIs (PCS instances). PME_Available_register contents are shown in Table 61–1. A diagram of the connectivity is shown in Figure 61–4.
b) Pairs of 4-to-1 connections, 32 PMEs are available for aggregation into 16 MIIs (PCS instances) in a manner that allows each PME to connect to one of 2 MIIs and each MII to aggregate up to 4 PMEs. PME_Available_register contents are shown in Table 61–2. A diagram of the connectivity is shown in Figure 61–5.
c) 24-to-12 fully flexible connections, 24 PMEs are available for aggregation into 12 MIIs (PCS instances) in a manner that allows any PME to connect to any MII. PME_Available_register

contents are shown in Table 61–3. No connectivity diagram is shown as any connection is possible between PMEs and MIIs.

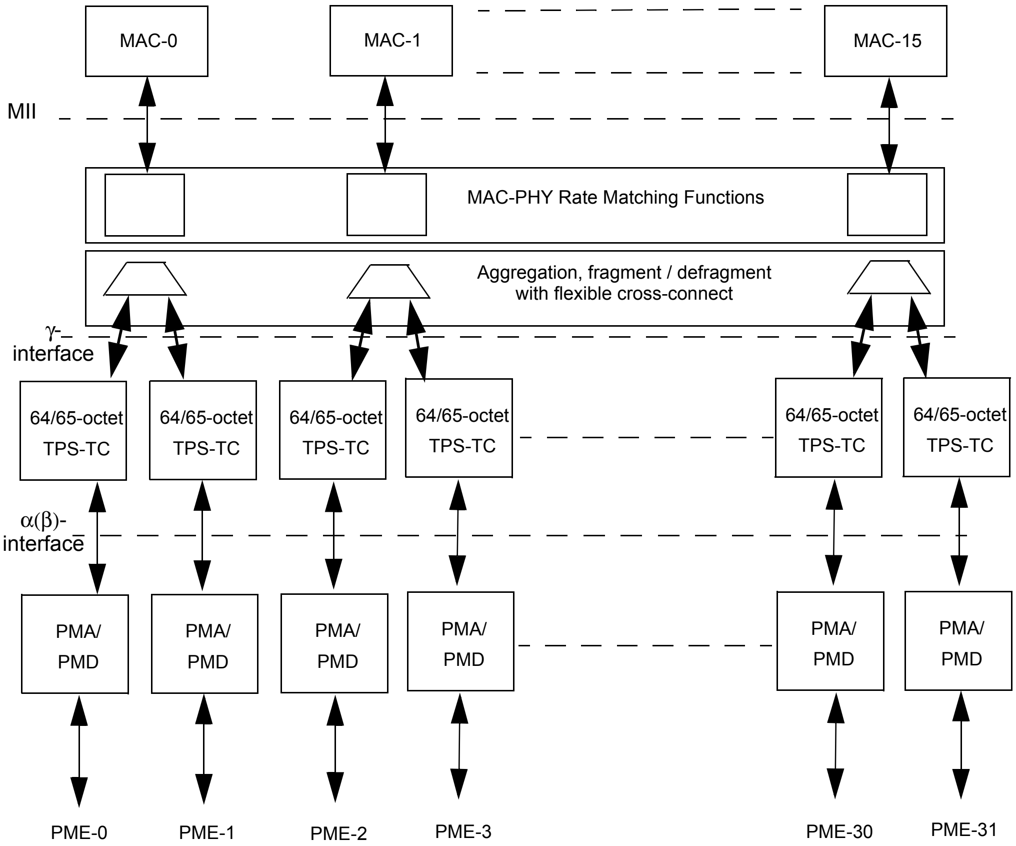


Figure 61–4—2 PME for each MII connectivity

Table 61–1—PME_Available_register contents (example a)

PME_Available_register	Contents
0.3.62 / 63	b11000000_00000000_00000000_00000000
1.3.62 / 63	b00110000_00000000_00000000_00000000
etc.	etc.
15.3.62 / 63	b00000000_00000000_00000000_00000011

Table 61–2—PME_Available_register contents (example b)[a]

PME_Available_register	Contents
0.3.62 / 63	b11110000_00000000_00000000_00000000
1.3.62 / 63	b11110000_00000000_00000000_00000000
etc.	etc.
15.3.62 / 63	b00000000_00000000_00000000_00001111

[a] A mapping in which the same PME is available for connection to several PCS instances (as shown) is only allowed at the CO-side.

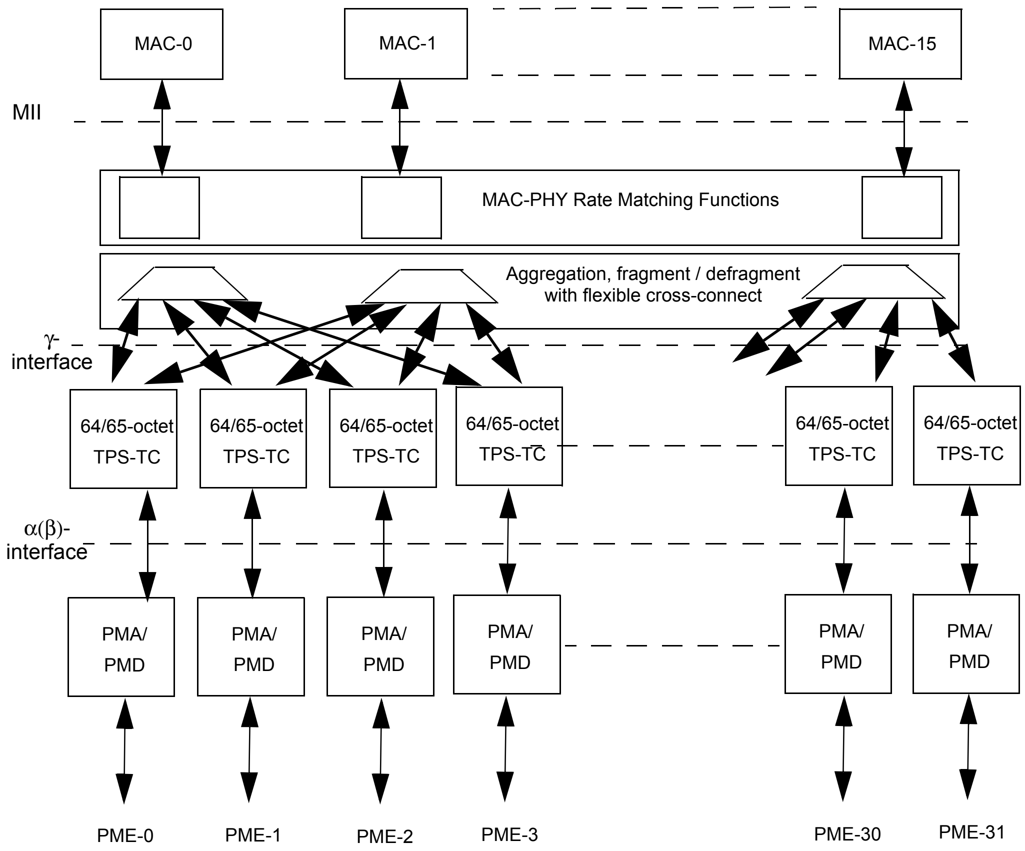


Figure 61–5—4 PME for each 2 MII connectivity

Table 61–3—PME_Available_register contents (example c)[a]

PME_Available_register	Contents
0.3.62 / 63	b11111111_11111111_11111111_00000000
1.3.62 / 63	b11111111_11111111_11111111_00000000
etc.	etc.
11.3.62/ 63	b11111111_11111111_11111111_00000000

[a] A mapping in which the same PME is available for connection to several PCS instances (as shown) is only allowed at the CO-side.

61.1.5.3.3 Setting PME aggregation connection

The PME aggregation connection is set using the PME_Aggregate_register (see 45.2.3.28). This register is writeable for each PCS instance (*x*) at register addresses *x*.3.64 and *x*.3.65. A bit is set in this register corresponding to the PME address for each PME that is to be aggregated through that PCS. Some examples are given that show register contents and connectivity for some popular configurations:

a) Simple two PME per MII connections (as shown in example a above), the first MII aggregates 2 PMEs, the second MII only connects through 1 PME, as does the sixteenth. PME_Aggregate_register contents are shown in Table 61–4.

b) Pairs of 4-to-1 connections (as shown in example b above), the first MII aggregates 3 PMEs, the second MII only connects through 1 PME, the sixteenth MII aggregates 2 PMEs. PME_Aggregate_register contents are shown in Table 61–5.

c) 24-to-12 fully flexible connections (as shown in example c above), the first MII aggregates 5 PMEs, the second MII only connects through the 24th PME, the eleventh MII is not used, twelfth MII aggregates 2 PMEs. PME_Aggregate_register contents are shown in Table 61–6.

Table 61–4—PME_Aggregate_register contents (example a)

PME_Aggregate_register	Contents
0.3.64 / 65	b11000000_00000000_00000000_00000000
1.3.64 / 65[a]	b00010000_00000000_00000000_00000000
etc.	etc.
15.3.64 / 65	b00000000_00000000_00000000_00000010

[a] The PME Aggregation functions have to be performed when PAF_enable is set, even if only 1 bit is set in the PME_Aggregate_register.

Table 61–5—PME_Aggregate_register contents (example b)

PME_Aggregate_register	Contents
0.3.64 / 65	b11100000_00000000_00000000_00000000
1.3.64 / 65[a]	b00010000_00000000_00000000_00000000
etc.	etc.
15.3.64 / 65	b00000000_00000000_00000000_00000110

[a] The PME Aggregation functions have to be performed when PAF_enable is set, even if only 1 bit is set in the PME_Aggregate_register.

Table 61–6—PME_Aggregate_register contents (example c)

PME_Aggregate_register	Contents
0.3.64 / 65	b11111000_00000000_00000000_00000000
1.3.64 / 65[a]	b00000000_00000000_00000001_00000000
etc.	etc.
10.3.64 / 65	b00000000_00000000_00000000_00000000
11.3.64 / 65	b00000000_00000000_00000110_00000000

[a] The PME Aggregation functions have to be performed when PAF_enable is set, even if only 1 bit is set in the PME_Aggregate_register.

61.1.5.4 Support for handshaking

It is the goal of the ITU-T that all specifications for digital transceivers for use on public telephone network copper subscriber lines use ITU-T G.994.1 for startup. ITU-T G.994.1 procedures allow for a common startup mechanism for identification of available features, exchange of capabilities and configuration information, and selection of operating mode. As the two loop endpoints are usually separated by a large distance (e.g., in separate buildings) and often owned and installed by different entities, ITU-T G.994.1 also aids in diagnosing interoperability problems. ITU-T G.994.1 codespaces have been assigned by ITU-T to ATIS T1, ETSI, and IEEE 802.3 in support of this goal.

The description of how ITU-T G.994.1 procedures are used for Ethernet in the First Mile handshaking and PHY control are contained in 61.4.

61.2 PCS functional specifications

61.2.1 MAC-PHY Rate Matching functional specifications

61.2.1.1 MAC-PHY Rate Matching functions

The PHY shall use CRS to match the MAC's faster rate of data transmission to the PHY's slower rate.

Upon receipt of a MAC frame on the MII, the PHY shall discard the Preamble and SFD fields, and transmit the resulting data frame across the physical link.

The PHY shall prepend the Preamble and the SFD fields to a received frame before sending it to the MAC.

The PHY shall support a mode of operation where it does not send data to the MAC while the MAC is transmitting (see MII receive during transmit register, defined in 45.2.3.26).

If the PAF is disabled or not present, transmit frames shall not be forwarded to the TC sublayer unless TC_link_state is true for the whole frame. If the PAF is enabled, transmit fragments shall not be forwarded from the PAF to a TC sublayer unless the TC_link_state value of that TC sublayer instance is true for the whole fragment.

NOTE—This implies that in the absence of an active PAF, frames being transmitted over the MII when TC_link_state becomes true are never forwarded to the TC sublayer. A frame being transmitted over the MII when TC_link_state becomes false is aborted.

61.2.1.2 MAC-PHY Rate Matching functional interfaces

61.2.1.2.1 MAC-PHY Rate Matching – MII signals

MII signals are defined in 22.2.2 and listed in Table 23–1 in 23.2.2.1.

COL shall be forced to logic zero by the PCS.

CRS behaves as defined in 61.2.1.3.2.

61.2.1.2.2 MAC-PHY Rate Matching–Management entity signals

See 61.2.3.

61.2.1.3 MAC-PHY Rate Matching state diagrams

61.2.1.3.1 MAC-PHY Rate Matching state diagram constants

No constants are defined for the MAC-PHY rate matching state diagrams.

61.2.1.3.2 MAC-PHY Rate Matching state diagram variables

CRS
: CRS signal of the MII as specified in Clause 22. It is asserted when either of crs_tx or crs_rx are true: CRS ⇐ crs_tx + crs_rx

crs_and_tx_en_infer_col
: True if a reduced-pin MAC-PHY interface is present that infers a collision when TX_EN and CRS are both true simultaneously.

crs_rx
: Asserted by the MAC-PHY rate matching receive state diagram to control CRS

crs_tx
: Asserted by the MAC-PHY rate matching transmit state diagram to control CRS

power_on
: 'power_on' is true while the device is powering up. It becomes false once the device has

reached full power. Values:
FALSE; The device is completely powered (default).
TRUE; The device has not been completely powered.

Reset
True when the PCS is reset via control register bit 3.0.15.

RX_DV
RX_DV signal of the MII as specified in Clause 22

rx_frame_available
Set when the PHY's receive FIFO contains one or more complete frames

transferFrameCompleted
Variable of type Boolean
TRUE if the transmission of the received frame over the MII has been completed,
FALSE otherwise.
The variable returns to the default state (FALSE) upon entry into any state.

tx_buffer_available
Set when the PHY's transmit FIFO has space to receive a maximum length packet from the MAC

TX_EN
TX_EN signal of the MII as specified in Clause 22

tx_rx_simultaneously
False if the MAC is configured in half duplex mode to support deference and it is not capable of transmitting and receiving simultaneously in this mode.

61.2.1.3.3 MAC-PHY Rate Matching state diagram timers

ipg_timer
Timer used to generate a gap between receive packets across the MII.
Duration: 960 ns, tolerance ±100 ppm.

rate_matching_timer
Timer used in rate matching state diagram
Duration: 1120 ns, tolerance ±100 ppm.

The rate_matching_timer operates in a manner consistent with 14.2.3.2. The timer is restarted on entry to the WAIT_FOR_TIMER_DONE state with the action: 'Start rate_matching_timer'. It is then tested in the exit condition with the expression "rate_matching_timer_done".

The duration is set to 1120 ns to allow 960 ns for the inter frame gap plus 160 ns for the MAC to recognize CRS. 160 ns is equivalent to 16 bit times and is consistent with the assumptions about MAC performance listed in Table 21–2 in 21.7.

61.2.1.3.4 MAC-PHY Rate Matching state diagram functions

transferFrame()
This function transmits a packet to the MAC across the MII, according to the MII protocol as described in 22.2. This function generates RX_DV to delimit the frame in accordance with 22.2.2.6. Upon completion of frame transfer to the MAC, this function sets the variable transferFrameCompleted to TRUE.

61.2.1.3.5 MAC-PHY Rate Matching state diagrams

The state diagrams for the MAC-PHY Rate Matching functions are shown in Figure 61–6, Figure 61–7, and Figure 61–8.

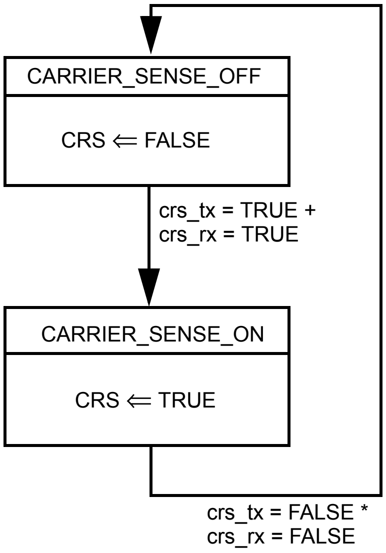


Figure 61–6—Carrier Sense state diagram

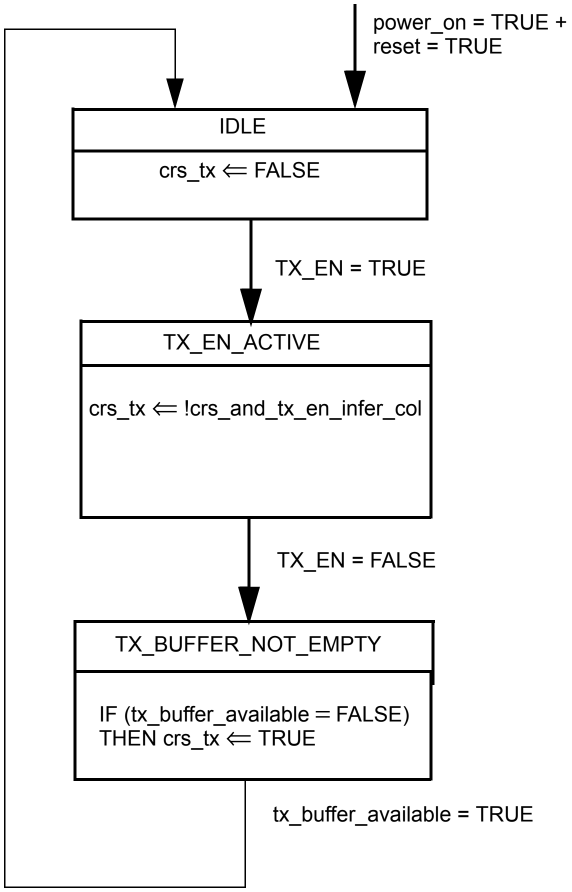


Figure 61–7—MAC-PHY rate matching transmit state diagram

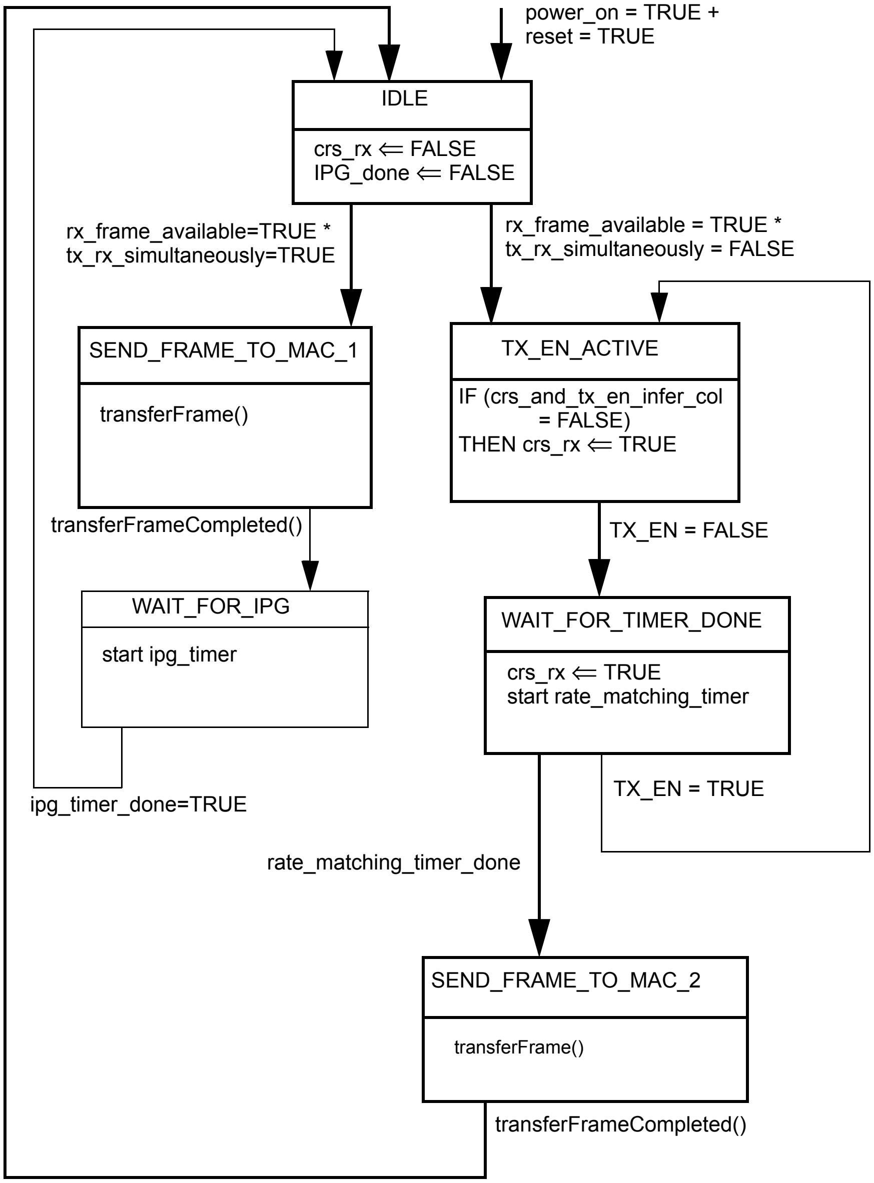


Figure 61–8—MAC-PHY rate matching receive state diagram

61.2.2 PME Aggregation functional specifications

This subclause defines an optional PME Aggregation Function (PAF) for use with Ethernet MACs in EFM copper PHYs. PME Aggregation allows one or more PMA/PMDs to be combined together to form a single logical Ethernet link.

The PAF is located between the MAC-PHY Rate Matching function and the TC sublayer as shown in Figure 61–2. The PAF interfaces with the TC sublayer instances across the γ-interface. The PAF interfaces to the MAC-PHY Rate Matching function using an abstract interface whose physical realization is left to the implementer, provided the requirements of this standard are met.

The PME Aggregation function has the following characteristics:

a) Supports aggregation of up to 32 PMA/PMDs
b) Supports individual PMA/PMDs having different data rates
c) Ensures low packet latency and preserves packet sequence
d) Scalable and resilient to PME failure
e) Independent of type of EFM copper PHY
f) Allows vendor discretionary algorithms for fragmentation

61.2.2.1 PAF Enable and Bypass

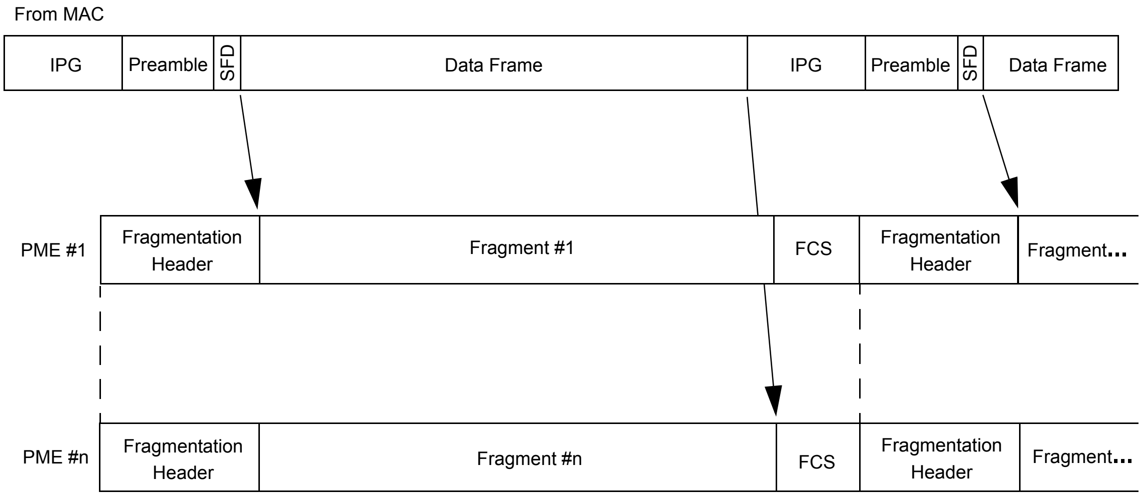
For systems that do not have the ability to aggregate loops PAF_available will not be asserted. Additionally, a system may have PAF_available asserted but PAF_enable will be deasserted to indicate that aggregation is not activated.

In both of these cases, the entire data frame is passed across the γ-interface to the TC sublayer without any fragmentation and without fragmentation header. On the receive end, entire data frames are transferred from the γ-interface to the MAC-PHY rate matching function without any reference to the PAF error detecting rules (see 61.2.2.7). If an error has been detected by the FCS in the TC then the MAC-PHY rate matching function shall assert RX_ER during at least one octet of the frame across the MII.

Systems that have the ability to aggregate but are not enabled for aggregation will have the connectivity between the PCS and one PME set either by default, by local management (for CO-subtype devices) or by remote management (for CPE-subtype devices). This will define which γ-interface is used for the transfer of non-fragmented frames. Refer to 61.2.2.8.3 for the function of PAF_available and PAF_enable and Clause 45 for access to these registers.

61.2.2.2 PME Aggregation functions

The PME Aggregation functions provide a fragmentation procedure at the transmitter and a reassembly procedure at the receiver. The fragmentation and reassembly procedures take a data frame and partition it into one or more fragments as shown in Figure 61–9. Each fragment is given a fragmentation header and transmitted over a specific TC sublayer instance. A Frame Check Sequence, known as the TC-CRC, is added to each fragment by the TC sublayer. The fragmentation header has the format shown in Figure 61–10. Short data frames can be transported over a single fragment, and consequently both StartOfPacket and EndOfPacket can be set to ‘1’ simultaneously.



NOTE—This is one example of how a frame may be fragmented across multiple PMEs.

Figure 61–9—Data frame fragmentation

SequenceNumber (14 bits)	StartOfPacket (1 bit)	EndOfPacket (1 bit)	Fragment Data

Figure 61–10—Fragment format

61.2.2.3 PME Aggregation Transmit function

The PME Aggregation transmit functions uses the following algorithm:

a) Select an active PME (i.e., one with TC_link_state asserted, see 61.3.1) for the next transmission.
b) Select the number of octets to transmit on that PME (shall not be less than minFragmentSize nor greater than maxFragmentSize, see 61.2.2.6).
c) Increment by one (modulo 2^{14}) and set fragment sequence number in the Fragmentation Header. There is a single sequence number stream for each aggregation, not one per PME. It is this sequence number stream that the receiver uses for fragment reassembly.
d) Set the start-of-packet and end-of-packet bits in the Fragmentation Header as appropriate.
e) Transmit fragment to the TC sublayer.

It is important to note that the selection of the next PME to use in transmission [step a)] and the number of octets to transmit [step b)] is implementation dependent. However, implementations shall follow the restrictions as outlined in 61.2.2.6.

61.2.2.4 PME Aggregation Receive function

The PME aggregation receive function requires per-PME queues as well as a per-MAC fragment buffer for fragment reassembly. The algorithm assumes only “good” fragments are placed on the per-PME receive queues (“bad” fragments are discarded according to the rules in 61.2.2.7).

The sequence number rolls over after it reaches the maximum value, thus all sequence number comparisons shall use “split horizon” calculations. Split horizon calculations are defined for comparisons that are valid for numbers that roll over after reaching the maximum value. Generically, “x is less than y” is defined as $x < y \le x + (\text{maxSequenceNumber}+1)/2$.

61.2.2.4.1 Expected sequence number

During initial start-up and in the event of certain errors, the receive algorithm has to determine which sequence number is expected next (expectedFragmentSequenceNumber). When the link state is changed to UP, the expected sequence number is unknown and no errors in fragment sequencing (see 61.2.2.7.2) shall be recorded.

61.2.2.4.2 PME Aggregation Receive function state diagram variables

The following variables are used in the PME Aggregation Receive function state diagram.

allQueuesNonEmpty
  variable of type Boolean that indicates whether any active queue is currently empty.
  TRUE if none of the active queues is currently empty
  FALSE if at least one active queue is currently empty

expectedFragmentSequenceNumber
  the sequence number expected in the receive process that would not result in a fragment error, initialized to the smallest sequence number of fragments at the head of per-PME queues when either all active queues are non-empty or at least one queue has been non-empty for maxDifferentialDelay bit times at the bit rate of the PMD associated with that queue

frameLengthOverflow
  variable of type Boolean, indicating that the reassembly buffer is overflowing due to a received frame that is too long, as described in 61.2.2.7.3.

TRUE if the overflow condition exists
FALSE during normal operation

missingStartOfPacket
variable of type Boolean, indicating that a fragment was received with the StartOfPacket bit deasserted while the packet assembly function was between frames (i.e., waiting for a Start of Packet).

nextFragmentSequenceNumber
smallest sequence number of fragments at the head of per-PME queues

noFragmentProcessed_Timer
variable of type Boolean that indicates whether at least one active queue has been non-empty for maxDifferentialDelay bit times at the bit rate of the PMD associated with that queue. Each fragment processed on any queue restarts all per-queue timers.
TRUE if a timeout of maxDifferentialDelay bit times has expired
FALSE if the timeout of maxDifferentialDelay bit times has not yet expired

oneQueueNonEmpty_Timer
variable of type Boolean that indicates whether at least one active queue has been non-empty for at least maxDifferentialDelay bit times.
TRUE if at least one active queue has been non-empty for at least maxDifferentialDelay bit times
FALSE otherwise

smallestFragmentSequenceNumber
smallest sequence number of fragments at the head of per-PME queues

unexpectedEndOfPacket
variable of type Boolean, indicating that a fragment was received with the EndOfPacket bit asserted and the StartofPacket bit deasserted while the packet assembly function was between frames (i.e., waiting for a Start of Packet)

unexpectedStartOfPacket
variable of type Boolean, indicating that a fragment is received with the StartOfPacket bit asserted while the packet assembly function was mid-frame (i.e., waiting for an End of Packet)

The following functions are used in the PME Aggregation Receive function state diagram.

errorDetection()
function comprising the process described in 61.2.2.7.2

fragmentError()
function comprising the process described in 61.2.2.7.3

61.2.2.4.3 PME Aggregation Receive function state diagram

The receive function executes the algorithm as shown in Figure 61–11. The initial state of the state diagram is INITIALIZING. This state is entered when at least one TC_link_state is asserted for the first time after system power-on, and each time when at least one TC_link_state is asserted after all having been deasserted for any reason.

61.2.2.4.4 PME Aggregation Receive function state diagram description

Aggregation receive algorithm is as follows:

a) Determine the nextFragmentSequenceNumber via the algorithm in 61.2.2.4.1.
b) If the nextFragmentSequenceNumber is equal to the expectedFragmentSequenceNumber, process that fragment and continue to step c). If (nextFragmentSequenceNumber is less than expectedFragmentSequenceNumber) or (all the active PME queues are non-empty and nextFragmentSequenceNumber ≠ expectedFragmentSequenceNumber) or (any PME queue has been non-empty for maxDifferentialDelay bit times without any fragment being processed) follow the fragment sequence error handling rules described in 61.2.2.7.2 before returning to normal fragment processing.

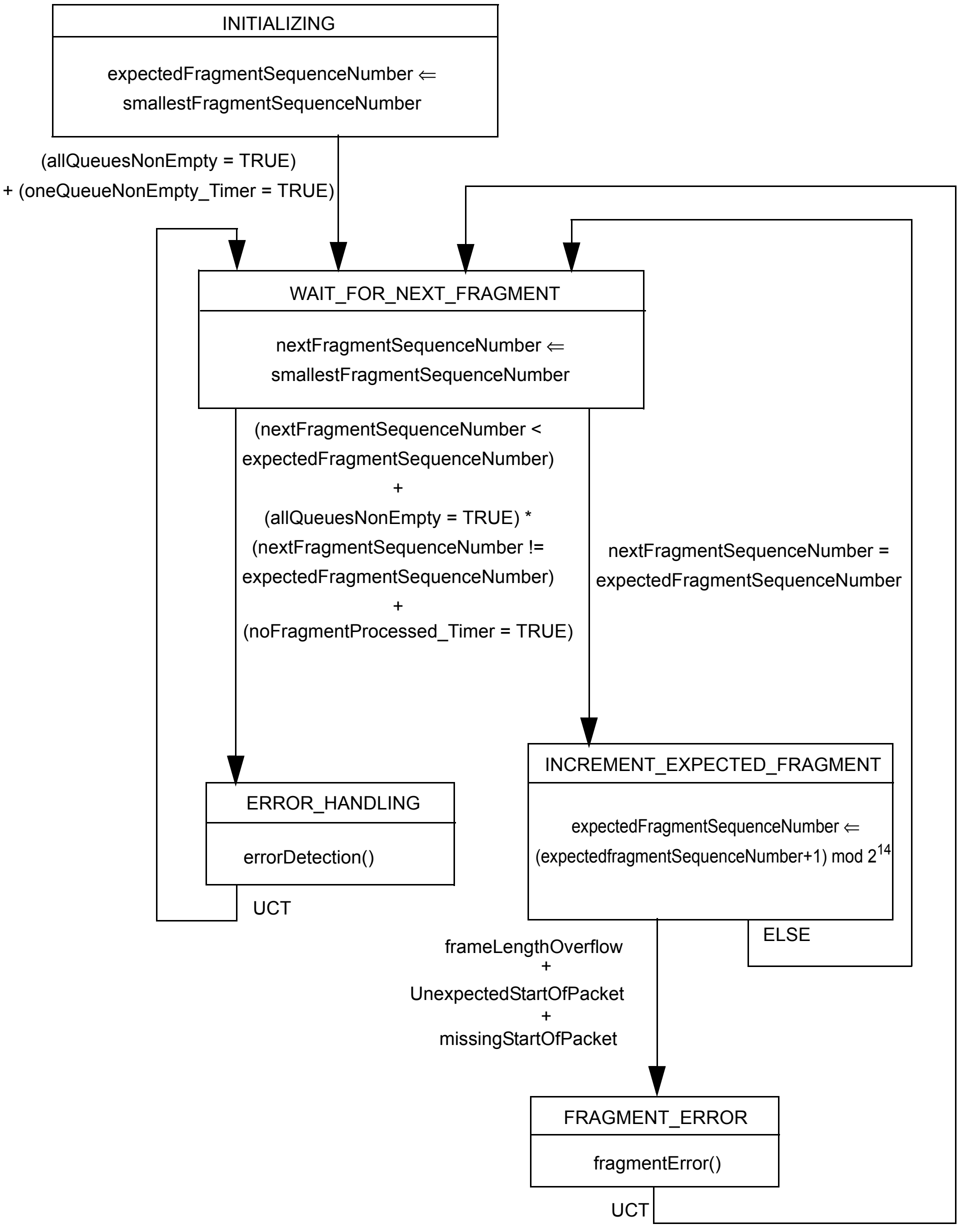


Figure 61–11—Aggregation receive function

c) Accept the fragment into the fragment buffer. If (accepting the fragment into the fragment buffer causes a frame length overflow) or (the fragment is an unexpected start of packet) or (the fragment is an unexpected end of packet) or (the fragment has the StartOfPacket bit deasserted when the start of a new packet is expected) then follow the error handling procedures described in 61.2.2.7.3. Else if that fragment is an end-of-packet, pass the packet to the MAC-PHY Rate Matching layer.
d) Increment (modulo 2^{14}) the expectedFragmentSequenceNumber.
e) Repeat processing.

61.2.2.5 PME Aggregation restrictions

In order to guarantee correct receiver operation, a transmitter must ensure that pairs in an aggregate group obey certain restrictions.

NOTE 1—These restrictions ensure that buffer sizes for receivers of 2^{14} bits per PME are sufficient.

One factor is the differential latency between multiple PMEs in an aggregated group. Differential latency measures the variation in the time required to transmit across different PMEs. To normalize the latency measurement for high and low speed links it is measured in bit times. A differential latency between two PMEs is defined as the number of bits, N, that can be sent across the fast link, in the time that it takes one maxFragmentSize fragment to be sent across the slow link. Large differential latencies generate greater variance in bit delivery times across aggregated PMEs, which in turn require large sequence number ranges. The PMD control of aggregated links controls the maximum latency difference between any two aggregated links. This is achieved by configuring the bit rate, error correction and interleaving functions in the PMA/PMD of each link. The burst noise protection offered by the error correction and interleaving[10] functions is directly proportional to the latency, therefore it is logical that multiple aggregated links in the same environment should be optimized to have similar latencies. Differences in electrical length will not contribute significantly to the differential latency; no additional per-PME buffer size is required for this variation.

NOTE 2—The value for differential latency for two identical links will be 4096 bit times because the definition includes the length of a maximum size fragment.

The speed ratio of the links also restricts what PMEs can be aggregated together. The speed ratio is defined as the ratio of the bit rate of the faster link divided by the bit rate of the slower link.

The restrictions that govern which PMEs can be aggregated are as follows:

a) The differential latency between any two PMEs in an aggregated group shall be no more than maxDifferentialDelay.
b) The highest ratio of speeds between any two aggregated links shall be maxSpeedRatio. A speed ratio of 4 may only be used if the latency is controlled to meet the restriction.

Table 61–7 specifies the values for constants maxDifferentialDelay and maxSpeedRatio.

Table 61–7—PME Aggregation constants

Constant name	Value
maxDifferentialDelay	15 000 bit times
maxSpeedRatio	4

61.2.2.6 PME Aggregation transmit function restrictions

There are factors that limit the freedom of the transmission algorithm specified in 61.2.2.3.

A first factor is the size of the fragments being transmitted across the PMEs. Very small fragments require larger sequence number ranges as there can be more fragments within the same number of bit times.

Another restriction on the size of the fragments, is that fragments shall be a multiple of 4 octets in size when possible.

The restrictions for the transmission algorithm in 61.2.2.3 are:

a) Fragments shall not be less than minFragmentSize not including PAF header.

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[10] Interleaving is the relevant issue here, since it affects latency. While 2BASE-TL does not have block error correction, it does use trellis coding, which is sometimes considered forward error correction.

b) Fragments shall not be more than maxFragmentSize not including PAF header.
c) The fragment size, not including PAF header, shall be a multiple of 4 octets except for the last fragment of a data frame.

NOTE—A fragment size of maxFragmentSize may only be used if the latency is controlled to meet the restriction a) in 61.2.2.5.

These restrictions allow the use of a 14-bit sequence number space. As a consequence, the maximum sequence number is $2^{14} – 1$ (maxSequenceNumber).

Table 61–8 specifies the values for constants maxFragmentSize and minFragmentSize.

Table 61–8—Fragment size constants

Constant name	Value
maxFragmentSize	512 octets
minFragmentSize	64 octets

61.2.2.7 Error-detecting rules

There are three classes of error detected by the PAF: Errors during fragment reception; Errors in fragment sequencing; and Errors during packet reassembly. In the case of an error detected by the PAF, it sends the frame or part of frame to the MAC with RX_ER asserted. When the PAF is unable to reconstruct or partially reconstruct a frame due to such errors, it sends a garbage frame up to the MAC, in order to allow higher-layer event counters to register the error. The garbage frame shall consist of 64 octets of 00 (including CRC). Preamble and SFD are prepended before the frame is sent to the MII according to 61.2.1.1.

The rules described in this subclause are applied by the functions errorDetection() and fragmentError() referenced in Figure 61–11.

61.2.2.7.1 Errors during fragment reception

The receive TC function passes all decapsulated fragments to the PAF across the γ-interface. If the TC detects an error in the encapsulation, it asserts Rx_Err on the γ-interface. If the TC detects an error in the TC-CRC, it asserts Rx_Err on the γ-interface. Asserting Rx_Err during fragment reception invalidates the entire fragment.

For each PMA α(β)-interface, the per-PMA buffering mechanism shall discard the fragment if any of the following conditions occur:

a) Rx_Err is asserted during the reception of the fragment across the γ-interface.
b) The fragment is too small — less than minFragmentSize as defined in 61.2.2.6.
c) The fragment is too large — more than maxFragmentSize as defined in 61.2.2.6.
d) The fragment would cause the per-PMA received buffer to overflow.

The PAF shall then assert one of the following per-PMA error flags as appropriate:

- TC_PAF_RxErrorReceived
- TC_PAF_FragmentTooSmall
- TC_PAF_FragmentTooLarge
- TC_PAF_Overflow

61.2.2.7.2 Errors in fragment sequencing

If nextFragmentSequenceNumber is outside the range (expectedFragmentSequenceNumber through expectedFragmentSequenceNumber + (maxSequenceNumber+1)/2) then assert PAF_BadFragmentReceived. Discard the fragment, do not increment ExpectedFragmentSequenceNumber.

If all active PMA buffers are non empty and nextFragmentSequenceNumber is greater than expectedFragmentSequenceNumber then assert PAF_LostFragment, set expectedFragmentSequenceNumber equal to nextFragmentSequenceNumber.

If any PMA buffer is non empty for maxDifferentialDelay bit times (for that PMA/PMD) and no fragment is transferred then assert PAF_LostFragment, set expectedFragmentSequenceNumber equal to nextFragmentSequenceNumber.

Having detected one of the above fragment sequencing errors, the packet assembly function shall act as follows:

- If the packet assembly function was mid-frame (i.e., waiting for an End of Packet), the first part of the frame shall be transferred across the MII, then assert RX_ER signal on the MII, abort frame transfer and flush PMA buffers until the next Start of Packet is received.
- If the packet assembly function was between frames (i.e., waiting for a Start of Packet), assert RX_ER signal on the MII and send a garbage frame as defined in 61.2.2.7 to the MAC.

61.2.2.7.3 Errors in packet reassembly

If a fragment is received with the StartofPacket bit deasserted while the packet assembly function was between frames (i.e., waiting for a Start of Packet), discard the offending fragment, assert RX_ER signal on the MII and send a garbage frame as defined in 61.2.2.7 to the MAC. Assert PAF_LostStart.

If a fragment is received with the StartOfPacket bit asserted while the packet assembly function was mid-frame (i.e., waiting for an End of Packet), the first part of the frame shall be transferred across the MII, then assert RX_ER signal on the MII, abort frame transfer and flush the PMA buffers, starting the next frame with the Start of Packet fragment just received. Assert PAF_LostEnd.

If a fragment is received while the packet assembly function was mid-frame (i.e., waiting for an End of Packet) and would cause the frame size to exceed the maximum supported frame size (see 4.2.4.2.1) then the first part of the frame, excluding the error causing fragment, shall be transferred across the MII, then assert RX_ER signal on the MII, abort frame transfer and flush PMA buffers until the next Start of Packet is received. Assert PAF_LostEnd.

61.2.2.8 PME aggregation functional interfaces

The PAF interfaces with the TC sublayer instances across the γ-interface. The PAF interfaces to the MAC-PHY Rate Matching function using an abstract interface whose physical realization is left to the implementer, provided the requirements of this standard are met.

61.2.2.8.1 PME aggregation–γ-interface signals

The PAF interfaces with the PMA/PMDs across the γ-interface. The γ-interface specification is defined in 61.3.1. This subclause specifies the data, synchronization and control signals that are transmitted between the TC sublayer and the PAF.

61.2.2.8.2 PME aggregation–management entity signals

The management entity signals pertaining to PME aggregation are specified in 61.2.3.

61.2.2.8.3 PME aggregation register functions

If an MDIO interface is provided (see Clause 22 and Clause 45), PME aggregation registers are accessed via that interface. If not, it is recommended that an equivalent access be provided.

Clause 45 defines one bit each in the EFM 10P/2B capability register and the 10P/2B PCS control register to control the PAF function (see 45.2.3.25 and 45.2.3.26 respectively). PAF_available is used to indicate that the system has the capability to aggregate PMEs, PAF_enable is used to control whether this ability is enabled or not. In all cases, the PAF_available bit is read-only; the PAF_enable bit is read-only when the PAF_available bit is not asserted.

For CO-subtype devices, both the PAF_available and the PAF_enable bits are only accessible locally, the PAF_enable bit is writeable.

For CPE-subtype devices, both the PAF_available and the PAF_enable bits are locally read only and remotely readable. Additionally, the PAF_enable bit is remotely writeable.

Clause 45 defines access to two registers which relate to the PME aggregation function: the PME_Available_register (see 45.2.3.27) and the PME_Aggregate_register (see 45.2.3.28). Additionally the remote_discovery_register and Aggregation_link_state_register shall be implemented.

NOTE—The remote_discovery_register is a variable which is defined for CPE-subtypes only. It is used during the PME aggregation discovery process. The Aggregation_link_state_register is a variable with significance for the PCS only. These variables have no associated management interface registers.

The PME_Available_register is read-only for CO-subtype and may be writeable for CPE-subtype (in order to restrict CPE-subtype connection capability according to 45.2.3.27). It indicates whether an aggregateable link is possible between this PCS and multiple PMDs. For a device that does not support aggregation of multiple PMEs, a single bit of this register shall be set and all other bits clear. The position of bits indicating aggregateable PME links correspond to the PMA/PMD sub-address defined in Clause 45.

For CPE-subtype devices, the PME_Available_register may optionally be writeable by the local management entity. The reset state of the register reflects the capabilities of the device. The management entity (through Clause 45 access) may clear bits which are set, in order to limit the mapping between MII and PME for PME aggregation. For CPE-subtype devices, PMD links shall not be enabled (such that it shall not respond to or initiate any G.994.1 handshaking sessions, on any of its PMEs) until the PME_Available register has been set to limit the connectivity such that each PME maps to at most one MII (see 45.2.3.27). This condition is necessary so that remote commands from the network-end which affect PCS registers have a defined target. PMDs that are not associated to any PCS shall not respond to or initiate any G.994.1 handshaking signals. Multiple PMEs per MII are allowed.

The PME_Aggregate_register is defined in Clause 45. For CO-subtype devices, access to this register is through Clause 45 register read and write mechanisms. For CPE-subtype devices the register may be read locally through Clause 45, and reads and writes shall be allowed from remote devices via the remote access signals passed across the γ-interface from the PMA (see 61.3.1). The operation of the PME_Aggregate_register for CPE-subtype devices is defined as follows:

a) If the remote_discovery_register is clear then the PME_Aggregate_register shall be cleared.
b) If write_remote_Aggregation_reg is asserted, the contents of remote_write_data bit zero is written to PME_Aggregate_register in the bit location corresponding to the PMA/PMD from which the request was received. Acknowledge_read_write is asserted for one octet clock cycle.
c) If read_remote_Aggregation_reg is asserted, the contents of PME_Aggregate_register are placed onto remote_read_data_bus, bits 31 through 0. Unsupported bits are written as zero if the full width of PME_Aggregate_register is not supported. Acknowledge_read_write is asserted for one octet clock cycle.

61.2.2.8.4 PME aggregation discovery register functions

The remote_discovery_register shall be implemented for CPE-subtype devices. The remote_discovery_register shall support atomic write operations and reads from remote devices via the remote access signals passed across the γ-interface from the PMA (see 61.3.1). The operation of the remote_discovery_register for CPE-subtype devices is defined as follows:

a) If read_remote_discovery_reg is asserted, which corresponds to a "Get" command as described in 61.4.7.1, the contents of remote_discovery_register are placed onto remote_read_data_bus. Acknowledge_read_write is asserted for one octet clock cycle[11].
b) If write_remote_discovery_reg is asserted, which corresponds to a "Set if Clear" command as described in 61.4.7.1, the action depends on the contents of remote_discovery_register. If the remote_discovery_register is currently clear (no bits asserted), the contents of the remote_write_data bus are placed into the remote_discovery_register. The new contents of remote_discovery_register are placed on the remote_read_data_bus. Acknowledge_read_write is asserted for one octet clock cycle. Else if the remote_discovery_register is not currently clear (any bit asserted), no data is written. The old contents of remote_discovery_register are placed on the remote_read_data_bus. NAcknowledge_read_write is asserted for one octet clock cycle. If multiple write_remote_discovery_reg signals are asserted (from multiple γ-interfaces) they shall be acted upon serially.
c) If clear_remote_discovery_reg is asserted, which corresponds to a "Clear if Same" command as described in 61.4.7.1, the action depends on the contents of remote_discovery_register. If the contents of the remote_write_data bus match that of the remote_discovery_register, the remote_discovery_register is cleared, the PME_Aggregate_register is cleared, the new contents of remote_discovery_register are placed on the remote_read_data_bus, and Acknowledge_read_write is asserted for one octet clock cycle. If the contents of the remote_write_data bus do not match that of the remote_discovery_register, the remote_discovery_register is unchanged; its contents are placed on the remote_read_data_bus; and NAcknowledge_read_write is asserted for one octet clock cycle.
d) If the logical AND of the Aggregation_link_state_register and the PME_Aggregate_register is clear then a timeout counter shall be started. If this condition continues for 30 seconds (the timeout period) then the remote_discovery_register shall be cleared.

A single device may be implemented which has multiple MIIs and (therefore) multiple PCS instances. There shall be one remote_discovery_register per PCS instance. The PME_Available_register shall be set prior to the enabling of links so that each PMA/PMD is linked to only one PCS. Access to the remote_discovery_register (read or write) shall be restricted to PMA/PMD instances for which the corresponding PME_Available_register bit is asserted.

The Aggregation_link_state_register is a pseudo-register corresponding to the TC_link_state bits from each γ-interface in the appropriate bit positions according to the PMA/PMD from which the signal is received. Bits corresponding to unsupported aggregation connections are zero.

The remote access mechanisms for the PME aggregation registers are defined in 61.4.7.

61.2.3 PCS sublayer: Management entity signals

The management interface has pervasive connections to all functions. Operation of the management control lines MDC and MDIO is specified in Clause 22 and Clause 45, and requirements for managed objects inside the PCS and PMA are specified in Clause 30.

The following MAC-PHY Rate Matching function signals are mapped to Clause 45 registers:

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[11] If the CPE device fails to respond, NAcknowledge_read_write is asserted with remote_read_data_bus set to 000000000000_{16}.

tx_rx_simultaneously

this signal is asserted by the management entity to indicate that the MAC which is connected to the PHY is capable of receiving and transmitting simultaneously while in half-duplex mode. The corresponding register ("MII receive during transmit") is defined in 45.2.3.26.

crs_and_tx_en_infer_col

this signal is asserted by the management entity to indicate that the MAC uses simultaneous detection of TX_EN and CRS to infer a collision. This signal is used in the rate matching state diagrams (Figure 61–7 and Figure 61–8). The corresponding register ("TX_EN and CRS infer a collision") is defined in 45.2.3.26.

The following PAF signals are mapped to Clause 45 registers or cause Clause 45 counters to increment:

PAF_available

this signal indicates to the management whether the PAF function is available for use. The corresponding register is defined in 45.2.3.25.1.

PAF_enable

this signal is asserted by the management entity to indicate that the PAF function is enabled. The corresponding register is defined in 45.2.3.26.3.

TC_PAF_RxErrorReceived

(for each PMA, γ-interface) this signal is asserted to indicate that a fragment has been received across the γ-interface with Rx_Err asserted. The errored fragment has been discarded. The corresponding register is defined in 45.2.3.29.

TC_PAF_FragmentTooSmall

(for each PMA, γ-interface) this signal is asserted to indicate that a fragment has been received across the γ-interface that was smaller than the minFragmentSize defined. The errored fragment has been discarded. The corresponding register is defined in 45.2.3.30.

TC_PAF_FragmentTooLarge

(for each PMA, γ-interface) this signal is asserted to indicate that a fragment has been received across the γ-interface that was larger than the maxFragmentSize defined. The errored fragment has been discarded. The corresponding register is defined in 45.2.3.31.

TC_PAF_Overflow

(for each PMA, γ-interface) this signal is asserted to indicate that a fragment has been received across the γ-interface that would have caused the receive buffer to overflow. The errored fragment has been discarded. The corresponding register is defined in 45.2.3.32.

PAF_BadFragmentReceived

this signal is asserted to indicate that a fragment has been received that does not fit into the sequence expected by the frame assembly function. The errored fragment has been discarded and the frame buffer flushed to the next valid frame start. The corresponding register is defined in 45.2.3.33.

PAF_LostFragment

this signal is asserted to indicate that a fragment (or fragments) expected according to sequence has not been received by the frame assembly function. The missing fragment (or fragments) has been skipped and the frame buffer flushed to the next valid frame start. The corresponding register is defined in 45.2.3.34.

PAF_LostStart

this signal is asserted to indicate that the packet reassembly function did not receive a StartOf Packet indicator in the appropriate sequence. The corresponding register is defined in 45.2.3.35.

PAF_LostEnd

this signal is asserted to indicate that the packet reassembly function did not receive an EndOfPacket indicator in the appropriate sequence. The corresponding register is defined in 45.2.3.36.

PCS_link_state

this signal is asserted to indicate that at least one TC_link_state in the assigned aggregation group is up.

Additionally, the following PAF register is mapped to a Clause 45 register:

remote_discovery_register

this register is implemented in CPE-subtype devices. It is written or read by the PME via the γ-interface. The PME relays this information to and from the associated CO-subtype device via the handshake messages described in 61.4.7. The CO-subtype device interprets the contents of the remote_discovery_register to determine which remote PMEs connect to the same PCS and may be aggregated. The corresponding Clause 45 register is defined in 45.2.6.6.1.

61.3 TC sublayer functional specifications

The functional model of the TC sublayer is presented in Figure 61–12. The term "TPS-TC" (Transport Protocol Specific - Transmission Convergence) is used in ITU-T Recommendation G.993.1. In this context the term "TC" (Transmission Convergence) is sufficient as no other types of TC are defined in this subclause (e.g., PMS-TC).

Because the PAF function is optional, either entire data frames or data frame fragments may be passed across the γ-interface. In this section, the term "fragment" will be used to describe either fragments or data frames depending on the existence of the PAF.

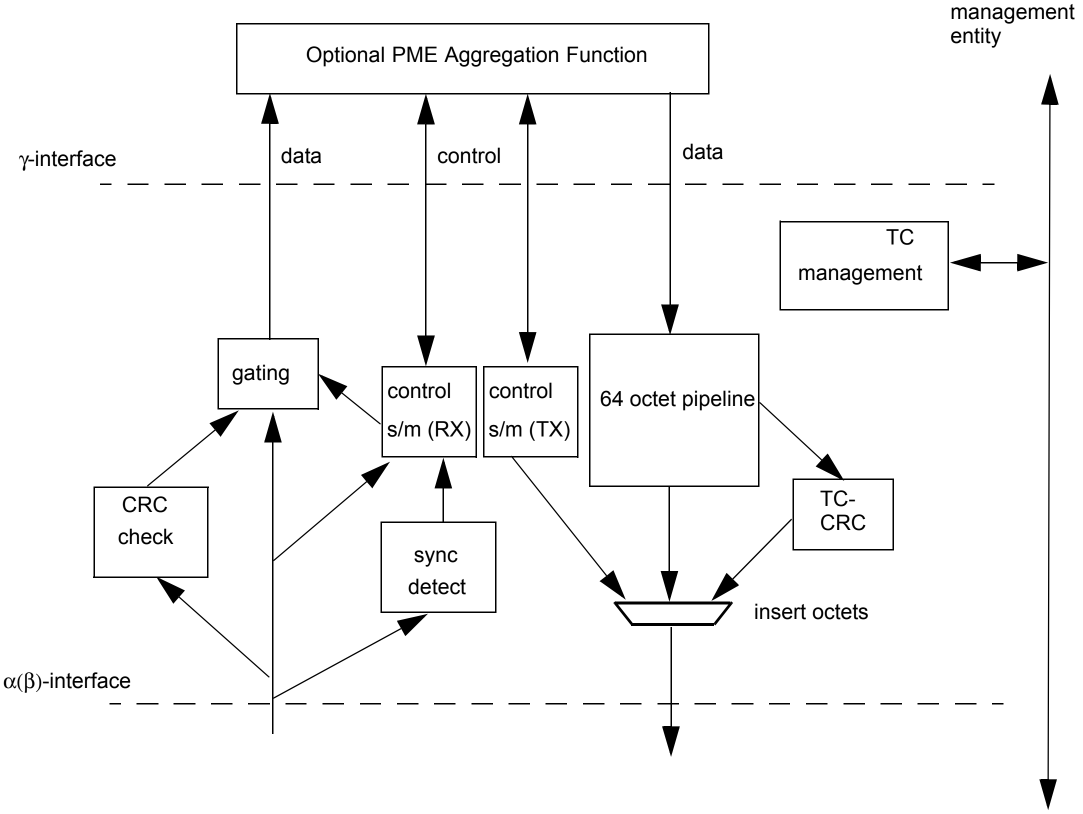

Figure 61–12—Functional diagram of TC sublayer

61.3.1 The γ-interface

The γ-interface is specified by incorporating section H.3.1 and all subsections of ITU-T Recommendation G.993.1 (Annex H) by reference, with the following exceptions and additions:

The PCS shall assert Tx_Avbl when an entire data fragment is available for transmission, and de-assert Tx_Avbl when there are no data fragments to transmit. Tx_Avbl shall never be de-asserted during the transmission of a data fragment.

OAM Information flow across the γ-interface supports access to registers referenced in Clause 45. Refer to Clause 45 for a complete description of access to TC, PMA and PMD registers from the MDIO interface.

Additional signals, which would be represented in the referenced document section H.3.1.4, are described in Table 61–9. Some of these signals may be unused when Clause 45 is not implemented.

Table 61–9—Additional γ-interface signals for OAM[a]

Signal	Size	Description	Direction
TC_link_state	1 bit	Control signal asserted when link is active and framing has synchronized according to the definition in 61.3.3 (TC_synchronized = TRUE) and remote_TC_out_of_sync (see 61.3.3.7) is not asserted.	TC → PCS
write_remote_aggregation_reg[b]	1 bit	Control signal to write PME_Aggregate_register. Active (min) 1 octet clock cycle	to PCS
write_remote_discovery_reg[b]	1 bit	Control signal to write remote_discovery_register. Active (min) 1 octet clock cycle	to PCS
clear_remote_discovery_reg[b]	1 bit	Control signal to clear remote_discovery_register. Active (min) 1 octet clock cycle	to PCS
read_remote_aggregation_reg[b]	1 bit	Control signal to read PME_Aggregate_register. Active (min) 1 octet clock cycle	to PCS
read_remote_discovery_reg[b]	1 bit	Control signal to read remote_discovery_register. Active (min) 1 octet clock cycle	to PCS
remote_write_data_bus[b]	48 bit	Data bus for writing to PME aggregation registers. Valid during octet clock cycle when write control is asserted	to PCS
remote_read_data_bus[b]	48 bit	Data bus for the results of a read or atomic write function. Valid during octet clock cycle when Acknowledge_read_write or NAcknowledge read_write is asserted	from PCS
Acknowledge_read_write[b]	1 bit	Control signal responding (positively) to read or write. Active 1 octet clock cycle	from PCS
NAcknowledge read_write[b]	1 bit	Control signal responding (negatively) to read or write. Active 1 octet clock cycle	from PCS

[a] The term “OAM” as used here refers to the OAM facilities as defined in the referenced G.993.1 document.

[b] These signals are defined only if PAF is implemented, and then only in CPE subtypes. They are used only during G.994.1 handshake. For CO subtypes, pervasive access by management may be used to obtain the corresponding information. In case of read/write collision the PAF has to process the read/write-requests sequentially.

61.3.2 The α(β)-interface

The α(β)-interface is specified by incorporating section 7.1 and all subsections of ITU-T Recommendation G.993.1 by reference.

NOTE—An identical α(β)-interface is defined in ITU-T G.991.2.

The α and β reference points define interfaces between the PCS and PMA in the 2BASE-TL-O/10PASS-TS-O and the 2BASE-TL-R/10PASS-TS-R, respectively. Both interfaces are functional, application independent and identical. Both interfaces are defined by the following signal flow:

a) Data flow
b) Synchronization flow
c) OAM flow[12]

61.3.2.1 α(β) data flow: reference G.993.1 section 7.1.1

Referenced as is, with the additions shown in Table 61–10.

Table 61–10— Additional α(β)-Interface signals

Signal(s)	Size	Description	Direction
PMA_receive_synchronized	1 bit	Receive PMA state diagram synchronized	PMA → TC
PMA_PMD_type	8 bit[a]	Signal indicating PMA/PMD mode of operation. Defined values: 00_{16} — 10PASS-TS CO subtype 01_{16} — 2BASE-TL CO subtype 02_{16}–$7B_{16}$ — reserved for allocation by IEEE 802.3 $7C_{16}$–$7F_{16}$ — reserved for allocation by ATIS T1E1.4 80_{16} – 10PASS-TS CPE subtype 81_{16} – 2BASE-TL CPE subtype 82_{16}–FB_{16} — reserved for allocation by IEEE 802.3 FC_{16}–FF_{16} — reserved for allocation by ATIS T1E1.4	PMA → TC

[a] NOTE—The MSB of this octet-wide signal is used to differentiate between CO-subtype and CPE-subtype.

61.3.2.2 α(β) synchronization flow

The synchronization flow comprises the following synchronization signals:

a) Transmission data flow octet synchronization (Osync_t)
b) Reception data flow octet synchronization (Osync_r)
c) Transmit and receive data flow bit-synchronization (Clk_t, Clk_r), optional
d) Transmit and receive data flow frame-synchronization (Fsync_t, Fsync_r), optional
e) Receive PMA state diagram synchronized (PMA_receive_synchronized)

The synchronization signals are asserted by the PMA and directed towards the PCS. The synchronization flow signals are described in Table 61–10.

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[12] The term "OAM" as used here refers to the OAM facilities as defined in the referenced G.993.1 document.

61.3.2.3 α(β) OAM flow[13]

The OAM Flow across the α(β)-interface exchanges OAM information between the PHY-OAM entity, the PMA and the PMD. The OAM flow is bi-directional and transports line related primitives, parameters, configuration setup and maintenance signals or commands.

Refer to Clause 62 and Clause 63 for definitions of the G.994.1 messaging, Operation Channel (OC) and Indicator Bits (IB) mechanisms for accessing remote parameters.

Refer to Annex 61A for an example of aggregation discovery.

61.3.3 TC functions

The TC shall provide full transparent transfer of data fragments between γ_O-interface and γ_R-interface (except non-correctable errors caused by the transmission medium). It shall also provide fragment integrity and fragment error monitoring capability.

In the transmit direction, the TC receives fragments from the PCS via the γ-interface. An additional 16- or 32-bit CRC is calculated on the data and appended. The TC then performs 64/65-octet encapsulation, and sends the resulting codewords to the PMA via the α(β)-interface. In the receive direction, the TC receives codewords from the PMA via α(β)-interface, recovers the transported TC fragment, checks the CRC, and submits the extracted fragment to the PCS via the γ-interface.

An implementation is shown in Figure 61–13 and some example timing diagrams are shown in Figure 61–14.

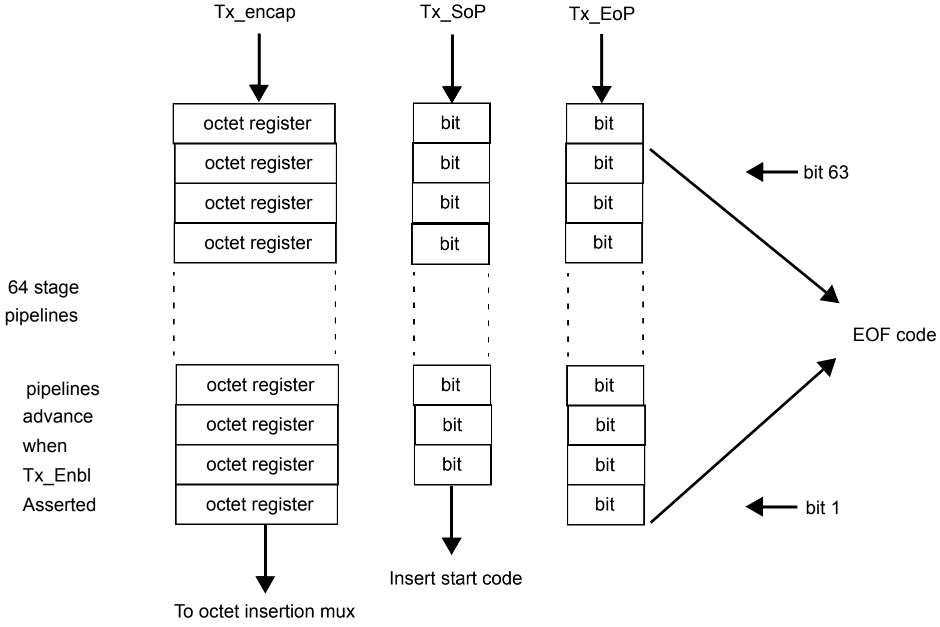

Figure 61–13—Example transmit pipeline

61.3.3.1 TC encapsulation and coding

A TC fragment consists of a fragment, followed by a 16- or 32-bit CRC (referred to as the TC-CRC) as defined in 61.3.3.3.

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[13] The term "OAM" as used here refers to the OAM facilities as defined in the referenced G.993.1 document.

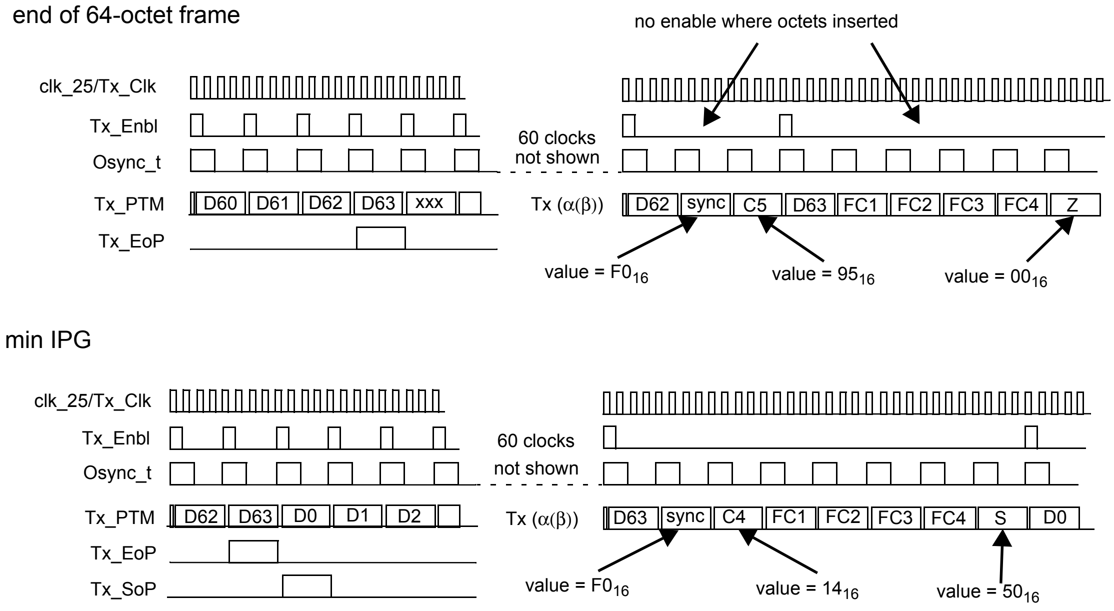


Figure 61–14—Example transmit timing

The TC coding function generates codewords with a fixed length of 65 octets (64/65-octet coding). A codeword consists of a Sync Octet and one of the following combinations:

a) all data: all of the octets in the codeword belong to the same TC fragment.
b) end of frame (go to idle): up to 63 octets in the codeword belong to the same TC fragment, the rest of the codeword consists of Idle octets.
c) end of frame (start new frame): up to 62 octets in the codeword belong to the same TC fragment, a number of Idle octets and a single Start of Frame octet precede the first data octets of the next TC fragment.
d) idle: all of the octets in the codeword are Idle octets.
e) idle (start new frame): a number of Idle octets and a single Start of Frame octet precede up to 63 data octets of the next TC fragment.
f) out-of-sync idle: all of the octets in the codeword are idle octets and the 64/65-octet receive state diagram is out-of-sync (TC_synchronized = FALSE).

Both transmit and receive data may be transferred across both the α(β) and the γ-interfaces at rates that are different from the rate across the MII; the frame buffering is managed in the sublayer above the γ-interface. The TC layer uses the γ-interface flow control signal, Tx_Enbl, to slow transmit data to the rate required for the encapsulated data across the α(β)-interface. The TC layer uses the γ-interface flow control signal, Rx_Enbl, to allow idle cycles in the flow of receive data across the γ-interface.

When a fragment arrives from the γ-interface while an End of Frame codeword is being transmitted, a Start of Frame octet shall be inserted prior to the transmission of data octets belonging to the next fragment. The Start of Frame octet *S* is distinct from the Idle octet *Z.* Valid locations for *S* are any valid location for *Z*, and the presence of an *S* rather than a *Z* octet indicates that what follows is the commencement of data for a new fragment.

No new fragment shall be transmitted when TC_link_state = FALSE (TC_link_state is defined in 61.3.3.7). If a fragment is being transmitted when TC_link_state becomes false, the End of Frame codeword completing the fragment shall not contain an *S* symbol after the end of the fragment. If an Idle codeword is being transmitted when TC_link_state becomes false, it shall be completed with *Z* symbols only. After the completed End of Frame or Idle codeword, only All Idle or All Idle Out-of-Sync codewords shall be transmitted until TC_link_state becomes TRUE again. After TC_link_state becomes true again, transmission of data can restart when a new fragment is available for transmission over the gamma-interface.

The data and sync format of the encapsulated data is shown in Table 61–11.

Table 61–11—Codeword formats

Type	Frame Data	Sync Octet	Octet fields 1–64									
all data	*DDDD—DDDD*	$0F_{16}$	D_0	D_1	D_2	D_3	D_4	D_5	...	D_{61}	D_{62}	D_{63}
end of frame	contains *k* *D*'s, where *k* = 0 to 63	$F0_{16}$	C_k	D_0	D_1	D_2	D_3	...	D_{k-1}	Z	...	Z
start of frame while transmitting	contains last *k* *D*'s of 1st frame, where *k*=0 to 62; & first *j* *D*'s of 2nd frame, where *j*=0 to 62-*k*	$F0_{16}$	C_k	D_0	...	D_{k-1}	Z	...	S	D_0	...	D_{j-1}
all idle	ZZZZ—ZZZZ	$F0_{16}$	Z	Z	Z	Z	Z	Z	...	Z	Z	Z
start of frame while idle	contains *k* *D*'s, where *k*=0 to 63, and contains *j* Z's, where *j*=63-*k*	$F0_{16}$	Z	Z	S	D_0	D_1	...	...	D_{k-3}	D_{k-2}	D_{k-1}
all idle out-of-sync	YZZZ—ZZZZ	$F0_{16}$	Y	Z	Z	Z	Z	Z	...	Z	Z	Z

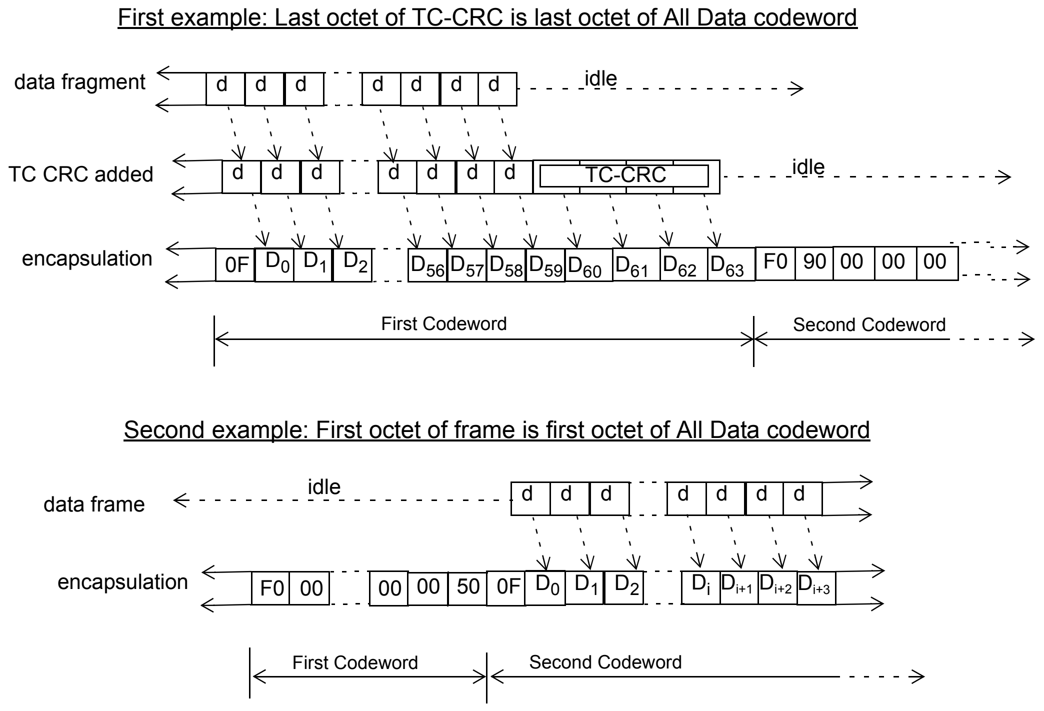
The end of a TC fragment is always marked with an "end of frame" or "start of frame while transmitting" codeword; e.g., the received sequence [All Data codeword][All Idle codeword] is considered a sequencing error. When any of the following events occur, signal TC_coding_error shall be asserted:

a) An incorrect octet is received when a Sync Octet is expected.
b) Outside a fragment, the received octet following a valid $F0_{16}$ sync is not a Z, Y, S.
c) Inside a fragment, the received octet following a valid $F0_{16}$ sync is not a valid value of C_k.
d) Z or S is expected, and a value different from Z and S is received.

Signal remote_TC_out_of_sync shall be asserted when Y is received after an expected $F0_{16}$ sync symbol, and remain asserted until the beginning of a codeword other than All Idle Out-of-Sync is detected.

NOTE—When the local TC is not synchronized (TC_synchronized = FALSE), it may fail to detect incoming "All Idle Out-of-Sync" codewords. However, this does not affect the behavior of the local TC, which is sending "All Idle Out-of-Sync" codewords itself. Higher sublayers only use the combined signal TC_link_state, defined in 61.3.1.

Figure 61–15 illustrates two interesting examples. In the first example, the last 60 octets of a data frame, plus the 4 encapsulation CRC octets, are transmitted in an All Data codeword. In other words, the end of the (TC-CRC-augmented) frame coincides with the end of the codeword. In this case, the next codeword begins with Sync Octet equal to $F0_{16}$, C_k equal to C_0 (90_{16}). The second codeword indicates an End Of Frame, but with no additional data; in other words, the data in the previous codeword were the last of the frame. In the second example, the first octet of a frame is aligned with the first octet of an All Data codeword.



All octets other than D_x are written in hexadecimal notation.

Figure 61–15—TC Encapsulation examples

The values of the TC control characters are shown in Table 61–12.

Table 61–12—TC control character values

Character	Value
Z	00_{16}
C_k, k=0–63	$C_k = k+10_{16}$, with MSB set so that resulting value has even parity; $C_0=90_{16}$, $C_1=11_{16}$, $C_2=12_{16}$, $C_3=93_{16}$, ... $C_{62}=4E_{16}$, $C_{63}=CF_{16}$
Y	$D1_{16}$
S	50_{16}
R	All other values[a]

[a] See the state diagram for the 64/65-octet receive function (Figure 61–19) for required action when receiving reserved codewords.

61.3.3.2 Sync insertion and transmit control

The transmit data path needs a 64 stage pipeline in order to generate the appropriate sync octet along with an end-of-frame indicator when required. The flow control signal, Tx_Enbl, is used to slow the flow of data across the γ-interface to cater for the difference in clock speed between the α(β)-interface and the γ-interface and also to allow for the insertion of sync octets and CRC codes into the data stream.

A simple implementation may use a 64 bit pipeline for the Tx_EOP control signal. In that case, an end of frame sync code ($F0_{16}$, then C_k) would be inserted whenever a bit is set in stages 63 to 1 of the pipeline (stage 64 is the first stage). The value of C_k inserted would be such that k is equal to the stage number of the bit that is set.

Some implementations may optimize the insertions of idles between fragments. In particular an implementation may remove idle characters between fragments to increase the effective bandwidth of the channel.

If PMA/PMD link status is not Up (i.e. either Down or Initializing), the TC sublayer shall transmit only Out-of-Sync Idle codewords. The PMA/PMD link status is defined in 45.2.1.16.4.

61.3.3.3 TC-CRC functions

The TC-CRC is generated for the entire payload fragment including any attached header (from PAF), including the Ethernet CRC; i.e., the TC-CRC is computed over octets from the first octet of the PAF header (if present), or the first octet of the DestinationAddress (in the case where the PAF header not present), to the last octet of the Ethernet CRC (for a frame) or the last octet of the fragment (if PAF fragmentation is operating), inclusive. The TC-CRC is added to the data stream after the end of the fragment in the transmit direction. The TC-CRC is checked against the last 2 or 4 octets of the fragment in the receive direction. If the receive TC-CRC is incorrect then Rx_Err is asserted to signal that the fragment is errored.

The encoding for 2BASE-TL is defined by the following generating polynomial in Equation (61–1).

$$\begin{aligned}&x^{32}+x^{28}+x^{27}+x^{26}+x^{25}+x^{23}+x^{22}+x^{20}+x^{19}+\\&x^{18}+x^{14}+x^{13}+x^{11}+x^{10}+x^{9}+x^{8}+x^{6}+1\ =\\&(x+1)(x^{31}+x^{30}+x^{29}+x^{28}+x^{26}+x^{24}+x^{23}+x^{21}+x^{20}+x^{18}+x^{13}+x^{10}+x^{8}+x^{5}+x^{4}+x^{3}+x^{2}+x+1)\end{aligned}\tag{61–1}$$

The encoding for 10PASS-TS is defined by the following generating polynomial in Equation (61–2).[14]

$$x^{16}+x^{12}+x^{5}+1\tag{61–2}$$

Mathematically, the TC-CRC value corresponding to a given payload fragment (including any attached header) is defined by the following procedure:

a) The first 32 bits (in the case of 2BASE-TL) or the first 16 bits (in the case of 10PASS-TS) of the payload are complemented.
b) The n bits of the payload are then considered to be the coefficients of a polynomial M(x) of degree n–1. (e.g., the first bit of the fragment corresponds to the x^{n-1} term and the last bit of the fragment corresponds to the x^0 term.)
c) $M(x)$ is multiplied by x^{32} (in the case of 2BASE-TL), or by x^{16} (in the case of 10PASS-TS), and divided by $G(x)$, the TC-CRC polynomial, producing a remainder $R(x)$ of degree 31 (in the case of 2BASE-TL), or degree 15 (in the case of 10PASS-TS).
d) The coefficients of $R(x)$ are considered to be a 32-bit sequence (in the case of 2BASE-TL), or a 16-bit sequence (in the case of 10PASS-TS).
e) The bit sequence is complemented and the result is the TC-CRC.

In the case of 2BASE-TL, the 32 bits of the TC-CRC value are placed so that the x^{31} term is the bit in position b_8 on the $\alpha(\beta)$-interface (as shown in Figure 61–16) of the first octet, and the x^0 term is the bit in position b_1 on the $\alpha(\beta)$-interface (as shown in Figure 61–16) of the last octet. (The bits of the CRC are thus transmitted in the order x^{31}, x^{30},.., x^1, x^0.) At the receiver, a payload received without error will result in the remainder $1C2D19ED_{16}$ when divided by $G(x)$.

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[14] For 10PASS-TS, a 16-bit TC-CRC is sufficient for detecting payload errors, as the error-detecting capabilities of its Reed-Solomon decoder is also employed (see 62.2.2). In 2BASE-TL PHYs, a Reed-Solomon decoder is not present, hence a stronger TC-CRC is required.

In the case of 10PASS-TS, the 16 bits of the TC-CRC value are placed so that the x^{15} term is the bit in position b_8 on the α(β)-interface (as shown in Figure 61–16) of the first octet, and the x^0 term is the bit in position b_1 on the α(β)-interface (as shown in Figure 61–16) of the last octet. (The bits of the CRC are thus transmitted in the order x^{15}, x^{14},.., x^1, x^0.) At the receiver, a payload received without error will result in the remainder $1D0F_{16}$ when divided by $G(x)$.

If, in the transmitter, the TX_Err signal is asserted during the transmission of the fragment across the γ-interface, the last octet of the TC-CRC shall be ones-complemented (i.e., intentionally corrupted by inverting all the bits of the last octet).

61.3.3.4 Bit ordering

In the transmitter, after encapsulation into 64/65-octet codewords, bits within each octet are labeled from b_1 to b_8, with the MSB labeled as b_1, the LSB labeled as b_8, and intervening bits labeled accordingly. In keeping with the labeling convention for the α(β)-interface in ITU-T Recommendations, bit b_8 is regarded as the MSB at the α(β)-interface, and is transmitted first if the α(β)-interface is serial by implementation.

Observe that the TC functionality defines a correspondence between the LSB at the γ-interface and b_8, between the next-order bit and b_7, etc., in order to conform to the Ethernet bit order convention of transmitting LSB first. See also H.4.1.1 in Annex H of ITU-T Recommendation G.993.1. In transmitting and calculating the TC-CRC, the octets at the γ-interface are processed LSB first.

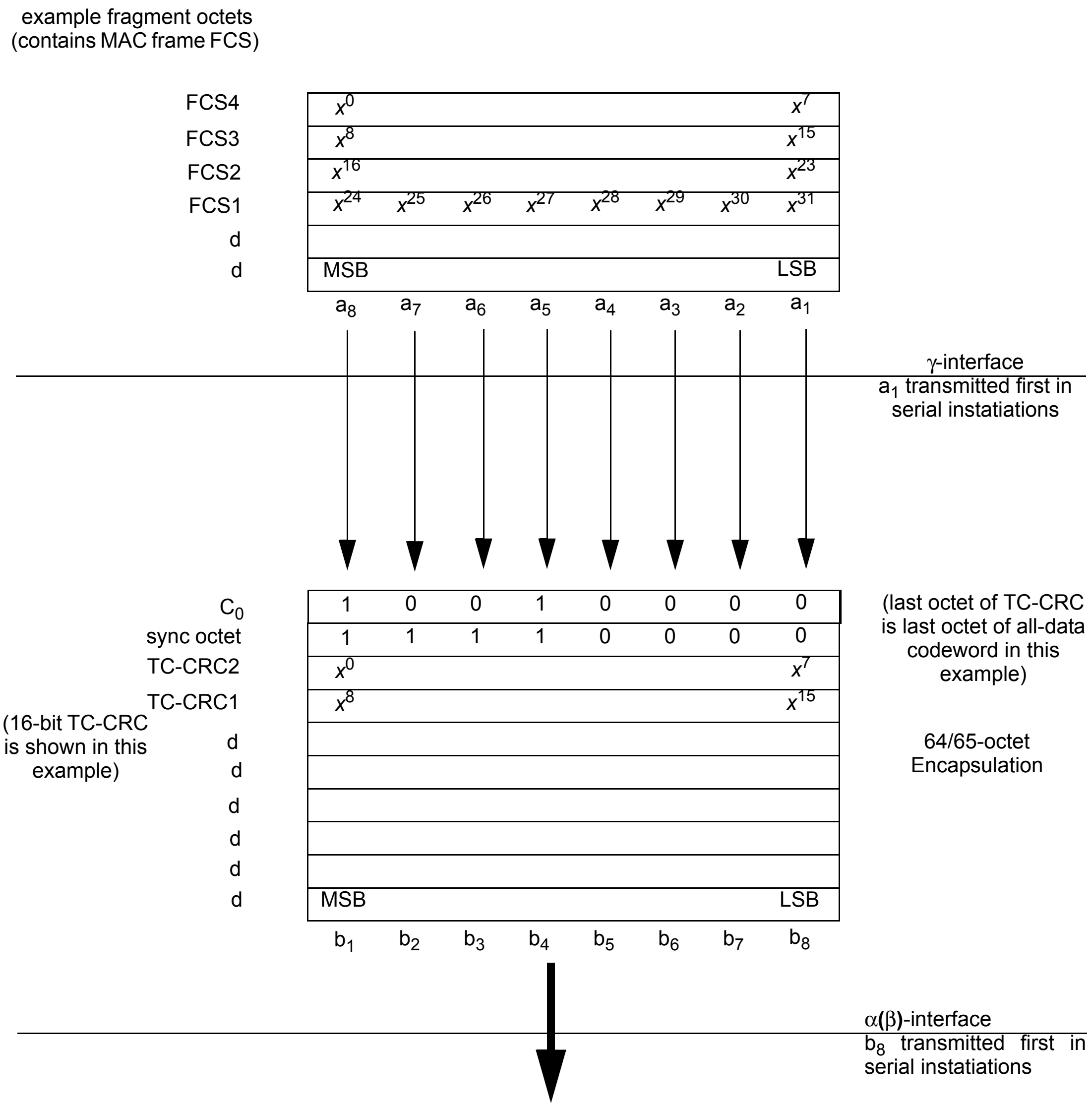

Figure 61–16—γ-interface to α(β)-interface bit ordering

61.3.3.5 Sync detection

The sync detection function serves two purposes. Firstly, the synchronization is acquired from the incoming data stream, the sync detection function controls the initial acquisition and maintenance of the synchronization. Secondly, the sync detection is needed so that the receive control state diagram can extract framing information from the receive data stream and remove the sync characters and CRC codes. The sync detection state diagram is shown in Figure 61–17.

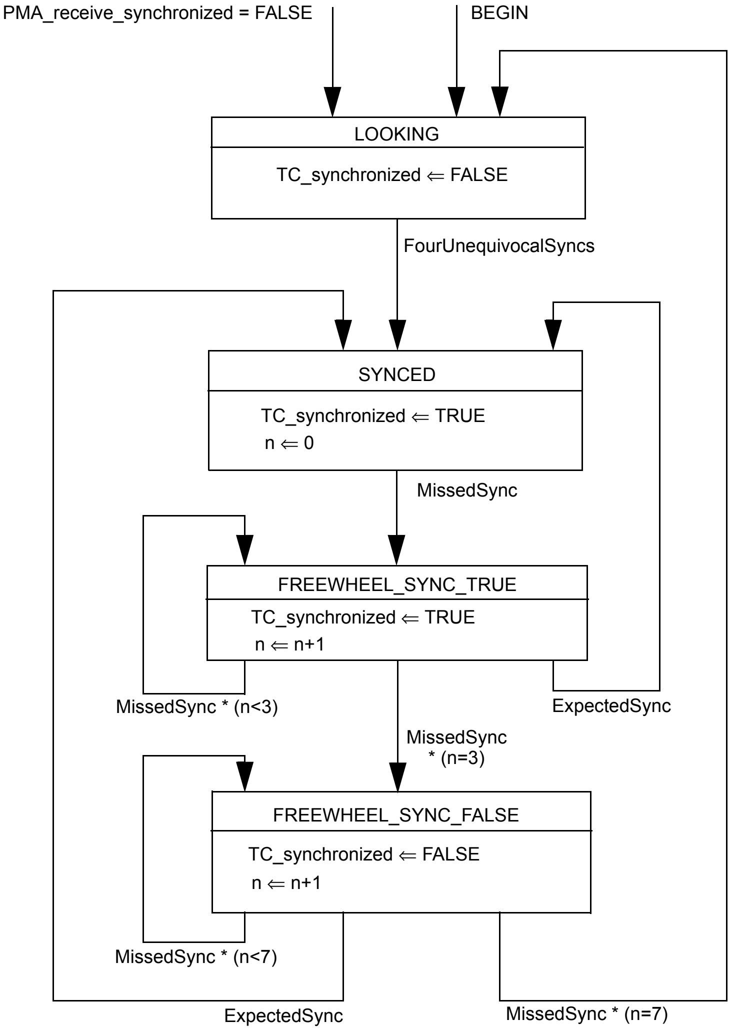

Figure 61–17—Sync detect state diagram

61.3.3.5.1 State diagram variables

BEGIN
: A variable that resets the functions within the sync detection function (see 45.2.1.1.1.)
TRUE when the TC sublayer is reset.
FALSE when (re-)initialization has completed.

ExpectedSync
: variable of type Boolean, TRUE indicating the occurrence of a sync character in the correct position in the octet stream. The default value of this variable is FALSE; the value of the variable resets to FALSE on every state transition.

FourUnequivocalSyncs
: variable of type Boolean, TRUE indicating the occurrence of a 196-octet sequence with the following two characteristics:

a)the sequence is of the form <sync><data><sync><data><sync><data><sync>, where each <sync> is $0F_{16}$ or $F0_{16}$ and each <data> is 64 octets of any value;

b)the pattern <sync><data><sync><data><sync> occurs nowhere in the sequence, where <sync> and <data> are as defined in (a, unless the <sync> values are coincident with those in (a;

The default value of this variable is FALSE; the value of the variable resets to FALSE on every state transition.

MissedSync
: variable of type Boolean, TRUE indicating the occurrence of a non-sync character in the octet stream position where a sync character is expected. The default value of this variable is FALSE; the value of the variable resets to FALSE on every state transition.

n
: variable of type integer, counting the occurrences of MissedSync = TRUE, used to determine when to leave state FREEWHEEL_SYNC_TRUE or FREEWHEEL_SYNC_FALSE.

PMA_receive_synchronized
: signal of the $\alpha(\beta)$-interface, see 61.3.2.

TC_synchronized
: variable of type Boolean, TRUE indicating that the state diagram is in state SYNCED or FREEWHEEL_SYNC_TRUE. This variable is used to calculate the value of signal TC_link_state on the γ-interface (see 61.3.1), and to generate “All Idle Out Of Sync” codewords in the 64/65-octet transmit function (see Figure 61–18).

61.3.3.5.2 State diagram

The receiver shall implement the sync detect state diagram shown in Figure 61–17.

61.3.3.6 Receive control

The receive control function removes the sync characters and encapsulation CRC octets from the data stream and passes it upward across the γ-interface. If TC_synchronized = false then signal RX_Enbl shall be de-asserted. If a CRC error is detected the receive controller shall assert signal TC_CRC_error. The receive controller shall assert signal RX_Err at the γ-interface during at least one octet of a fragment as it is passed up across the γ-interface, if TC_CRC_error is asserted, or if the fragment contains data from a block of data in which the PMA detected errors, but did not correct them (the means by which the PHY passes this information from the PMA to the TC is unspecified).

61.3.3.7 State diagrams for 64/65-octet encapsulation

This subclause contains the state diagrams for the 64/65-octet encapsulation function. Only the signals that affect the operation of the state diagrams are explicitly mentioned in the state diagrams. Other signals are to be set and read in accordance with the specifications of the γ-interface (see 61.3.1) and the α(β)-interface (see 61.3.2).

61.3.3.7.1 Transmit state diagram

The following variables are used in the state diagram.

BEGIN

A variable that resets the functions within the sync detection function.
TRUE when the TC-sublayer is reset.
FALSE when (re-)initialization has completed.

k

variable of type integer, used to keep track of the number of octets used in the current codeword, not including the sync symbols

loop

variable of type Boolean, keeping track of the fact that an Out-of-Sync Idle codeword is being transmitted, thus preventing a Start-of-Frame to occur within this codeword (initial value is TRUE).

TC_link_state

variable of type Boolean, indicating the current state of the TC_link_state signal on the γ-interface

TC_link_stateCHANGE

This function monitors the TC_link_state variable for a state change. The function is set to TRUE on state change detection.
Values:
TRUE; A TC_link_state variable state change has been detected.
FALSE; A TC_link_state variable state change has not been detected (default).

NOTE—TC_link_stateCHANGE is set by this function definition; it is not set explicitly in the state diagrams. TC_link_stateCHANGE evaluates to its default value upon state entry.

TC_synchronized

variable of type Boolean, indicating whether synchronization has been acquired (as used in Figure 61–17)

Tx_Avbl

variable of type Boolean, indicating the current state of the Tx_Avbl (transmit data available) signal on γ-interface

Tx_EoP

variable of type Boolean, indicating the current state of the Tx_EoP (end of packet) signal on γ-interface

The following functions are used in the state diagram:

flushBuffer()
: function that removes any octets that have been pulled from the PCS by the function pullOctet() from the transmit fifo.

pullOctet()
: function that receives a single octet of data from the γ-interface. This function takes one cycle of the Tx_Enbl (transmit enable) signal (see 61.3.1) to complete. At the end of a fragment, this function returns the octets of the TC-CRC in the order specified in 61.3.3.3.

transmitAllDataSync()
: function that transmits the all-data sync symbol ($0F_{16}$) to the α(β)-interface. This function takes one cycle of the Osync_t signal (see 61.3.3.2) to complete.

transmitC(int k)
: function that transmits the C_k symbol as specified in Table 61–10 to the α(β)-interface. This function takes one cycle of the Osync_t signal (see 61.3.3.2) to complete.

transmitData()
: function that transmits all data currently in the transmit fifo to the α(β)-interface. This function takes one cycle of the Osync_t signal (see 61.3.3.2) per octet of data transmitted to complete.

transmitS()
: function that transmits the *S* symbol as specified in Table 61–12 to the α(β)-interface. This function takes one cycle of the Osync_t signal (see 61.3.3.2) to complete.

transmitSync()
: function that transmits the regular sync symbol ($F0_{16}$) to the α(β)-interface. This function takes one cycle of the Osync_t signal (see 61.3.3.2) to complete.

transmitZ(int k, Boolean loop)
: function that transmits the *Y* symbol ($D1_{16}$) to the α(β)-interface if (k=1) and (loop=TRUE), and transmits the *Z* symbol (00_{16}) to the α(β)-interface otherwise. This function takes one cycle of the Osync_t signal (see 61.3.3.2) to complete.

Figure 61–18 specifies the 64/65-octet encapsulation (transmit) function.

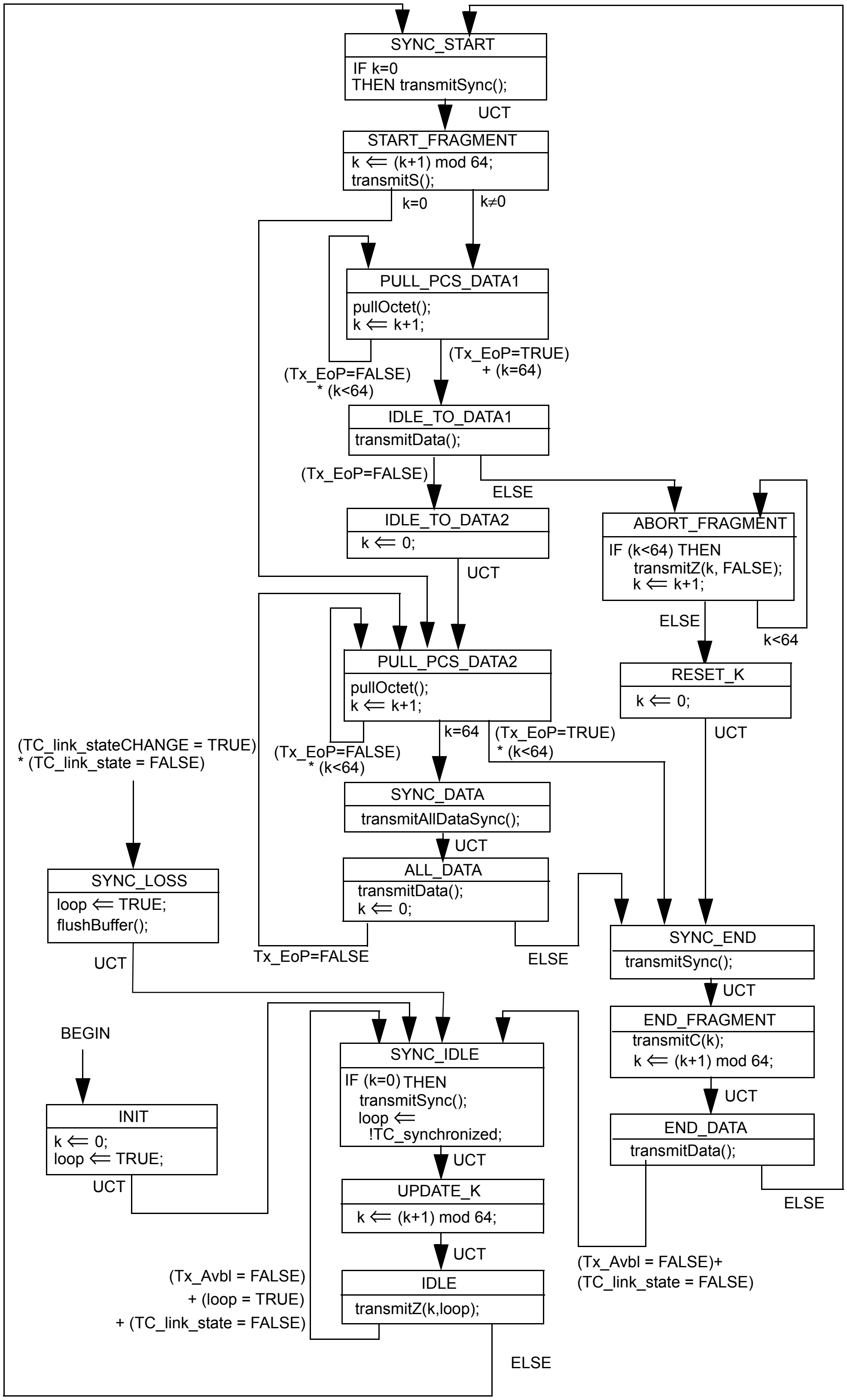

Figure 61–18—State diagram for 64/65-octet transmit function

61.3.3.7.2 Receive state diagram

The following variables are used in the state diagram.

B

variable of type octet, used to store a single received octet

C

variable of type octet, used to store a received C_k symbol

codingViolation

variable of type Boolean, used to mark detection of a coding violation when a sync octet was expected

expectedSync

variable of type Boolean, used to mark successful sync octet detections, which are counted towards achieving synchronization as specified in Figure 61–17. The default value of this variable is FALSE; it returns to FALSE on every state transition.

k

variable of type integer, used to keep track of the number of octets received in the current codeword, not including the sync symbols

kmax

variable of type integer, used to store the decoded value of a C_k symbol

missedSync

variable of type Boolean, used to mark unsuccessful sync octet detections, which are counted towards losing synchronization as specified in Figure 61–17. The default value of this variable is FALSE; it returns to FALSE on every state transition.

remote_TC_out_of_sync

variable of type Boolean, representing the state of the remote TC synchronization state diagram (see 45.2.6.13).
TRUE if the remote TC has lost synchronization according to 61.3.3.5
FALSE if the remote TC has acquired synchronization according to 61.3.3.5

Rx_Err

variable of type Boolean, representing the corresponding signal (receive error) on the γ-interface

TC_coding_error

when this signal is asserted, the TPS-TC coding violations counter register is incremented (see 45.2.6.12). The default value of this variable is FALSE; it returns to FALSE on every state transition. If TC_coding_error becomes true during the reception of a fragment, Rx_Err is asserted on the γ-interface to signal this condition to the PCS, thus invalidating the entire fragment.

TC_synchronized

variable of type Boolean, identical to the variable TC_synchronized defined in 61.3.3.7.1.

TC_synchronizedCHANGE

This function monitors the TC_synchronized variable for a state change. The function is set to TRUE on state change detection.
Values:
TRUE; A TC_synchronized variable state change has been detected.
FALSE; A TC_synchronized variable state change has not been detected (default).

NOTE—TC_synchronizedCHANGE is set by this function definition; it is not set explicitly in the state diagrams. TC_synchronizedCHANGE evaluates to its default value upon state entry.

The following functions are used in the state diagram.

decode(octet B)

function that decodes the C_k symbol as specified in Table 61–12. A return value between 0 and 63 indicates a valid C_k symbol was read.

receiveOctet()

function that receives a single octet of data over the α(β)-interface. This function takes one cycle of the Osync_r signal (see 61.3.2.2) to complete.

sendOctetToPCS()

function that sends a single octet of data over an internal γ-interface to an intermediate fifo. The size of the intermediate fifo is more than 2 octets for 10PASS-TS and more than 4 octets for 2BASE-TL. Data is transmitted at the same rate from the intermediate fifo to the PCS (if present) over the γ-interface. This function takes one cycle of the Rx_clk (receive clock) signal (see 61.3.1) to complete. At the end of a fragment, the fifo contains the TC_CRC octets. The TC_CRC octets are never forwarded over the γ-interface. After verification of the TC_CRC octets, the result of the TC_CRC verification is signalled to the PCS (if present) over the γ-interface.

Figure 61–19 specifies the 64/65-octet decapsulation (receive) function.

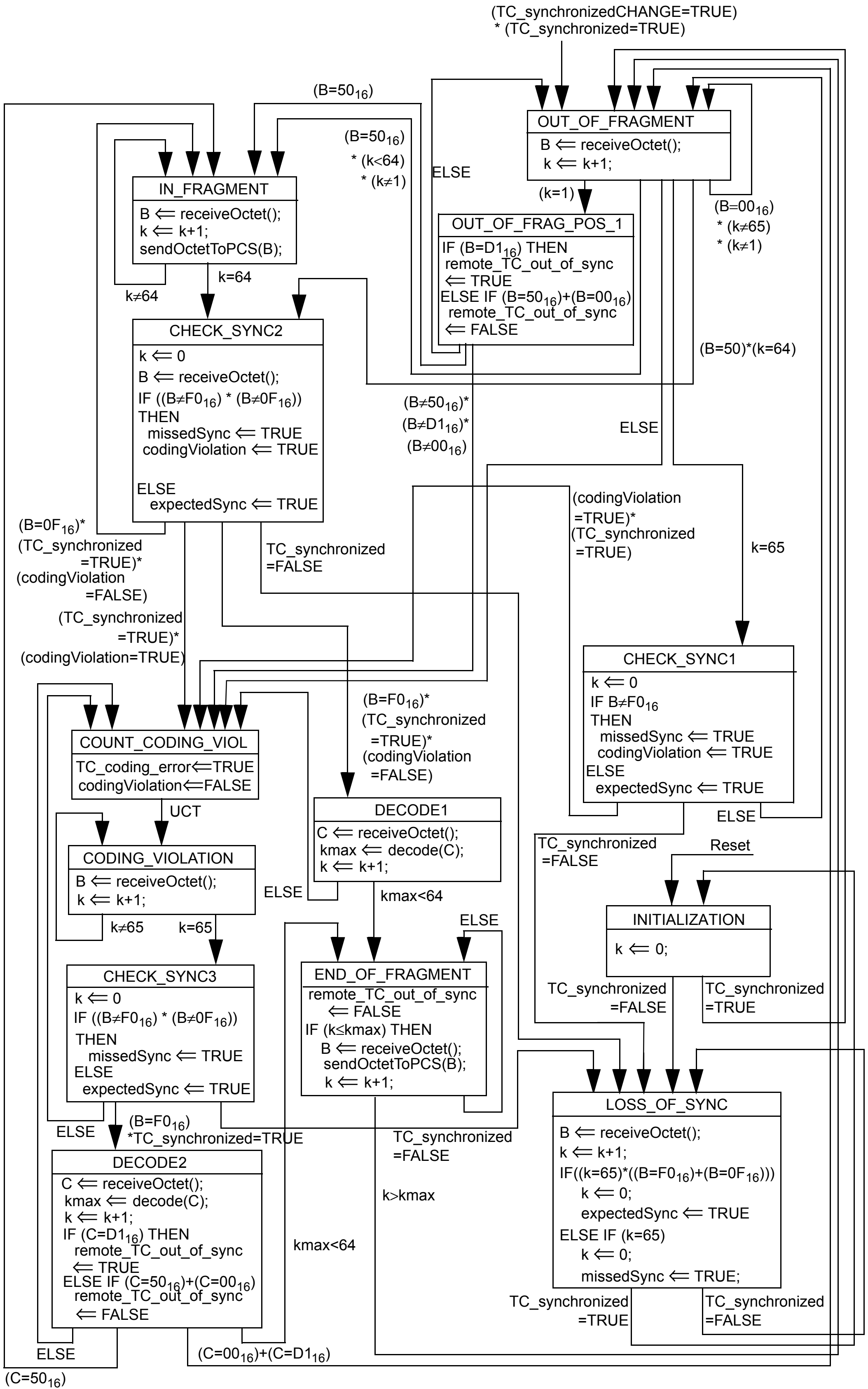

Figure 61–19—State diagram for 64/65-octet receive function

61.3.3.8 TC sublayer management entity signals

The following TC sublayer signals are mapped to Clause 45 registers or cause Clause 45 counters to increment:

remote_TC_out_of_sync
: (for each PMA, γ-interface) this signal is asserted to indicate that the remote TC has signaled loss-of-sync. See Figure 61–19 and 45.2.6.13.

TC_synchronized
: (for each PMA, γ-interface) this signal is asserted to indicate that the state diagram has achieved codeword synchronization. See Figure 61–17 and 45.2.6.10.

TC_CRC_error
: (for each PMA, γ-interface) this signal is asserted to indicate that the synchronization state diagram has detected a false CRC code for a received frame (see 45.2.6.11).

TC_coding_error
: (for each PMA, γ-interface) this signal is asserted to indicate that a coding violation has been detected in the received octet stream (see 45.2.6.12).

61.4 Handshaking and PHY control specification for type 2BASE-TL and 10PASS-TS

61.4.1 Overview

This subclause defines the startup and handshaking procedures by incorporating ITU-T Recommendation G.994.1 by reference, with the exceptions listed below. Where there is conflict between specifications in G.994.1 and those in this standard, those of this standard will prevail. The G.994.1 parameter values and options to be used by 2BASE-TL and 10PASS-TS are specified here.

At the time of publication, G.994.1 Revision 3 (2004) is in force. Earlier Revisions of this Recommendation shall not be implemented in 2BASE-TL or 10PASS-TS.

61.4.2 Replacement of 1, "Scope"

61.4.2.1 Scope

This subclause defines signals, messages, and procedures for exchanging these between 2BASE-TL and 10PASS-TS port types, when the modes of operation of the equipment need to be automatically established and selected, but before signals are exchanged which are specific to a particular port type.

The startup procedures defined here are compatible with those used by other equipment on the public access network, such as DSL transceivers compliant with ITU-T Recommendations. For interrelationships of this subclause with ITU-T G.99x-series Recommendations, see Recommendation G.995.1 (informative).

The principal characteristics of this subclause are as follows:

a) Use over metallic local loops
b) Provisions to exchange capabilities information between DSL equipment and EFM PHYs to identify common modes of operation
c) Provisions for equipment at either end of the loop to select a common mode of operation or to request the other end to select the mode
d) Provisions for exchanging non-standard information between equipment
e) Provisions to exchange and request service and application related information
f) Support for both duplex and half-duplex transmission modes
g) Support for multi-pair operation
h) Provisions for equipment at the remote end of the loop (xTU-R) to propose a common mode of operation

61.4.2.2 Purpose

It is the goal of the ITU-T that all specifications for digital transceivers for use on public telephone network copper subscriber lines use G.994.1 for startup. G.994.1 procedures allow for a common mechanism for identification of available features, exchange of capabilities and configuration information, and selection of operating mode. As the two loop endpoints are usually separated by a large distance (e.g., in separate buildings) and often owned and installed by different entities, G.994.1 also aids in diagnosing interoperability problems. G.994.1 codespaces have been assigned by ITU-T to ATIS, ETSI, and IEEE 802.3 in support of this goal.

In private networks, the management entity may additionally use G.994.1 tones or messages to autoconfigure the subtype (CO or CPE) in devices which implement both (see 61.1).

61.4.3 Changes to 6.1, “Description of signals”

NOTE 4 and NOTE 5 are not applicable.

Replace paragraph 3 of 6.1.1, “4.3125 kHz signaling family” with the following.

The carrier sets in this family are mandatory for the port types listed in Table 61–13. One or more carriers listed in Reference Table 1 or Reference Table 3 may be transmitted in addition to the mandatory carrier set listed in Table 61–13. Carriers not listed in Reference Table 1 or Reference Table 3 shall not be transmitted.

Table 61–13—Mandatory carrier sets

Port Types	Carrier set designation
10PASS-TS	V43

Replace paragraph 3 of section 6.1.2, “4 kHz signaling family” with the following.

The carrier sets in this family are mandatory for the port types listed in Table 61–14. One or more carriers listed in Reference Table 1 or Reference Table 3 may be transmitted in addition to the mandatory carrier set listed in Table 61–14. Carriers not listed in Reference Table 1 or Reference Table 3 shall not be transmitted.

Table 61–14—Mandatory carrier sets

Port Types	Carrier set designation
2BASE-TL	A4

61.4.4 Changes to 9.4, “Standard information field (S)”

Paragraphs 1–5: referenced as is.

Table 11.1 to Table 11.52 and Table 11.57 and beyond are not applicable.

The Standard information field (S) codepoints specified in Annex 61B shall be used in the transactions specified in this subclause.

61.4.5 Changes to 9.5, “Non-standard information field (NS)”

Add this paragraph: The contents of the NS information field are outside the scope of this standard.

61.4.6 Applicability of Annex A–B and Appendix I–VI

Annex A / G.994.1—Support for legacy non-G.994.1 devices—Not applicable

Annex B / G.994.1—Operation over multiple wire pairs—Not applicable to the multipair operation for EFM

Appendix I / G.994.1—Not applicable

Appendix II / G.994.1—Provider Code contact Information —Referenced as is

Appendix III / G.994.1—Support for legacy DMT-based devices —Not applicable

Appendix IV / G.994.1—Procedure for the assignment of additional G.994.1 parameters—Not applicable

Appendix V / G.994.1—Rules for code point table numbering—Not applicable

Appendix VI / G.994.1—Bibliography

61.4.7 PME Aggregation – remote access of PME Aggregation registers

As the CO-subtype accesses PME Aggregation registers (i.e., remote_discovery_register and PME_Aggregate_register) in the CPE-subtype prior to training and establishment of the PMD-to-PMD link, it is performed using G.994.1 handshake messages.

The G.994.1 handshake messages described in this subclause shall assert the “Ethernet bonding” NPar(2) codepoint if and only if PAF_available is asserted. The “TDIM Bonding” NPar(2) bit shall be deasserted. In addition, the “Ethernet bonding” NPar(2) codepoint shall be asserted by the -O device in an MS message if and only if PAF_enable is asserted.

NOTE 1—A G.994.1 session including configuration of the PME Aggregation Function may violate the maximum activation time specified for SHDSL transceivers by ITU-T Recommendation G.991.2.

NOTE 2—In the transactions specified in this subclause, each CLR message may be preceded by MR/REQ-CLR messages. Each CL message is followed by an ACK(1). These messages are not shown in the diagrams.

61.4.7.1 Remote_discovery_register

2BASE-TL-R and 10PASS-TS-R PHYs shall assert the PME Aggregation Discovery SPar(2) bit in all G.994.1 CLR messages, if and only if its local PAF_available bit is set. CPE-subtypes shall place the contents of the remote_discovery_register in the corresponding NPar(3) bits in the outgoing CLR message, with the “Clear if Same” NPar(3) set to zero.

In response to a “Get” command, the CO-subtype shall perform a G.994.1 capabilities exchange with the CPE-subtype. The contents of the NPar(3) remote_discovery_register bits in the CLR message received from the CPE-subtype shall be reported as the result. The CL message sent by the CO-subtype in response to the CLR shall have the PME Aggregation Discovery SPar(2) bit set to zero.

In response to a “Set if Clear” command, the CO-subtype shall perform two back-to-back G.994.1 capabilities exchanges with the CPE-subtype. The contents of the NPar(3) remote_discovery_register bits in the first CLR message received from the CPE-subtype shall be ignored. The CL message sent by the CO-subtype in response to this first CLR shall have the PME Aggregation Discovery SPar(2) bit set to one, the Clear if Same NPar(3) bit set to zero, and the NPar(3) remote_discovery_register bits set to the CO-subtype

PME Aggregation Discovery Code register. The CPE-subtype shall set the remote_discovery register to this value if it is currently clear. The contents of the NPar(3) remote_discovery_register bits in the CLR message received from the CPE-subtype during the second capabilities exchange shall be reported as the result. The CL message sent by the CO-subtype in response to this second CLR shall have the PME Aggregation Discovery SPar(2) bit set to zero.

In response to a “Clear if Same” command, the CO-subtype shall perform two back-to-back G.994.1 capabilities exchanges with the CPE-subtype. The contents of the NPar(3) remote_discovery_register bits in the first CLR message received from the CPE-subtype shall be ignored. The CL message sent by the CO-subtype in response to this first CLR shall have the PME Aggregation Discovery SPar(2) bit set to one, the Clear if Same NPar(3) bit set to one, and the NPar(3) remote_discovery_register bits set to the CO-subtype PME Aggregation Discovery Code register. The CPE-subtype shall clear the remote_discovery register if it is currently equal to this value. The contents of the NPar(3) remote_discovery_register bits in the CLR message received from the CPE-subtype during the second capabilities exchange shall be reported as the result. The CL message sent by the CO-subtype in response to this second CLR shall have the PME Aggregation Discovery SPar(2) bit set to zero.

Figure 61–20 illustrates the relevant sequences of G.994.1 transactions.

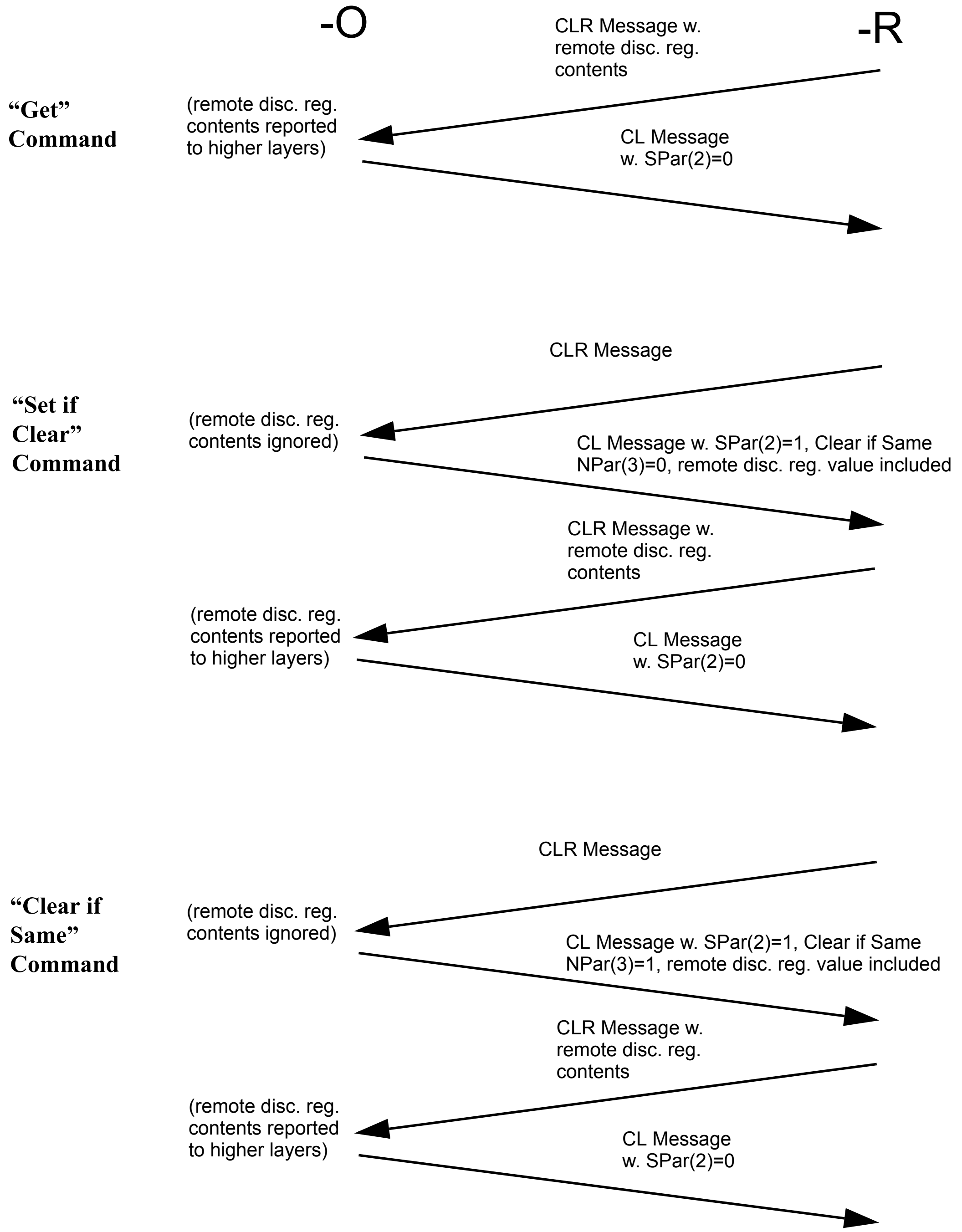

Figure 61–20—G.994.1 transactions for remote_discovery_register access

61.4.7.2 PME_Aggregate_register

2BASE-TL-R and 10PASS-TS-R PHYs shall assert the PME Aggregation SPar(2) bit in all G.994.1 CLR messages, if and only if its local PAF_available bit is set. CPE-subtypes shall place the contents of the PME_Aggregate_register in the corresponding NPar(3) bits in the outgoing CLR message.

In response to a "get" command, the CO-subtype shall perform a G.994.1 capabilities exchange with the CPE-subtype. The contents of the NPar(3) PME_Aggregate_register bits in the CLR message received from the CPE-subtype shall be reported as the result. The CL message sent by the CO-subtype in response to the CLR shall have the PME Aggregation SPar(2) bit set to zero.

In response to a “set” command, the CO-subtype shall perform two back-to-back G.994.1 capabilities exchanges with the CPE-subtype. The contents of the NPar(3) PME_Aggregate_register bits in the first CLR message received from the CPE-subtype shall be ignored. The CL message sent by the CO-subtype in response to this first CLR shall have the PME Aggregation SPar(2) bit set to one and the NPar(3) PME_Aggregate_register bit zero. The -R device sets the bit position in the PME_Aggregate_register corresponding to the PME upon which the G.994.1 exchange takes place. The contents of the NPar(3) PME_Aggregate_register bits in the CLR message received from the CPE-subtype during the second capabilities exchange shall be reported as the result. The CL message sent by the CO-subtype in response to this second CLR shall have the PME Aggregation SPar(2) bit set to zero.

61.4.7.3 Timing and preferred transactions

This subclause is applicable to devices in which 10PASS-TS and/or 2BASE-TL are the only G.994.1-initiated PHYs implemented and enabled. Start-up procedures for devices that include additional G.994.1-initiated modes of operation are outside the scope of this standard.

NOTE 1—Handshake operations specified in this subclause occur autonomously in the PHY, without intervention of the STA. They may however be triggered by an STA using the management interface.

If the PMA/PMD link control bit is set to 1 in the -O device (Table 45–18), or discovery register operations are initiated (Table 45–189), or link partner aggregation register operations are initiated (Table 45–192), the -O device initiates G.994.1 startup procedures by transmitting C-TONES.

If the PMA/PMD link control bit is set to 1 in the -R device (Table 45–18), the -R device initiates G.994.1 startup procedures by transmitting R-TONES-REQ.

At the conclusion of G.994.1 startup, the -R device shall begin G.994.1 transactions by transmitting an MR message. The -O device responds by sending C-TONES if the Ignore incoming handshake register bit (see 45.2.1.11) is set to 0_b.

If the G.994.1 session was initiated by the PMA/PMD link control bit (signifying that the link is to be brought up) in either the -O or -R device, then the -O device shall respond with an MS message specifying the configured mode of operation. However, if the PMA/PMD type selection bits in the -O device are set to the value 0011 or 0100, and a capabilities exchange has not previously taken place, the -O device shall instead respond with an REQ-CLR so that a capabilities exchange is performed. Following the final message of the capabilities exchange [i.e., an ACK(1)], the -R device once again sends an MR message. The -O device shall respond with an MS message specifying the configured mode of operation.

If the G.994.1 session was initiated in response to discovery register operations (Table 45–189), or link partner aggregation register operations (Table 45–192), then the -O device shall respond with an REQ-CLR message (MR received before) or with a CL message (CLR received before). This is then followed by one or two capability exchanges as described in the previous two subclauses. Following the final message of the final capabilities exchange [i.e., an ACK(1)], the CPE device once again sends an MR message. If neither the PMA/PMD control bit nor the discovery or link partner aggregation register operations are activated within the next 0.5 seconds, the -O shall transmit an MS message with the SPar(1) silent bit set.

NOTE 2—It is understood that the entire activation sequence consisting of PAF Discovery, PAF and line activation is time-consuming, therefore 2BASE-TL and 10PASS-TS devices are encouraged to exchange only relevant information in G.994.1 sessions during various stages of initialization.

61.5 Link segment characteristics

As stated in 61.1, the channel characteristics of voice grade copper are very diverse. Some typical channels are defined as part of the Performance Guidelines contained in Annex 62B (for 10PASS-TS) and Annex 63B (for 2BASE-TL). These annexes also define the reference performance levels for each PHY in these conditions. Behavior in other voicegrade installations may be interpolated or extrapolated from that set of references.

61.6 MDI specification

The MDI interface for 10PASS-TS and the Service Splitter and Electrical Characteristics for 10PASS-TS are defined in 62.3.5.

The Electrical Characteristics of the MDI interface for 2BASE-TL are defined in 63.3.2.

The local regulations may dictate interface characteristics in addition to or in place of some or all of these requirements.

61.7 System considerations

Both EFM Copper port types are defined for full duplex operation only, although certain MACs may still require to be configured for half duplex operation in order to respond to the carrier Sense signal, as required by the specification of MAC-PHY Rate Matching. The requirements of 31B.1 restrict the transmission of PAUSE frames to DTEs configured to the full duplex mode of operation. If PAUSE frames are used on an EFM Copper link, consideration should be given to the link latency, and the fact that the MAC-PHY Rate Matching mechanism can interfere with the expected operation of the PAUSE frame mechanism.

NOTE—It is recognized that an EFM Copper system may have to comply with additional requirements and/or restrictions outside the scope of this standard (see 61.6 and 61.8 for examples) in order to be allowed to be connected to a public infrastructure in a certain geographic area or regulatory environment. These additional requirements and/or restrictions may prohibit operation under certain profiles, or degrade the performance of the system when working under certain profiles.This may limit the system’s compliance with this standard, as compliant systems support all profiles (see Annex 62A for 10PASS-TS and Annex 63A for 2BASE-TL) and meet all performance guidelines (see Annex 62B for 10PASS-TS and Annex 63B for 2BASE-TL).

A compliant CPE-side system cannot distinguish a CO-side system designed to operate under a limited set of profiles from a fully compliant CO-side system, as the selection of profiles is under control of the CO-side. A CPE-side system designed to operate under a limited set of profiles cannot be guaranteed to correctly interoperate with compliant CO-side systems.

It is recommended that vendors of systems that support a limited set of profiles provide PICS forms to indicate which profiles are supported, in order to allow users to assess the impact on interoperability.

61.8 Environmental specifications

The requirements of 14.7 should be considered as baseline Environmental Specifications for types 10PASS-TS and type 2BASE-TL. Since equipment specified in this Clause will typically be deployed into public network environments, the specific requirements of the network operator or the local authority having jurisdiction shall prevail in all cases, and shall be considered in the development of such equipment. Such requirements may be statutory and may include product safety, electromagnetic compatibility and protection of the public network against harms from attached equipment.

61.9 PHY labeling

It is recommended that PHY equipment (and supporting documentation) be labeled in a manner visible to the user with at least the following parameters:

a) PMA/PMD (sub-)type. A type (e.g., 10PASS-TS) can be specified if both -O and -R subtypes are supported. A subtype should be specified (e.g. 10PASS-TS-R) if only a single subtype is supported.
b) PAF capability if supported. The following information should be provided: number of MII/PCS ports provided; maximum number of PMEs per MII/PCS; total number of PMEs. For example:
    1) x8 or 1x8:8 for a single MII port with 8 PMEs
    2) 2x2:4 for a device with 2 MII ports and 4 PMEs, which can be aggregated up to 2 PMEs per port
    3) 4x4:4 for a device with 4 MII ports and 4 PMEs, which can be aggregated up to 4 PMEs per port
c) Homologation information
d) Applicable safety warnings

61.10 Protocol implementation conformance statement (PICS) proforma for Clause 61, Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications type 10PASS-TS, 2BASE-TL[15]

61.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 61, Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications type 10PASS-TS, 2BASE-TL, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

61.10.2 Identification

61.10.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification--e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

61.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 61, Physical Coding Sublayer (PCS) and common specifications, type 10PASS-TS and 2BASE-TL.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[15] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

61.10.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
RM	MAC-PHY Rate Matching	61.2.1	CRS deference mechanism supported.	M	Yes [ ]
TC	64/65-octet Encapsulation	61.3	The Ethernet-specific TPS-TC, between α(β)-interface and γ-interface is implemented.	M	Yes [ ]
*PAF	PME Aggregation	61.2.2	Up to 32 PMA/PMD instances can be aggregated into a single MAC.	O	Yes [ ] No [ ]
HS	Support for G.994.1 handshake	61.4	PHY uses G.994.1 handshake to identify remote transceiver and exchange capabilities.	M	Yes [ ]
*2BO	2BASE-TL-O subtype	61, 63	The 2BASE-TL CO subtype is implemented.	O.1	Yes [ ] No [ ]
*2BR	2BASE-TL-R subtype	61, 63	The 2BASE-TL CPE subtype is implemented.	O.1	Yes [ ] No [ ]
*10PO	10PASS-TS-O subtype	61, 62	The 10PASS-TS CO subtype is implemented.	O.1	Yes [ ] No [ ]
*10PR	10PASS-TS-R subtype	61, 62	The 10PASS-TS CPE subtype is implemented.	O.1	Yes [ ] No [ ]

61.10.4 PICS proforma tables for the Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications type 10PASS-TS, 2BASE-TL

61.10.4.1 MAC-PHY Rate Matching

Item	Feature	Subclause	Value/Comment	Status	Support
RM-1	MAC-PHY Rate Matching functions	61.2.1.1	The PHY uses CRS to match the MAC’s faster rate of data transmission to the PHY’s slower rate.	M	Yes [ ]
RM-2	MAC-PHY Rate Matching functions	61.2.1.1	Upon receipt of a MAC frame from the MII, the PHY discards the Preamble and SFD fields, and transmits the resulting data frame across the physical link.	M	Yes [ ]
RM-3	MAC-PHY Rate Matching functions	61.2.1.1	The PHY prepends the Preamble and the SFD fields to a received frame before sending it to the MAC.	M	Yes [ ]
RM-4	MAC-PHY Rate Matching functions	61.2.1.1	The PHY supports a mode of operation where it does not send data to the MAC while the MAC is transmitting.	M	Yes [ ]

61.10.4.2 64/65-octet Encapsulation

Item	Feature	Subclause	Value/Comment	Status	Support
TC-1	The γ-interface	61.3.1	The PAF asserts Tx_Avbl when it has a whole data fragment available for transmission, and de-assert Tx_Avbl when there are no data fragments to transmit.	M	Yes [ ]
TC-2	TC functions	61.3.3	The TC provides full transparent transfer of data frames between γ_O-interface and γ_R-interface.	M	Yes [ ]
TC-3	TC functions	61.3.3	The TC provides fragment integrity and fragment error monitoring capability.	M	Yes [ ]
TC-4	TC functions	61.3.3	The bit rate of data transport in the upstream and downstream directions are set independently of each other to any eligible value up to the maximum rate determined by the PMD.	M	Yes [ ]
TC-5	TC Encapsulation and Coding	61.3.3.1	When a frame arrives from the γ-interface while an End of Frame codeword is being transmitted, a Start of Frame octet is inserted prior to the transmission of data octets belonging to the next frame.	M	Yes [ ]
TC-6	Sync detection	61.3.3.5	The synchronization is acquired from the incoming data stream.	M	Yes [ ]
TC-7	Sync detection	61.3.3.5.2	The receiver implements the sync detect state diagram shown in Figure 61–17.	M	Yes [ ]
TC-8	Receive control	61.3.3.6	If TC_synchronized = false then signal RX_Enbl is de-asserted.	M	Yes [ ]
TC-9	Receive control	61.3.3.6	If a TC-CRC error is detected, the receive controller asserts signal RX_Err during at least one octet of the fragment as it is passed up across the γ-interface.	M	Yes [ ]
TC-10	Receive control	61.3.3.6	If the fragment contains data from a block in which the PMA detected errors but did not correct them, the receive controller asserts signal RX_Err during at least one octet of a fragment as it is passed up across the γ-interface.	M	Yes [ ]

61.10.4.3 PME Aggregation[16]

Item	Feature	Subclause	Value/Comment	Status	Support
PAF-1	PME Aggregation Receive function	61.2.2.4	When the link state is changed to UP, the expected sequence number is unknown and no frame sequence errors are recorded.	*PAF:M	Yes [ ]
PAF-2	PME Aggregation Transmit Function Restrictions	61.2.2.6	The differential latency between any two PMEs in an aggregated group is no more than 15 000 bit times.	*PAF:M	Yes [ ]
PAF-3	PME Aggregation Transmit Function Restrictions	61.2.2.6	Fragments are not less than 64 octets.	*PAF:M	Yes [ ]
PAF-4	PME Aggregation Transmit Function Restrictions	61.2.2.6	Fragments are not more than 512 octets.	*PAF:M	Yes [ ]
PAF-5	PME Aggregation Transmit Function Restrictions	61.2.2.6	The highest ratio of speeds between any two aggregated links is 4.	*PAF:M	Yes [ ]
PAF-6	PME Aggregation Transmit Function Restrictions	61.2.2.6	The fragment size is a multiple of 4 octets except for the last fragment of a data frame.	*PAF:M	Yes [ ]
PAF-7	Error-detecting Rules	61.2.2.7	For each PMA, the per-PMA buffering mechanism discards the fragment if any of the listed conditions occur, and asserts the PAF error flags as appropriate. If the packet assembly function was mid-frame, the first part of the frame is transferred across the MII, then the RX_ER signal is asserted on the MII, the frame transfer is aborted and PMA buffers are flushed until the next Start of Packet is received.	*PAF:M	Yes [ ]
PAF-8	Error-detecting Rules	61.2.2.7	If a fragment is received with the StartOfPacket bit asserted while the packet assembly function was mid-frame, the first part of the frame is transferred across the MII, then the RX_ER signal is asserted on the MII, the frame transfer is aborted and PMA buffers are flushed until the next Start of Packet is received.	*PAF:M	Yes [ ]
PAF-9	PME aggregation register functions	61.2.2.8.3	The remote_discovery_register and Aggregation_link_state_register are implemented.	*PAF:M	Yes [ ]
PAF-10	PME aggregation register functions	61.2.2.8.3	The PME_Available_register is read-only.	*PAF: *2BO:M *10PO:M	Yes [ ]

PAF-11	PME aggregation register functions	61.2.2.8.3	The PME_Available_register is writeable.	*PAF: *2BR:O *10PR:O	Yes [ ] No [ ]
PAF-12	PME aggregation register functions	61.2.2.8.3	For a device that does not support aggregation of multiple PMEs, a single bit of the PME_Available_register is set and all other bits clear.	*PAF:M	Yes [ ]
PAF-13	PME aggregation register functions	61.2.2.8.3	The PME_Available_register is read-only.	*PAF: *2BO:M *10PO:M	Yes [ ]
PAF-14	PME aggregation register functions	61.2.2.8.3	The PME_Available_register is writeable.	*PAF: *2BR:O *10PR:O	Yes [ ] No [ ]
PAF-15	PME aggregation register functions	61.2.2.8.3	For CPE-subtype devices, PMD links are not enabled until the PME_Available_register has been set to limit the connectivity such that each PME maps to one, and only one MII.	*PAF:M	Yes [ ]
PAF-16	PME aggregation register functions	61.2.2.8.3	If the remote_discovery_register is clear then the PME_Aggregate_register is cleared.	*PAF:M	Yes [ ]
PAF-17	PME aggregation register functions	61.2.2.8.3	The remote_discovery_register is implemented for CPE-subtype devices.	*PAF: *2BR:M *10PR:M	Yes [ ]
PAF-18	PME aggregation register functions	61.2.2.8.3	The remote_discovery_register supports atomic write operations and reads from remote devices via the remote access signals passed across the γ-interface from the PMA.	*PAF:M	Yes [ ]
PAF-19	PME aggregation register functions	61.2.2.8.3	If multiple write_remote_discovery_reg signals are asserted they are acted upon serially.	*PAF:M	Yes [ ]
PAF-20	PME aggregation register functions	61.2.2.8.3	If the logical AND of the Aggregation_link_state_register and the PME_Aggregate_register is clear then a time-out counter is started. If this condition continues for 30 seconds then the remote_discovery_register is cleared.	*PAF:M	Yes [ ]
PAF-21	Remote access of PME Aggregation registers	61.4.7	The “TDIM Bonding” SPar(1) bit is deasserted.	*PAF:M	Yes [ ]

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[16] All items listed in this section are only applicable if the optional PME Aggregation Function is supported.

PAF-22	Remote_discovery_register	61.4.7.1	2BASE-TL-R and 10PASS-TS-R PHYs assert the PME Aggregation Discovery SPar bit in all G.994.1 CLR messages, if and only if its local PAF_available bit is set.	*PAF:M	Yes [ ]
PAF-23	Remote_discovery_register	61.4.7.1	CPE-subtypes place the contents of the remote_discovery_register in the corresponding NPar bits in the outgoing CLR message, with the “Clear if Same” NPar set to zero.	*PAF:M	Yes [ ]
PAF-24	Remote_discovery_register	61.4.7.1	In response to a “Get” command, the CO-subtype performs a G.994.1 capabilities exchange with the CPE-subtype. The contents of the NPar remote_discovery_register bits in the CLR message received from the CPE-subtype are reported as the result.	*PAF:M	Yes [ ]
PAF-25	Remote_discovery_register	61.4.7.1	The CL message sent by the CO-subtype in response to the CLR has the PME Aggregation Discovery SPar bit set to zero.	*PAF:M	Yes [ ]
PAF-26	Remote_discovery_register	61.4.7.1	In response to a “Set if Clear” command, the CO-subtype performs two back-to-back G.994.1 capabilities exchanges with the CPE-subtype. The contents of the NPar remote_discovery_register bits in the first CLR message received from the CPE-subtype are ignored.	*PAF:M	Yes [ ]
PAF-27	Remote_discovery_register	61.4.7.1	The CL message sent by the CO-subtype in response to the first CLR has the PME Aggregation Discovery SPar bit set to one, the Clear if Same NPar bit set to zero, and the NPar remote_discovery_register bits set to the CO-subtype PME Aggregation Discovery Code register.	*PAF:M	Yes [ ]
PAF-28	Remote_discovery_register	61.4.7.1	In a set-if-clear exchange, the CPE-subtype sets the remote_discovery register to the value of the Remote Discovery register NPar(3) if it is currently clear.	*PAF:M	Yes [ ]

PAF-29	Remote_discovery_register	61.4.7.1	The contents of the NPar remote_discovery_register bits in the CLR message received from the CPE-subtype during the second capabilities exchange are reported as the result.	*PAF:M	Yes [ ]
PAF-30	Remote_discovery_register	61.4.7.1	The CL message sent by the CO-subtype in response to the second CLR has the PME Aggregation Discovery SPar bit set to zero.	*PAF:M	Yes [ ]
PAF-31	Remote_discovery_register	61.4.7.1	In response to a "Clear if Same" command, the CO-subtype performs two back-to-back G.994.1 capabilities exchanges with the CPE-subtype. The contents of the NPar remote_discovery_register bits in the first CLR message received from the CPE-subtype are ignored.	*PAF:M	Yes [ ]
PAF-32	Remote_discovery_register	61.4.7.1	The CL message sent by the CO-subtype in response to the first CLR has the PME Aggregation Discovery SPar bit set to one, the Clear if Same NPar bit set to one, and the NPar remote_discovery_register bits set to the CO-subtype PME Aggregation Discovery Code register.	*PAF:M	Yes [ ]
PAF-33	Remote_discovery_register	61.4.7.1	In a clear-if-same exchange, the CPE-subtype clears the remote_discovery register if it is currently equal to the value of the Remote Discovery register NPar(3).	*PAF:M	Yes [ ]
PAF-34	Remote_discovery_register	61.4.7.1	The contents of the NPar remote_discovery_register bits in the CLR message received from the CPE-subtype during the second capabilities exchange are reported as the result.	*PAF:M	Yes [ ]
PAF-35	Remote_discovery_register	61.4.7.1	The CL message sent by the CO-subtype in response to the second CLR has the PME Aggregation Discovery SPar bit set to zero.	*PAF:M	Yes [ ]
PAF-36	PME_Aggregate_register	61.4.7.2	2BASE-TL-R and 10PASS-TS-R PHYs assert the PME Aggregation SPar bit in all G.994.1 CLR messages, if and only if their local PAF_available bit is set.	*PAF:M	Yes [ ]

PAF-37	PME_Aggregate_register	61.4.7.2	CPE-subtypes place the contents of the PME_Aggregate_register in the corresponding NPar bits in the outgoing CLR message.	*PAF:M	Yes [ ]
PAF-38	PME_Aggregate_register	61.4.7.2	In response to a “get” command, the CO-subtype performs a G.994.1 capabilities exchange with the CPE-subtype. The contents of the NPar PME_Aggregate_register bits in the CLR message received from the CPE-subtype are reported as the result.	*PAF:M	Yes [ ]
PAF-39	PME_Aggregate_register	61.4.7.2	The CL message sent by the CO-subtype in response to the CLR has the PME Aggregation SPar bit set to zero.	*PAF:M	Yes [ ]
PAF-40	PME_Aggregate_register	61.4.7.2	In response to a “set” command, the CO-subtype performs two back-to-back G.994.1 capabilities exchanges with the CPE-subtype. The contents of the NPar PME_Aggregate_register bits in the first CLR message received from the CPE-subtype are ignored.	*PAF:M	Yes [ ]
PAF-41	PME_Aggregate_register	61.4.7.2	The CL message sent by the CO-subtype in response to the first CLR has the PME Aggregation SPar bit set to one and the NPar PME_Aggregate_register bit zero.	*PAF:M	Yes [ ]
PAF-42	PME_Aggregate_register	61.4.7.2	The contents of the NPar PME_Aggregate_register bits in the CLR message received from the CPE-subtype during the second capabilities exchange are reported as the result.	*PAF:M	Yes [ ]
PAF-43	PME_Aggregate_register	61.4.7.2	The CL message sent by the CO-subtype in response to the second CLR has the PME Aggregation SPar bit set to zero.	*PAF:M	Yes [ ]
PAF-44	Timing and preferred transactions	61.4.7.3	At the conclusion of G.994.1 startup, the -R device begins G.994.1 transactions by transmitting an MR message.	*PAF:M	Yes [ ]
PAF-45	Timing and preferred transactions	61.4.7.3	If the G.994.1 session was initiated by the PMA/PMD link control bit in either the -O or -R device, then the -O device responds with an MS message specifying the configured mode of operation.	*PAF:M	Yes [ ]

PAF-46	Timing and preferred transactions	61.4.7.3	If the PMA/PMD type selection bits in the -O device are set to the value 0011 or 0100, and a capabilities exchange has not previously taken place, the -O device instead responds with an REQ-CLR so that a capabilities is performed.	*PAF:M	Yes [ ]
PAF-47	Timing and preferred transactions	61.4.7.3	The -O device responds with an MS message specifying the configured mode of operation.	*PAF:M	Yes [ ]
PAF-48	Timing and preferred transactions	61.4.7.3	If the G.994.1 session was initiated in response to discovery register operations, or link partner aggregation register operations, then the -O device responds with an REQ-CLR message or with a CL message.	*PAF:M	Yes [ ]
PAF-49	Timing and preferred transactions	61.4.7.3	If neither the PMA/PMD control bit nor the discovery or link partner aggregation register operations are activated within 0.5 seconds after an MR message, the -O transmits an MS message with the SPar silent bit set.	*PAF:M	Yes [ ]

61.10.4.4 Handshaking

Item	Feature	Subclause	Value/Comment	Status	Support
HS-1	Revision number: reference G.994.1 section 9.3.2	61.4.1	G.994.1 Revision Number 3 or higher is implemented.	M	Yes [ ]
HS-2	Summary of handshaking and PHY control specification	61.1.4.3	Devices implementing both 2BASE-TL and 10PASS-TS port types use G.994.1 to determine a common mode of operation.	O	Yes [ ] No [ ]
HS-3	4.3125 kHz signaling family: reference G.994.1 section 6.1.1	61.4.3	The mandatory carrier set listed in Table 61–13 is transmitted.	10PR:M 10PO:M	Yes [ ]
HS-4	4 kHz signaling family: reference G.994.1 section 6.1.2	61.4.3	The mandatory carrier set listed in Table 61–14 is transmitted.	2BR:M 2BO:M	Yes [ ]
HS-5	Prohibited carrier sets	61.4.3	Carriers not listed in Reference Table 1 or Reference Table 3 are not transmitted.	M	Yes [ ]
HS-6	Optional carrier sets	61.4.3	One or more carriers listed in Reference Table 1 or Reference Table 3 are transmitted in addition to a mandatory carrier set listed in Table 61–13 or Table 61–14.	O	Yes [ ] No [ ]
HS-7	Standard information field coding	61.4.4	The Standard information field (S) codepoints specified in Annex 61B are used in the transactions specified in 61.4.4.	M	Yes [ ]

62. Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS

62.1 Overview

62.1.1 Scope

This clause specifies the 10PASS-TS Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD) for voice grade twisted-pair wiring. In order to form a complete 10PASS-TS PHY, the 10PASS-TS PMA and PMD are integrated with the TC and PCS of Clause 61. Parts of register 3.0, parts of register 3.4, and registers 3.60 through 3.73 specified in Clause 45 may be used to control the PCS of Clause 61. Parts of register 6.0 and registers 6.16 through 6.23 specified in Clause 45 may be used to control the TC sublayer of Clause 61. Registers 1.16 through 1.71 may be used to control the 10PASS-TS PMA and PMD.

62.1.2 Objectives

The following are the objectives for the 10PASS-TS PMA and PMD:

a) To provide 10Mb/s encapsulated packet data rate at the α(β)-interface.
b) To provide full duplex operation.
c) To provide for operating over non-loaded voice grade twisted pair cable at distances up to 750 m.
d) To provide a communication channel with a mean bit error ratio, at the α(β)-interface, of less than one part in 10^7 with 6 dB noise margin.

62.1.3 Relation of 10PASS-TS to other standards

The specifications of 10PASS-TS PMA and PMD are based on the VDSL transceiver specified in ANSI T1.424.

62.1.4 Summary of Physical Medium Attachment (PMA) specification

This layer is defined by the α(β)-interface and the I-interface.

62.1.4.1 α(β)-interface

A complete definition of the α(β)-interface is contained in 61.3.2.

62.1.4.2 I-interface

The I_O and I_R reference points define interfaces between the PMA and PMD in the 10PASS-TS-O and 10PASS-TS-R, respectively. Both interfaces are functional, application independent and identical. Both interfaces are defined by the following signal flows:

a) Data flow
b) Synchronization flow

62.1.4.2.1 I Data Flow

The data flow consists of the following two octet-oriented streams, both with the PMA frame format, with the bit rates defined by the PMD transmission profile:

a) Transmitted data (Tx)
b) Received data (Rx)

If data streams are implemented serially, the MSB of each octet is sent first.

Each stream bit rate value is set during PMD configuration.

62.1.4.2.2 I Synchronization Flow

The synchronization flow consists of the transmitted and received octet synchronization signals (Clko_t, Clko_r). Optional transmit and receive bit-synchronization signals (Clkp_t, Clkp_r) are defined too.

Synchronization signals are asserted by the PMD and directed towards the PMA.

The synchronization flow signals are described in Table 62–1.

Table 62–1—I-interface signals

Signal(s)	Description	Direction	Notes
Data signals			
Tx	Transmitted data stream	PMA → PMD	Transmission frame format.
Rx	Received data stream	PMA ← PMD	
Synchronization signals			
Clko_t	Transmitted octet timing	PMA ← PMD	
Clko_r	Received octet timing	PMA ← PMD	
Clkp_t	Transmitted bit timing	PMA ← PMD	Optional
Clkp_r	Received bit timing	PMA ← PMD	Optional

62.2 PMA functional specifications

For the purpose of transmission over a serial implementation of the α(β)-interface or the I-interface, bit b_8 as defined in Figure 61–16 is considered MSB and shall therefore be transmitted first. However, for the purpose of all serial processing (e.g., scrambling, CRC calculation) bit b_8 is considered LSB and shall therefore be the first bit processed. Thus, the outside world MSB is considered as the 10PASS-TS LSB.

62.2.1 PMA functional diagram

Figure 62–1 shows a diagram of the PMA sublayer.

62.2.2 PMA functional specifications

The 10PASS-TS PMA is specified by incorporating the VDSL standard, ANSI T1.424, by reference, with the modifications noted below. This standard provides support for voice-grade twisted pair. For improved legibility in this clause, ANSI T1.424, will henceforth be referred to as MCM-VDSL.

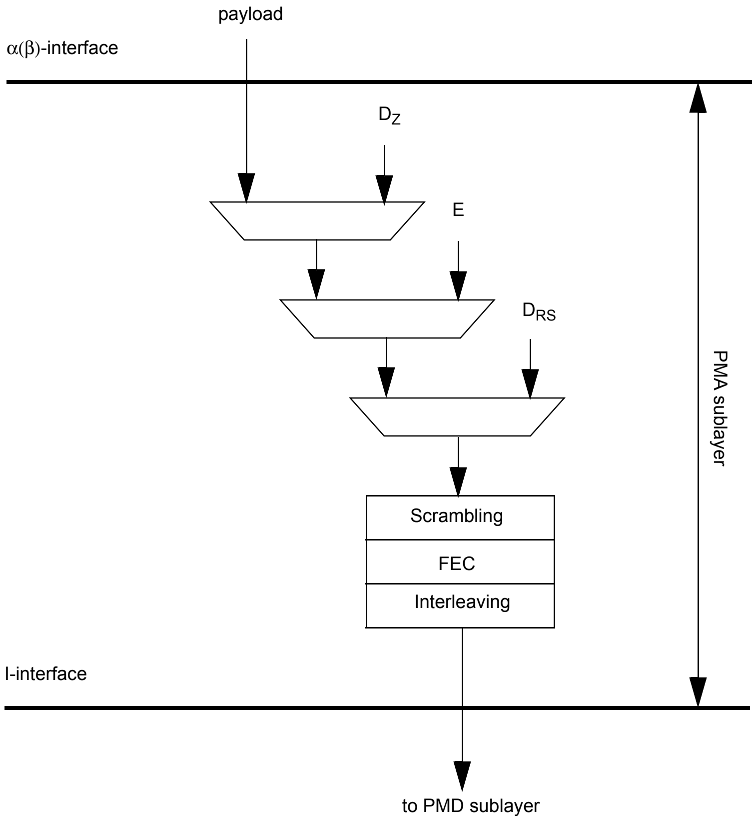

Figure 62–1—Diagram of PMA sublayer

62.2.3 General exceptions

The 10PASS-TS PMA is precisely the PMS-TC specified in MCM-VDSL, with the following general modifications:

a) There are minor terminology differences between this standard and MCM-VDSL that do not cause ambiguity. The terminology used in 10PASS-TS was chosen to be consistent with other IEEE 802 standards, rather than with MCM-VDSL. Terminology is both defined and consistent within each standard. Special note should be made of the interpretations shown in Table 62–2.
b) The 10PASS-TS PMA does not support the “fast path”.

Table 62–2—Interpretation of general MCM-VDSL terms and concepts

MCM-VDSL term or concept	Interpretation for 10PASS-TS
PMS-TC	PMA
VTU-O, LT	10PASS-TS-O
VTU-R, NT	10PASS-TS-R
Transmission medium dependent interface	MDI
U1-interface (splitter present)	
U2-interface (splitter absent)	

62.2.4 Specific requirements and exceptions

The 10PASS-TS PMA shall comply to the requirements of MCM-VDSL Section 9.3 with the exceptions listed below. Where there is conflict between specifications in MCM-VDSL and those in this standard, those of this standard shall prevail.

62.2.4.1 Replacement of 9.3.1, "PMS-TC functional diagram"

Replace 9.3.1 of MCM-VDSL by the PMA functional diagram in 62.2.1.

62.2.4.2 Changes to 9.3.3, "Forward error correction"

Referenced as is, with the exception of required Reed-Solomon encoder and interleaver settings.

The mandatory settings in MCM-VDSL (144,128) and (240,224) shall be supported. Other values are out of scope.

The following interleaver parameters shall be supported:

a) For (N,K)=(144,128) the following values for M and I shall be supported: I=36 and M between 2 and 52
b) For (N,K)=(240,224) the following values for M and I shall be supported: I=30 and M between 2 and 62

Other settings for M and I are out of scope.

62.2.4.3 Changes to 9.3.5, "Framing"

Referenced as is, with following exceptions:

a) The "fast" buffer is not supported
b) There shall be 1 VOC byte per packet; other values of V as defined in 9.3.5.5 are outside the scope of this standard
c) 9.3.5.5.4 (NTR) is not applicable
d) In Table 9-4 (9.3.5.5.3), following changes apply
    1) bits B2, B3 of Byte #2 are reserved
    2) bits B1, B2, B3, B4 of Byte #3 shall be set to 0

Additional text: the signal PMA_receive_synchronized, defined in 61.3.2.2, shall be asserted when 10PASS-TS is in the state "STEADY_STATE_TRANSMISSION" (see Figure 62–4), and deasserted when 10PASS-TS is in any other state.

62.3 PMD functional specifications

62.3.1 PMD Overview

The 10PASS-TS PMD functional model is presented in Figure 62–2. In the transmit direction, the PMD layer receives frames from the PMA layer. It sends a DMT modulated signal towards the physical medium over the MDI.

The bytes within the frame are encoded to a set of QAM constellation points that are used to modulate the carriers of the DMT symbol. The time-domain symbol is cyclically extended and then windowed to reduce sidelobe energy.

In the receive direction, a modulated signal is received from the transmission medium over the MDI. The PMD layer outputs a data frame to the PMA layer. The receiver is responsible for equalization and demodulation of the signal.

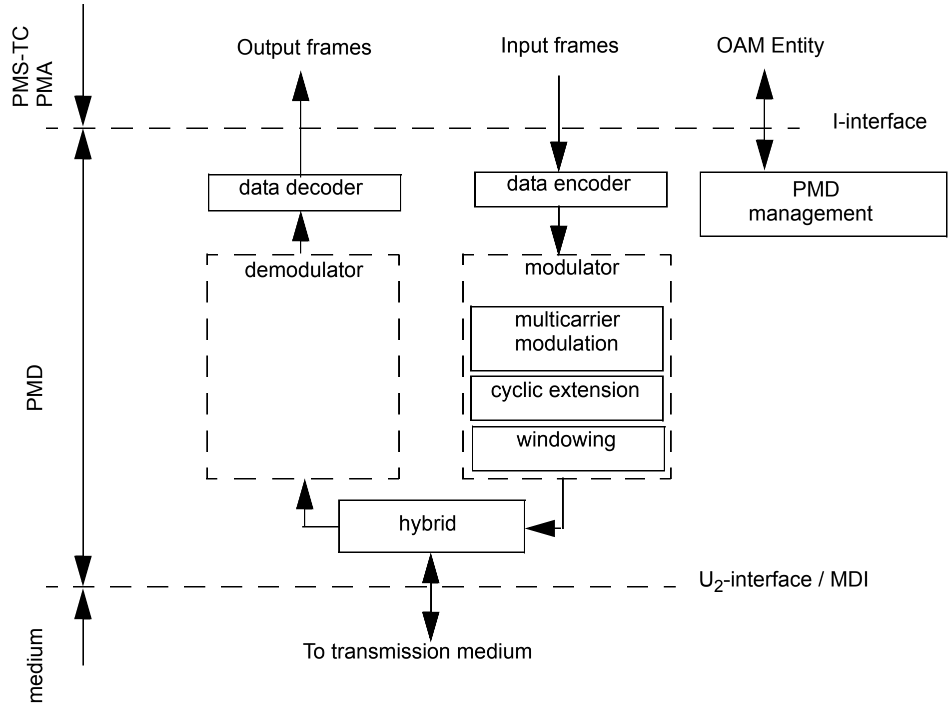

Figure 62–2—Functional diagram of PMD sublayer

62.3.2 PMD functional specifications

The 10PASS-TS PMD (and MDI) is specified by incorporating the MCM-VDSL standard, ANSI T1.424, by reference, with the modifications noted below. This standard provides support for voice-grade twisted pair.

62.3.3 General exceptions

The 10PASS-TS PMD is precisely the PMD specified as MCM-VDSL, with the following general modifications:

There are minor terminology differences between this standard and MCM-VDSL that do not cause ambiguity. The terminology used in 10PASS-TS was chosen to be consistent with other IEEE 802 standards, rather than with MCM-VDSL. Terminology is both defined and consistent within each standard. Special note should be made of the interpretations shown in Table 62–3.

Table 62–3—Interpretation of general MCM-VDSL terms and concepts

MCM-VDSL term or concept	Interpretation for 10PASS-TS
PMS-TC	PMA
VTU-O, LT	10PASS-TS-O
VTU-R, NT	10PASS-TS-R
Transmission medium dependent interface	MDI
U1-interface (splitter present)	
U2-interface (splitter absent)	

62.3.4 Specific requirements and exceptions

The 10PASS-TS PMD (including MDI) shall comply to the requirements of MCM-VDSL Section 8 [Physical medium dependent (PMD) sublayer], Section 10 (Operations and maintenance), Section 11 (Link activation and deactivation) and Section 18 (Normative Annex 4—Handshake procedure for VDSL) with the exceptions listed below. Section 12 (Test procedures and requirements), Section 13 (Physical conditions), Section 14 (Environmental conditions), Section 15 (Normative Annex 1: International amateur bands), Section 16 (Informative Annex 2: VDSL PSD templates figures), Section 17 (Informative Annex 3: Utopia implementation of the ATM-TC interface), Section 19 (Informative Annex 5: FMT implementation), Section 20 (Informative Annex 6: 8.625 kHz tone spacing), Section 21 (Normative Annex 7: Electrical characteristics of service splitter at remote subscriber end), Section 22 (Informative Annex 8: Electrical characteristics of service splitter at network end), and Section 23 (Informative Annex 9: Alien crosstalk descriptions), are outside the scope of this standard. Where there is conflict between specifications in MCM-VDSL and those in this standard, those of this standard shall prevail. Optional specifications in MCM-VDSL are out of scope unless explicitly referenced in this document as mandatory. If out-of-scope optional features are implemented, the mode of operation of the PHY cannot be labeled “10PASS-TS” when these features are activated.

NOTE—If optional features are implemented, their use is negotiated during initialization.

62.3.4.1 Replacement of 8.2.1, “Multi-carrier Modulation”

10PASS-TS transceivers shall use Frequency Division Duplexing (FDD) to separate upstream and downstream transmission. 10PASS-TS transceivers shall support modulation of $N_{SC} = 4096$ subcarriers ($n = 4$). Disjoint subsets of the N_{SC} subcarriers shall be defined for use in the downstream and upstream directions. These subsets are determined by the choice of frequency plan. The exact subsets of subcarriers used to modulate data in each direction shall be determined during initialization and shall be based on management system settings and the signal-to-noise ratios (SNRs) of the subchannels. In many cases the number of subcarriers used in a direction will be less than the maximum number allowed by the partitioning.

Frequency plans are defined in Annex 62A. In standard frequency plans, frequency bands are allocated as shown in Figure 62–3. The values of the splitting frequencies are given in Annex 62A. Adherence to a particular frequency plan may be mandatory under local regulations when 10PASS-TS is deployed in public networks. Other frequency plans, for use in private networks, can be supported by means of Clause 45 register settings (see Annex 62C for examples).

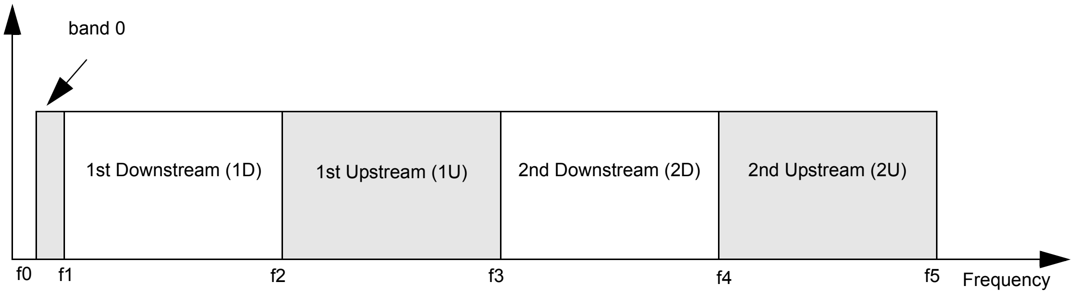

Figure 62–3—10PASS-TS band allocation

8.2.1.1 (Tone Spacing) is referenced as is.

8.2.1.2 (Data Sub Carriers) is referenced as is.

8.2.1.3 (IDFT modulation) is referenced as is.

62.3.4.2 Changes to 8.2.2, “Cyclic extension”

8.2.2 of MCM-VDSL is further restricted by the following normative text:

The cyclic extension length is specified by the value of parameter m. In 10PASS-TS, support for the values $m = 10$, $m = 20$, and $m = 40$ is mandatory. The value m=20 is the default setting. Support for other values is out of scope.

62.3.4.3 Changes to 8.2.3, “Synchronization”

8.2.3.1 of MCM-VDSL is further clarified by the following text:

Support for pilot tones is mandatory. 10PASS-TS-O PHYs shall support the transmission of a pilot tone on any downstream tone.

8.2.3.2 (Loop Timing) is referenced as is.

8.2.3.3 (Timing Advance) is referenced as is.

8.2.3.4 of MCM-VDSL is replaced with the following:

The use of synchronous mode as defined in MCM-VDSL 8.2.3.4 may improve operation in certain binder environments and is a system implementation item that is outside the scope of this standard.

62.3.4.4 Replacement of 8.2.4, “Power back-off in the upstream direction”

To mitigate the effects of FEXT from short lines into long lines in distributed cable topologies, upstream power back-off shall be applied. Transceivers shall be capable of performing frequency-dependent power back-off.

It shall be possible to temporarily disable UPBO for performance testing purposes (as required by Annex 62B). In normal operation, only one UPBO mode shall be supported as described below:

a) It shall be possible for the network management system to set the limiting transmit PSD template PSD_0 for the 10PASS-TS-R to one of the standard transmit PSD templates as defined in the applicable section of 62A.3.3.
b) The 10PASS-TS-R shall perform UPBO autonomously, i.e., without sending any significant information to the 10PASS-TS-O until the UPBO is applied.
c) After UPBO has been applied as described in item b), the 10PASS-TS-O shall be capable of adjusting the transmit PSD selected by the 10PASS-TS-R; the adjusted transmit PSD shall be subject to the limitations given in the applicable section of 62A.3.3.

To enable the 10PASS-TS-R to initiate a connection with the 10PASS-TS-O, which will occur before UPBO has been applied, the 10PASS-TS-R shall be allowed to cause more degradation to other loops than expected when using the mode described below.

NOTE—Initiation refers to a request from the 10PASS-TS-R to start the initialization of the link. The particular method is in MCM-VDSL 11.2.

The 10PASS-TS-R shall explicitly estimate the electrical length of its line, kl_0, and use this value to calculate the transmit PSD template $TxPSD(kl_0,f)$. The 10PASS-TS-R shall then adapt its transmit signal PSD to conform to the template $TxPSD(kl_0,f)$ and the corresponding PSD mask, which is defined in the applicable section of 62A.3.3.

The transmit PSD template shall be calculated as shown in Equation (62–1):

$$TxPSD(kl_0,f) = \min\,(PSD\_REF(f) + LOSS(kl_0,f), PSD_0)\text{, in dBm/Hz} \qquad (62–1)$$

where PSD_0 as defined in item a) in the previous list, and:

$$LOSS = kl_0 \operatorname{sqrt}(f)\text{, in dB} \qquad (62–2)$$

where the *LOSS* function is an approximation of the loop attenuation (insertion loss).

NOTE—The estimation of the electrical length should be sufficiently accurate to avoid spectrum management problems and additional performance loss.

PSD_REF will depend on the limiting transmit PSD template PSD_0 and on the noise model that is relevant for a given deployment scenario. The values of *PSD_REF* depend on the selected UPBO Reference PSD profile, as shown in Table 62A-3. The same bandwidth as for all regular transmit PSD masks defined in the applicable section of 62A.3.3 shall be used to check the conformance of *TxPSD* with power back-off. The general methodology for testing PSD conformance is defined in 6.1 of T1.417. Conformance with the PSD template shall be verified using a 100 kHz sliding window in the in-band frequency range below 1 MHz and a 1 MHz sliding window in the in-band frequency range above 1 MHz.

PSD_REF shall be input via the management interface (by means of the UPBO Reference PSD field in the 10P tone control parameter register, see 45.2.1.39) and shall be transmitted from the 10PASS-TS-O to the 10PASS-TS-R.

The 10PASS-TS-R shall estimate the insertion losses of the upstream bands based on the received downstream signals. From this, the shape of the *LOSS* function (or, equivalently, the electrical length) as defined above shall be derived. The 10PASS-TS-R shall then compute the transmit PSD by dividing the reference PSD in the upstream bands by the estimated *LOSS* function. Next, the 10PASS-TS-R shall take a tone-by-tone minimum of this computed PSD and the maximum allowed transmit PSD in the upstream direction. The result shall be used as the initial upstream transmit PSD. The PSD received by the 10PASS-TS-O should approximate the reference PSD. Upon receiving signals from the 10PASS-TS-R, the 10PASS-TS-O shall compare the actual received PSD to the reference PSD. If necessary, it shall instruct the 10PASS-TS-R to fine-tune its PSD.

The 10PASS-TS-O shall also have the capability to directly impose a maximum allowed transmit PSD at the 10PASS-TS-R. This maximum transmit PSD shall also be input via the management interface and shall be transmitted from 10PASS-TS-O to 10PASS-TS-R in the early stages of the initialization. The 10PASS-TS-O shall allow the operator to select one of these two methods. If the PBO is defined as a maximum transmit PSD at the 10PASS-TS-R, the 10PASS-TS-R shall adjust its transmit PSD such that it does not exceed the maximum allowed transmit PSD. The restrictions specified in the previous paragraph shall also apply in this case (i.e., the 10PASS-TS-O shall not impose a transmit PSD mask that violates the mask specified there).

62.3.4.5 Changes to 8.2.5, "Constellation encoder"

In 8.2.5 of MCM-VDSL, the constraints on B_{max_d} and B_{max_u} are replaced by the following constraints:

$$B_{max\_d} = 12 \qquad (62–3)$$

$$B_{max\_u} = 12 \qquad (62–4)$$

62.3.4.6 Changes to 8.2.8, "U-interface characteristics"

8.2.8 is replaced with the requirements specified in 62A.3.5.

All other subclauses in MCM-VDSL Clause 8 are referenced as is.

62.3.4.7 Changes to section 10, “Operations and maintenance”

Referenced as is, with the addition of the mapping between VTU-R data registers and Clause 45 register access shown in Table 62–4.

Table 62–4—Mapping of VTU-R data registers to Clause 45

VTU-R data register (eoc)		Clause 45 register access 10PASS-TS-O		Clause 45 register access 10PASS-TS-R	
Register number	**Description**[a]	**register**	**Subclause**	**Clause 45 register**	**Subclause**
0_{16}	VTU-R vendor ID	not applicable			
1_{16}	VTU-R revision number	not applicable			
2_{16}	VTU-R serial number	not applicable			
3_{16}	Self-test results	PMA/PMD link status[b]	45.2.1.16.4	PMA/PMD link status[c]	45.2.1.16.4
4_{16}	Performance[d]	bytes 00_{16}–03_{16}: attainable DS rate bytes 04_{16}–05_{16}: FEC correctable errors bytes 08_{16}–09_{16}: FEC uncorrectable errors	45.2.1.45 45.2.1.28 45.2.1.29	bytes 00_{16}–03_{16}: attainable DS rate bytes 04_{16}–05_{16}: FEC correctable errors bytes 08_{16}–09_{16}: FEC uncorrectable errors	45.2.1.45 45.2.1.26 45.2.1.27
5_{16}	Vendor-discretionary	not applicable			
6_{16}	Loop attenuation	10P/2B line attenuation	45.2.1.23	10P/2B line attenuation	45.2.1.22
7_{16}	SNR margin	10P/2B RX SNR margin	45.2.1.21	10P/2B RX SNR margin	45.2.1.20
8_{16}	VTU-R configuration	not applicable			
9-F_{16}	For future use	not applicable			

[a] This is the description of the VTU-R data registers as given in MCM-VDSL.
[b] A non-zero value of the Self-test results register shall cause PMA/PMD link status to be cleared to 0.
[c] A non-zero value of the Self-test results register shall cause PMA/PMD link status to be cleared to 0.
[d] This field contains 16 bytes in total. The bytes that are not mapped to a Clause 45 register in this table, are reserved.

62.3.4.8 Changes to 11.1, “VDSL Link State and Timing Diagram”

See Figure 62–4.

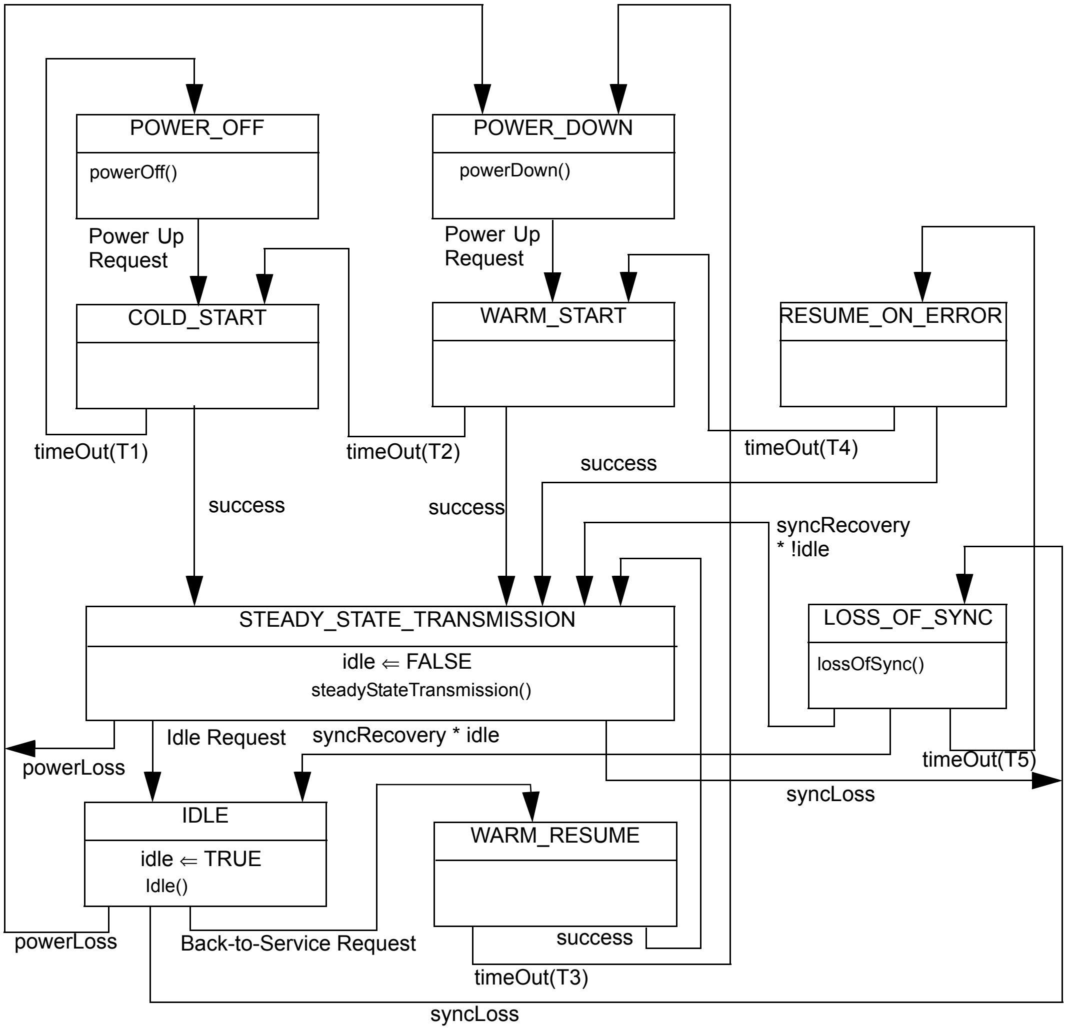

Figure 62–4—Link state and timing diagram

The function timeOut (time) returns FALSE upon entry of the associated state, and returns TRUE as soon as the interval specified by the argument “time” has expired. In addition, the state diagram uses following variables and constants:

T1	Constant indicating the maximum cold-start activation time, equal to 10 000 ms
T2	Constant indicating the maximum warm-start activation time, equal to 5000 ms
T3	Constant indicating the maximum warm-resume activation time, equal to 100 ms
T4	Constant indicating the maximum resume-on-error activation time, equal to 300 ms
T5	Constant indicating the maximum sync-loss recovery time, equal to 200 ms

idle Variable that indicates if the PMD has transitioned from STEADY_STATE_TRANSMISSION to IDLE. The idle variable becomes TRUE when the PMD enters the IDLE state, and becomes FALSE when the PMD enters the STEADY_STATE_TRANSMISSION mode.

success

Variable that is TRUE if and only if the procedures in the associated state were completed without error.

The following procedures are introduced to represent the actions associated with various states, as defined in MCM-VDSL.

powerOff()

See description of *Power-off* in MCM-VDSL section 11.1.1.1

steadyStateTransmission()

See description of *Steady-State Transmission* in MCM-VDSL section 11.1.1.1

lossOfSync()

See description of *Loss of Sync (Loss of Signal)* in MCM-VDSL section 11.1.1.1

powerDown()

See description of *Power Down* in MCM-VDSL section 11.1.1.1

idle()

See description of *Idle* in MCM-VDSL section 11.1.1.1

The remaining actions and transitions are documented in MCM-VDSL section 11.1, referenced as is.

62.3.4.9 Changes to section 18 (Annex 4), “Handshake procedure for VDSL”

62.3.4.9.1 Replacement of 18.1, “Introduction”

The 10PASS-TS handshake procedure is based on ITU-T Recommendation G.994.1 (G.hs). The carrier set used is specified in 61.3. During the handshake procedure, the following parameters shall be transmitted:

a) The size of IDFT/DFT;
b) the initial length of the cyclic extension;
c) flags indicating the use of the optional band, 25–138 kHz.

The parameters above shall be encoded using the information fields specified in 61.4.

62.3.4.9.2 Replacement of 18.2, “Description of signals”

The carrier set and signals used are specified in 61.4.

62.3.4.9.3 Replacement of 18.3, “Message coding format”

The message coding format and field definition tables are specified in 61.4.

62.3.4.9.4 Replacement of 18.4.1, “Handshake - 10PASS-TS-O”

The detailed procedures for handshake at the 10PASS-TS-O are defined in Recommendation G.994.1. A 10PASS-TS-O, after power-up, loss of signal, recovery from errors during the initialization procedure, shall enter the initial G.994.1 state C-SILENT1. The 10PASS-TS-O may transition to the Initialization Reset Procedure under instruction from the network. From either state, operation shall proceed according to the procedures defined in G.994.1.

If Recommendation G.994.1 procedures select 10PASS-TS as the mode of operation, the10PASS-TS-O shall transition to state O-QUIET at the conclusion of G.994.1 operation.

A 10PASS-TS-O wishing to indicate 10PASS-TS capabilities during in a G.994.1 CL message shall do so by setting to 1_b the Level 1 SPar(1)10PASS-TS bit as defined in G.994.1. The NPar(2) and SPar(2) fields corresponding to the "10PASS-TS" Level 1 bit are defined in 61.4. For each Level 2 SPar(2) bit set to 1_b, a corresponding NPar(3) field shall also be present. These NPar(3) fields are defined in 61.4. The Level 2 bits in a CL message are defined in Table 62–5 and Table 62–6.

Table 62–5—10PASS-TS-O CL message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of 25 kHz–138 kHz band	If set to 1_b, signifies that the 10PASS-TS-O is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the upstream transmission.
Downstream use of 25 kHz–138 kHz band	If set to 1_b, signifies that the 10PASS-TS-O is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the downstream transmission.
EOC-Clear	If set to 1_b, signifies that the 10PASS-TS-O supports transmission and reception of G.997.1 OAM frames.

Table 62–6—10PASS-TS-O CL message SPar(2) bit definitions

NPar(2) bit	Definition
Used bands in upstream	The use of this bit is optional. If set to 1_b, indicates the used upstream bands. The optional band between 25 kHz and 138 kHz shall not be included.
Used bands in downstream	The use of this bit is optional. If set to 1_b, indicates the used downstream bands. The optional band between 25 kHz and 138 kHz shall not be included.
IDFT/DFT size	Always set to 1_b in a CL message. Indicates the maximum IDFT/DFT size that 10PASS-TS-O can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	If set to 0_b, it signifies that the 10PASS-TS-O can support only the mandatory cyclic extension length of $40*2^n$ for a number of tones equal to $256*2^n$. If set to 1_b in a CL message, it indicates the initial sample length of the cyclic extension that 10PASS-TS-O can support. It also signifies that the 10PASS-TS-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems supports only the mandatory value, then this value shall be used.
RFI bands	The use of this bit is optional. If set to 1_b, indicates the RFI bands.

A PHY selecting 10PASS-TS mode of operation in a G.994.1 MS message shall do so by setting to 1_b the Level 1 SPar(1) 10PASS-TS-O bit as defined in G.994.1. The NPar(2) and SPar(2) fields corresponding to this bit are defined in 61.3. For each Level 2 SPar(2) bit set to 1b, a corresponding NPar(3) field shall also be present, as defined in 61.3. The Level 2 bits in an MS message from the 10PASS-TS-O are defined in Table 62–7 and Table 62–8.

If both bits Upstream use of optional band and Downstream use of optional band are enabled in the CL and CLR message, one and only one of the bits shall be set to 1_b in an MS message sent from the 10PASS-TS-O, and the use of the band between 25 kHz and 138 kHz is at the 10PASS-TS-O's discretion. If the 10PASS-TS-O and 10PASS-TS-R have no common usage of the optional band, both bits shall be set to 0_b in an MS message sent from the 10PASS-TS-O.

Table 62–7—10PASS-TS-O MS message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of 25 kHz–138 kHz band	Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for the upstream transmission.
Downstream use of 25 kHz–138 kHz band	Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for the downstream transmission.
EOC-Clear	Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. Signifies that both 10PASS-TS-O and 10PASS-TS-R may transmit and receive G.997.1 OAM frames.

Table 62–8—10PASS-TS-O MS message SPar(2) bit definitions

NPar(2) bit	Definition
Used bands in upstream	Always set to 0_b in an MS message.
Used bands in downstream	Always set to 0_b in an MS message.
IDFT/DFT size	Always set to 1_b in an MS message. Indicates the maximum IDFT/DFT size that both 10PASS-TS-O and 10PASS-TS-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	Set to 0_b if and only if this bit was set to 0_b in the last previous CL message or the last previous CLR message, or both. It signifies that both 10PASS-TS-O and 10PASS-TS-R shall use only the mandatory cyclic extension length. Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both 10PASS-TS-O and 10PASS-TS-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to 0_b in an MS message.

62.3.4.9.5 Replacement of 18.4.2, “Handshake - 10PASS-TS-R”

The detailed procedures for handshake at the 10PASS-TS-R are defined in Recommendation G.994.1. An 10PASS-TS-R, after power-up, loss of signal, recovery from errors during the initialization procedure, shall enter the initial G.994.1 state R-SILENT0. Upon command from the host controller, the 10PASS-TS-R shall initiate handshaking by invoking the Initialization Reset Procedure. Operation shall then proceed according to the procedures defined in G.994.1.

If Recommendation G.994.1 procedures select 10PASS-TS as the mode of operation, the 10PASS-TS-R shall transition to state R-QUIET at the conclusion of G.994.1 operation.

A 10PASS-TS-R wishing to indicate 10PASS-TS capabilities during in a G.994.1 CLR message shall do so by setting to 1_b the Level 1 SPar(1) 10PASS-TS bit as defined in G.994.1. The NPar(2) and SPar(2) fields corresponding to the “10PASS-TS” Level 1 bit are defined in 61.4. For each Level 2 SPar(2) bit set to 1_b, a corresponding NPar(3) field shall also be present. These NPar(3) fields are defined in 61.4. The Level 2 bits in a CLR message are defined in Table 62–9 and Table 62–10.

Table 62–9—10PASS-TS-R CLR message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of 25 kHz–138 kHz band	If set to 1_b, signifies that the 10PASS-TS-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the upstream transmission.
Downstream use of 25 kHz–138 kHz band	If set to 1_b, signifies that the 10PASS-TS-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the downstream transmission.
EOC-Clear	If set to 1_b, signifies that the 10PASS-TS-R supports transmission and reception of G.997.1 OAM frames.

Table 62–10—10PASS-TS-R CLR message SPar(2) bit definitions

NPar(2) bit	Definition
Used bands in upstream	Always set to 0_b in a CLR message.
Used bands in downstream	Always set to 0_b in a CLR message.
IDFT/DFT size	Always set to 1_b in a CLR message. Indicates the maximum IDFT/DFT size that 10PASS-TS-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	If set to 0_b, it signifies that the 10PASS-TS-R can support only the mandatory cyclic extension length of 40×2^n for a number of tones equal to 256×2^n. If set to 1_b in a CLR message, it indicates the initial sample length of the cyclic extension that 10PASS-TS-R can support. It also signifies that the 10PASS-TS-R can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems supports only the mandatory value, then this value shall be used.
RFI bands	Always set to 0_b in a CLR message.

A 10PASS-TS-R selecting 10PASS-TS mode of operation in a G.994.1 MS message shall do so by setting to 1_b the Level 1 SPar(1) 10PASS-TS bit as defined in G.994.1. The NPar(2) and SPar(2) fields corresponding to this bit are defined in 61.4. For each Level 2 SPar(2) bit set to 1_b, a corresponding NPar(3) field shall also be present, as defined in 61.4. The Level 2 bits in an MS message from the 10PASS-TS-R are defined in Table 62–11 and Table 62–12.

If both bits Upstream use of optional band and Downstream use of optional band are enabled in the CL and CLR message, one and only one of the bits shall be set to 1_b in an MS message sent from the 10PASS-TS-R, and the use of the band between 25 kHz and 138 kHz shall be at the 10PASS-TS-R's discretion. If the 10PASS-TS-O and 10PASS-TS-R have no common usage of the optional band, both bits shall be set to 0_b in an MS message sent from the 10PASS-TS-R.

62.3.5 Transmission medium interface characteristics

This subclause specifies the interface between the transceiver and the transmission medium (U2 reference point). The interface at U1 reference point (see MCM-VDSL Section 5.1 for VDSL reference model) is specified by the corresponding characteristics of the service splitter. The definition of the service splitter is outside the scope of this standard. Relevant specifications may be found in MCM-VDSL Clause 21 and Clause 22.

Table 62–11—10PASS-TS-R MS message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of 25 kHz–138 kHz band	Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for the upstream transmission.
Downstream use of 25 kHz–138 kHz band	Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for the downstream transmission.
EOC-Clear	Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. Signifies that both 10PASS-TS-O and 10PASS-TS-R may transmit and receive G.997.1 OAM frames.

Table 62–12—10PASS-TS-R MS message SPar(2) bit definitions

NPar(2) bit	Definition
Used bands in upstream	Always set to 0_b in an MS message.
Used bands in downstream	Always set to 0_b in an MS message.
IDFT/DFT size	Always set to 1_b in an MS message. Indicates the maximum IDFT/DFT size that both 10PASS-TS-O and 10PASS-TS-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of *CE*	Set to 0_b if and only if this bit was set to 0_b in the last previous CL message or the last previous CLR message, or both. It signifies that both 10PASS-TS-O and 10PASS-TS-R shall use only the mandatory cyclic extension length. Set to 1_b if and only if this bit was set to 1_b in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both 10PASS-TS-O and 10PASS-TS-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to 0_b in an MS message.

62.3.5.1 Transmit signal characteristics

62.3.5.1.1 Wide-band power

The average wide-band power of the transmitted 10PASS-TS signal measured over the frequency range between 25 kHz to 12 MHz shall be no greater than the values listed in Table 62–13 when terminated with resistive impedance of $R_V = 100\ \Omega$.

NOTE 1—For compliance with this requirement, the 10PASS-TS transceiver is terminated with the impedance R_V and configured to transmit pseudo-random data with any repetitive framing patterns enabled.

NOTE 2—Power is measured across the termination resistance of R_V. No energy is inserted into the POTS/ISDN port of the splitter (if applied) during this test.

Table 62–13—10PASS-TS maximum transmit power

Central office deployment scenario		Cabinet deployment scenario	
Downstream [dBm]	**Upstream [dBm]**	**Downstream [dBm]**	**Upstream [dBm]**
14.5	14.5	11.5	14.5

62.3.5.1.2 Power spectral density (PSD)

Transmit PSD is characterized by the PSD template and PSD mask. PSD templates and masks are defined in Annex 62A.

62.3.5.1.3 Egress control

To avoid potential harm to amateur radio service due to radiated emission from 10PASS-TS, it shall be possible to reduce the PSD of the transmit signal within the amateur radio bands. Specifications for egress power control are described in Annex 62A.

62.3.5.2 Termination impedance

A termination impedance of $R_V = 100\ \Omega$ (purely resistive, either source or load) shall be used over the entire 10PASS-TS frequency band for both the 10PASS-TS-O and 10PASS-TS-R when matching to the metallic wire-pair.

This termination impedance approximates (and is based upon) the insertion-point impedance of the 10PASS-TS test loop. It enables a compromise high-frequency impedance match to the various types of unshielded cable in metallic access networks.

62.3.5.3 Return loss

The return loss requirement is defined to limit signal power uncertainties due to the tolerance of the line interface impedance. The return loss *RL* specifies the amount of reflected differential signal upon a reference impedance R_V

$$RL = 20 \times \log\left|\frac{Z + R_V}{Z - R_V}\right| \tag{62–5}$$

where Z is the internal impedance of the VTU. Note that in Equation (62–5), the log is taken to base 10, such that *RL* is expressed in dB.

The in-band return loss value of the 10PASS-TS transceiver shall be greater than or equal to 12 dB. The out-of-band return loss value shall be greater than or equal or 3 dB. In-band and out-of-band frequencies are defined by the frequency plan as shown in Figure 62–3 and by the transmit direction.

The value of 12 dB assumes a flat transmit PSD is applied over the entire in-band region. Requirements may be relaxed in the frequency ranges of reduced PSD values. The exact value requirements are outside the scope of this standard.

The return loss shall be measured on a resistive test load of $R_V = 100\ \Omega$ while the tested implementation of the 10PASS-TS transceiver is powered.

NOTE—If a splitter is used, the return-loss requirements should be met for the full range of possible values of the POTS/ISDN port termination.

62.3.5.4 Output signal balance

Output signal balance (*OSB*) is a measure of unwanted longitudinal signals at the output of the transceiver, as defined by Equation (62–6). The longitudinal output voltage (V_{cm}) to the differential output voltage (V_{diff}) ratio shall be measured while the 10PASS-TS transmitter is active in accordance with ITU-T Recommendation G.117 and ITU-T Recommendation O.9.

$$OSB = 20\log\left|\frac{V_{diff}}{V_{cm}}\right| \tag{62–6}$$

The *OSB* of the 10PASS-TS transceiver shall be equal to or greater than 35 dB in the entire 10PASS-TS band.

NOTE—The equipment balance should be better than the anticipated cable balance in order to minimize the unwanted emissions and susceptibility to external RFI. The typical worst case balance for an aerial drop-wire has been observed to be in the range 30 dB – 35 dB, therefore the balance of the 10PASS-TS equipment should be equal or better.

62.4 Protocol implementation conformance statement (PICS) proforma for Clause 62, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS[17]

62.4.1 Introduction

The supplier of a protocol implementation that claimed to conform to Clause 62, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

62.4.2 Identification

62.4.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification--e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

62.4.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 62, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[17] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

62.4.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
10PPMA	MCM-VDSL based PMA	62.2	The PMA based on the PMS-TC specified in American National Standard T1.424 is implemented.	M	Yes [ ]
10PPMD	MCM-VDSL based PMD	62.3	The PMD based on the PMD specified in American National Standard T1.424 is implemented.	M	Yes [ ]

62.4.4 PICS proforma tables for the Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS

62.4.4.1 MCM-VDSL based PMA

Item	Feature	Subclause	Value/Comment	Status	Support
10PPMA-1	DMT PMA functional specifications	62.2	All data bytes are transmitted MSB first.	M	Yes [ ]
10PPMA-2	DMT PMA functional specifications	62.2	All serial processing is performed LSB first, with the outside world MSB considered as the VDSL LSB.	M	Yes [ ]
10PPMA-3	Specific requirements and exceptions	62.2.4	The 10PASS-TS PMA complies to the requirements of MCM-VDSL Section 9.3, with the exception of support for the fast path, support for V>1, NTR, and TPS-TC specific bits as listed.	M	Yes [ ]
10PPMA-4	Specific requirements and exceptions: Reed-Solomon	62.2.4.2	The 10PASS-TS PMA supports Reed-Solomon settings (144,128) and (240, 224).	M	Yes [ ]
10PPMA-5	Specific requirements and exceptions: Interleaver	62.2.4.2	For $(N,K) = (144,128)$ the following values for M and I are supported: I=36 and M between 2 and 52. For $(N,K)=(240,224)$ the following values for M and I are supported: I=30 and M between 2 and 62.	M	Yes [ ]

62.4.4.2 MCM-VDSL based PMD

Item	Feature	Subclause	Value/Comment	Status	Support
10PPMD-1	Specific requirements and exceptions	62.3.4	The PMD complies to the requirements of MCM-VDSL Section 8, Section 10, Section 11, and Section 12, with the exceptions listed.	M	Yes [ ]
10PPMD-2	Duplexing and Modulation	62.3.4.1	The PMD uses Frequency Division Duplexing to separate upstream and downstream transmission.	M	Yes [ ]
10PPMD-3	Duplexing and Modulation	62.3.4.1	The PMD supports modulation of $N_{SC} = 4096$ subcarriers.	M	Yes [ ]
10PPMD-4	Duplexing and Modulation	62.3.4.1	The PMD supports modulation of $B_{max\_d} = 12$ bits per downstream subcarrier and $B_{max\_u} = 12$ bits per upstream subcarrier.	M	Yes [ ]
10PPMD-5	Duplexing and Modulation	62.3.4.1	Disjoint subsets of the N_{SC} subcarriers are defined for use in the downstream and upstream directions.	M	Yes [ ]
10PPMD-6	Duplexing and Modulation	62.3.4.1	The exact subsets of subcarriers used to modulate data in each direction are determined during initialization, based on management system settings and the signal-to-noise ratios of the subchannels.	M	Yes [ ]
10PPMD-7	Duplexing and Modulation	62.3.4.1	The use of the band between 25 kHz and 138 kHz is negotiated during the initialization to indicate if the capability exists and select one of the following options: use for upstream transmission, use for downstream transmission, not used.	M	Yes [ ]
10PPMD-8	Duplexing and Modulation	62.3.4.1	10PASS-TS-O PMD supports the transmission of a pilot tone on any downstream tone.	M	Yes [ ]
10PPMD-9	Upstream Power Back-Off	62.3.4.1	Upstream power back-off is applied to mitigate the effects of FEXT from short lines into long lines in distributed cable topologies.	M	Yes [ ]
10PPMD-10	Upstream Power Back-Off	62.3.4.1	The PMD is capable of performing frequency-dependent power back-off.	M	Yes [ ]
10PPMD-11	Upstream Power Back-Off	62.3.4.1	It is possible for the network management system to set the limiting transmit PSD template PSD_0 for the 10PASS-TS-R to one of the standard transmit PSD templates as defined in the applicable section of 62A.3.4.	M	Yes [ ]
10PPMD-12	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-R PMD performs UPBO autonomously, i.e., without sending any significant information to the 10PASS-TS-O until the UPBO is applied.	M	Yes [ ]
10PPMD-13	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-O is capable of adjusting the transmit PSD selected by the 10PASS-TS-R, after UPBO has been applied. The adjusted transmit PSD is subject to the limitations given in the applicable section of 62A.3.3.	M	Yes [ ]

10PPMD-14	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-R estimates the insertion losses of the upstream bands based on the received downstream signals. The 10PASS-TS-R explicitly estimates the electrical length of its line, kl_0, and uses this value to calculate the transmit PSD template TxPSD per Equation (62–1) and Equation (62–2).	M	Yes [ ]
10PPMD-15	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-R adapts its transmit signal PSD to conform to the template TxPSD and the corresponding PSD mask which is defined in the applicable section of 62A.3.3. The same bandwidth as for all regular transmit PSD masks defined in the applicable section of 62A.3.3 are used to check the conformance of TxPSD with power back-off. Conformance with the PSD template is verified using a 100 kHz sliding window in the in-band frequency range below 1 MHz and a 1 MHz sliding window in the in-band frequency range above 1 MHz.	M	Yes [ ]
10PPMD-16	Upstream Power Back-Off	62.3.4.1	PSD_REF is input via the management interface.	M	Yes [ ]
10PPMD-17	Upstream Power Back-Off	62.3.4.1	PSD_REF is transmitted from the 10PASS-TS-O to the 10PASS-TS-R.	M	Yes [ ]
10PPMD-18	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-R takes a tone-by-tone minimum of this computed PSD and the maximum allowed transmit PSD in the upstream direction. The result is used as the initial upstream transmit PSD.	M	Yes [ ]
10PPMD-19	Upstream Power Back-Off	62.3.4.1	Upon receiving signals from the 10PASS-TS-R, the 10PASS-TS-O compares the actual received PSD to the reference PSD. If necessary, it instructs the 10PASS-TS-R to fine-tune its PSD.	M	Yes [ ]
10PPMD-20	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-O has the capability to directly impose a maximum allowed transmit PSD at the 10PASS-TS-R.	M	Yes [ ]
10PPMD-21	Upstream Power Back-Off	62.3.4.1	The maximum transmit PSD is input via the management interface.	M	Yes [ ]
10PPMD-22	Upstream Power Back-Off	62.3.4.1	The maximum transmit PSD is transmitted from 10PASS-TS-O to 10PASS-TS-R during initialization.	M	Yes [ ]
10PPMD-23	Upstream Power Back-Off	62.3.4.1	The 10PASS-TS-O allows the operator to select between the UPBO method based on Reference PSD and the UPBO method based on maximum transmit PSD.	M	Yes [ ]
10PPMD-24	Handshake	62.3.4.9	The handshake uses the 4.3125 kHz signaling family and the duplex transmission mode.	M	Yes [ ]

10PPMD-25	Handshake	62.3.4.9	The handshake proceeds as specified in 61.4.	M	Yes [ ]
10PPMD-26	Wide-band power	62.3.5.1.1	The average wide-band power of the transmitted 10PASS-TS signal measured over the frequency range between 25 kHz to 12 MHz is no greater than the values listed in Table 62–13 when terminated with resistive impedance of RV = 100 Ohm.	M	Yes [ ]
10PPMD-27	Egress control	62.3.5.1.3	To avoid potential harm to amateur radio service due to radiated emission from 10PASS-TS, it is possible to reduce the PSD of the transmit signal within the amateur radio bands.	M	Yes [ ]
10PPMD-28	Termination impedance	62.3.5.2	A termination impedance of Rv = 100 Ohm is used over the entire 10PASS-TS frequency band for both the 10PASS-TS-O and 10PASS-TS-R when matching to the metallic wire-pair.	M	Yes [ ]
10PPMD-29	Return loss	62.3.5.3	The in-band return loss value of the 10PASS-TS transceiver are greater than or equal to 12 dB.	M	Yes [ ]
10PPMD-30	Return loss	62.3.5.3	The out-of-band return loss value are greater than or equal or 3 dB.	M	Yes [ ]
10PPMD-31	Return loss	62.3.5.3	Requirements are relaxed in the frequency ranges of reduced PSD values.	O	Yes [ ] No [ ]
10PPMD-32	Return loss	62.3.5.3	The return loss are measured on a resistive test load of R_V = 100 Ohm while the tested implementation of the 10PASS-TS transceiver is powered.	M	Yes [ ]
10PPMD-33	Output signal balance	62.3.5.4	The longitudinal output voltage to the differential output voltage ratio is measured while the VTU transmitter is active in accordance with ITU-T Recommendation G.117 and ITU-T Recommendation O.9.	M	Yes [ ]
10PPMD-34	Output signal balance	62.3.5.4	The OSB of the 10PASS-TS transceiver is equal to or greater than 35 dB in the entire 10PASS-TS band.	M	Yes [ ]

63. Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 2BASE-TL

63.1 2BASE-TL Overview

63.1.1 Scope

This clause specifies the 2BASE-TL Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD) sublayer for voice grade twisted-pair wiring. In order to form a complete 2BASE-TL PHY, the 2BASE-TL PMA and PMD are integrated with the TC and PCS of Clause 61. Parts of register 3.0, parts of register 3.4 and registers 3.60 through 3.73 specified in Clause 45 may be used to control the PCS of Clause 61. Parts of register 6.0 and registers 6.16 through 6.23 specified in Clause 45 may be used to control the TC sublayer of Clause 61. Registers 1.16 through 1.42 and 1.80 through 1.109 specified in Clause 45 may be used to control the 2BASE-TL PMA and PMD.

63.1.2 Objectives

The following are the objectives for the 2BASE-TL PMA and PMD:

a) To provide 2 Mb/s encapsulated packet data rate at the $\alpha(\beta)$-interface.

b) To provide full duplex operation.

c) To provide for operating over non-loaded voice grade twisted pair cable at distances up to 2700 m.

d) To provide a communication channel with a mean bit error ratio, at the $\alpha(\beta)$-interface, of less than one part in 10^7 with 5 dB noise margin.

63.1.3 Relation of 2BASE-TL to other standards

The specifications of the 2BASE-TL PMA and PMD are based on the SHDSL transceiver (PMD and PMS-TC) specified in ITU-T Recommendation G.991.2.

Item	Feature	Subclause	Value/Comment	Status	Support

63.1.4 Summary of Physical Medium Attachment (PMA) specification

This layer is defined by the $\alpha(\beta)$-interface and the I-interface. Figure 63–1 shows a functional diagram of the 2BASE-TL PMA layer functionality. The payload is formed into a 2BASE-TL PMA frame with overhead added (for example, the PME aggregation Header). The framed data is then scrambled and sent to the PMD sublayer. One distinguishes between the data mode PMA specification that is used during normal data operation and the activation PMA specification that is used when the PMD is training.

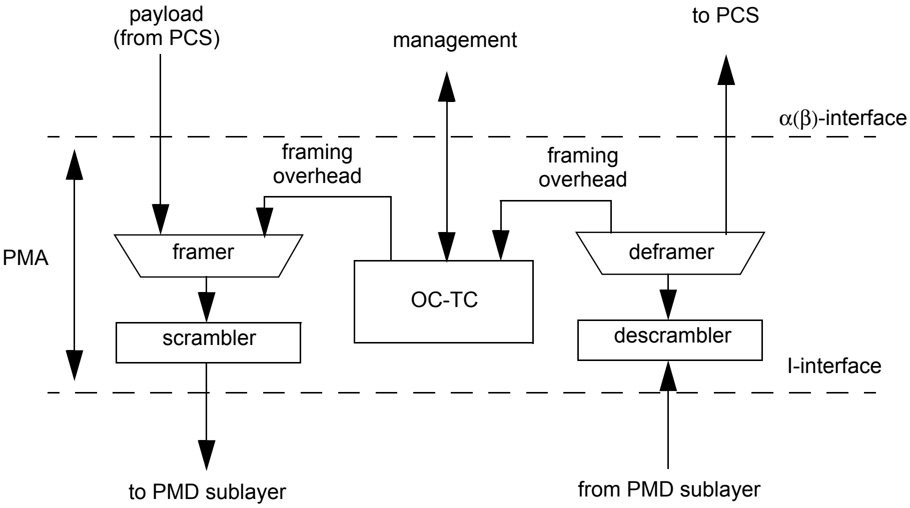

Figure 63–1—Diagram of PMA sublayer

63.1.4.1 α(β)-interface

A complete definition of the α(β)-interface is contained in 61.3.2. The signal PMA_receive_synchronized, defined in 61.3.2.2, shall be asserted when the LOSW bit is set to 0 (see 63.2.2.2), and deasserted when the LOSW is set to 1.

63.1.4.2 The I-interface

The I_O and I_R reference points define interfaces between the PMA and PMD in the 2BASE-TL-O and 2BASE-TL-R, respectively. Both interfaces are functional, application independent and identical. Both interfaces are defined by the following signal flows:

a) Data flow
b) Synchronization flow

The specification of the I-interface is implicit in ITU-T Recommendation G.991.2.

63.1.4.2.1 The I Data Flow

The data flow consists of two octet-oriented streams, both with the PMA frame format, with the bit rates defined by the PMD transmission profile:

a) Transmit data (Tx)
b) Receive data (Rx)

If data streams are implemented serially, the LSB of each octet (i.e., b_8 of Figure 61–16) shall be sent first. In section 7.1.1 of G.991.2, with i = 0, the payload blocks are made of a stream of octets. Each octet consists of 8 bits. The first bit of each octet (i.e., lowest frame bit number in an octet) maps to b_8 in Figure 61–16 and the last bit of each octet maps to b_1 of Figure 61–16.

Each stream bit rate value is set during PMD configuration.

63.1.4.2.2 I Synchronization Flow

The synchronization flow consists of the transmitted and received octet synchronization signals (Clko_t, Clko_r). Optional transmit and receive bit-synchronization signals (Clkp_t, Clkp_r) are defined too.

Synchronization signals are asserted by the PMD and directed towards the PMA.

The synchronization signals are described in Table 63–1.

Table 63–1—I-interface signals

Signal(s)	Description	Direction	Notes
Data Signals			
Tx	Transmit data stream	PMA → PMD	Transmission frame format.
Rx	Receive data stream	PMA ← PMD	
Synchronization Signals			
Clko_t	Transmitted octet timing	PMA ← PMD	
Clko_r	Received octet timing	PMA ← PMD	
Clkp_t	Transmitted bit timing	PMA ← PMD	Optional
Clkp_r	Received bit timing	PMA ← PMD	Optional

63.1.4.3 Operation Channel (OC)

The OC-TC function of the PMA shall receive the EOC and overhead indicators over the OC-TC interface. For each 2BASE-TL PMA frame, the OC shall deliver a fixed number of embedded operations channel (EOC) and overhead indicators bits to the framer. These bits shall be included in the overhead sections of the 2BASE-TL PMA frames.

63.1.5 Summary of Physical Medium Dependent (PMD) specification

The PMD specification is based on Pulse Amplitude Modulation (PAM) and is divided into three consecutive phases, summarized as follows:

a) Preactivation: during this phase, the PMDs determine each other capabilities and the bit rate they will operate at in data mode. Reference section 6.3.1 (included in this standard per 63.3.2.2) describes the preactivation reference model. The preactivation uses G.994.1 as a handshake mechanism to exchange parameters in accordance with the specifications in 61.4. It also offers an optional line probing capability. The line probe uses 2-level PAM signals to determine a suitable bit rate to run at on the copper link.
b) Activation: during this phase, the PMDs train and exchange information necessary to adapt and operate the various filters and processes necessary during data mode operation. Reference section 6.2.1 describes the Activation reference model. The activation uses 2-level PAM to train the various filters.
c) Data Mode: once pre-activation and activation are complete, the PMD can start transmitting payload data. Reference section 6.1.1 describes the Data Mode reference model.

NOTE—Line activation takes place after entire discovery and PME aggregation operation.

63.2 2BASE-TL PMA functional specifications

The 2BASE-TL PMA is specified by incorporating the SHDSL standard, ITU-T Recommendation G.991.2 (02/2001) with the changes specified in G.991.2 Amendment 1 (11/2001), by reference, with the modifications noted below. This standard provides support for voice-grade twisted pair. For improved legibility in this clause, ITU-T Recommendation G.991.2 and G.991.2 Amendment 1, will henceforth be referred to as G.991.2.

63.2.1 General exceptions

The 2BASE-TL PMA is precisely the PMS-TC specified in G.991.2, with the following general modifications:

a) There are minor terminology differences between this standard and G.991.2 that do not cause ambiguity. The terminology used in 2BASE-TL was chosen to be consistent with other IEEE 802 standards, rather than with G.991.2. Terminology is both defined and consistent within each standard. Special note should be made of the interpretations shown in Table 63–2.

Table 63–2—Interpretation of general G.991.2 terms and concepts

G.991.2 term or concept	Interpretation for 2BASE-TL
PMS-TC	PMA
STU-C, LT	2BASE-TL-O
STU-R, NT	2BASE-TL-R
Transmission medium dependent interface, U-interface	MDI
byte	octet

b) The 2BASE-TL PMA supports only one channel of user data with an associated γ-interface.
c) The 2BASE-TL PMA does not support the optional “four-wire mode”. Operation over multiple pairs is optional; if implemented, multi-pair operation shall comply to the specifications in 61.2.2.
d) The 2BASE-TL PMA does not support “plesiochronous mode”.
e) The 2BASE-TL PMA shall be octet oriented; hence, the bit oriented parameter i defined for Equation (63–1) shall be equal to 0 in all cases.
f) The 2BASE-TL PMA does not support the notion of “sub-blocks” in the Payload Block. Each payload block consists of a contiguous sequence of $12n$ octets, with parameter n as defined for Equation (63–1).

63.2.2 Specific requirements and exceptions

The 2BASE-TL PMA shall comply to the requirements of G.991.2 Section 7 and Section 9 with the exceptions listed below. Where there is conflict between specifications in G.991.2 and those in this standard, those of this standard shall prevail.

Implementation of optional specifications in G.991.2 is not required for compliance with this standard. Reference Section 8 (TPS-TC Layer Functional Characteristics), Reference Annex D (Signal Regenerator Operation), Reference Annex E (Application-specific TPS-TC Framing) and Reference Appendices I, II, and III are out of scope for 2BASE-TL PMA. Deployment of compatible versions of G.991.2 Annex D is an implementation specific option for the purposes of 2BASE-TL.

63.2.2.1 Changes to 7.1, “Data Mode Operation”

Reference 7.1.1 (Frame Structure) is replaced with the following:

Table 7-1 of the Reference summarizes the SHDSL frame structure. Complete bit definitions may be found in Reference 7.1.2. The size of each payload block is defined as k bits, where $k = 96n$. The payload rate r (in kb/s) is given by Equation (63–1) and Equation (63–3), with $i = 0$. The value of n is limited by Equation (63–2) and Equation (63–4).

Reference 7.1.2.6 (Stuff Indicator bits) is replaced with the following:

2BASE-TL operates in synchronous mode, therefore *sbid1* and *sbid2* are spare bits.

Reference 7.1.2.7 (Stuffing Bits) is replaced with the following:

2BASE-TL operates in synchronous mode, therefore *stb1* and *stb2* shall be present in every frame, and *stb3* and *stb4* shall not be present.

Reference 7.1.4 (Frame synchronization) is replaced with the following:

The precise manner in which frame synchronization is acquired or maintained is the choice of the receiver designer. Since different frame synchronization algorithms may require different values for the bits of the FSW, a provision has been made to allow the receiver to inform the far end transmitter of the particular values that are to be used for this field in the transmitted PMS-TC frame.

All other subsections of Reference 7.1 are referenced as is.

63.2.2.2 Changes to Section 9, “Management”

Referenced as is, with the exception of 9.5.5.6 where Message IDs 17 “ATM Cell Status Request”, 20 “ISDN Request”, 145 “ATM Cell Status Information” and 148 “ISDN Response” are out of scope.

63.2.2.3 Relation between the 2BASE-TL registers and the SHDSL management functions

The parameters of the various 2BASE-TL registers of the -R device, defined in Clause 45, are gathered via the SHDSL management. SNR margin, code violations, ES, SES, LOSW, UAS, SNR margin defect, Loop attenuation defect and loss of sync word failure shall be obtained in the following way:

The 2BASE-TL-O shall send a Status Request (Msg ID 11) EOC message. If there has been any change in performance status other than SNR margin since the last time a unit was polled, the peer 2BASE-TL-R shall respond with an SHDSL Network Side Performance Status (Msg ID 140) EOC message.

The following octets and bits are then mapped to the Clause 45 registers (see Table 63–3):

Otherwise, the peer 2BASE-TL-R shall respond with a Status/SNR (Msg ID 139) EOC message, in which the SNR margin is communicated in octet 2.

Loop attenuation and SNR margin threshold for both 2BASE-TL-O and 2BASE-TL-R devices shall be set in the Clause 45 register of the 2BASE-TL-O device; the 2BASE-TL-R thresholds will be passed to the 2BASE-TL-R using message ID 3.

The segment defect is defined in section 9.2.4 and uses a dedicated framing bit rather than the EOC messaging.

The retrieval of the remote vendor ID is defined in G.997.1. The use of this mechanism is outside the scope of this standard.

Table 63–3—Mapping of registers to "Network Side Performance Status" EOC message octets

register	octets / bits
LOSW failure	octet 2 / bit 1
Loop attenuation defect	octet 2 / bit 2
SNR margin defect	octet 2 / bit 3
SNR margin	octet 3
Loop attenuation	octet 4
ES	octet 5
SES	octet 6
Code violations	octet 7 and 8
LOSW	octet 9
UAS	octet 10
See footnote[a]	octet 11

[a] Bit 6 and 7 of octet 11 indicate that either an overflow or reset condition has occurred on any of the code violations / ES/ SES / LOSW / UAS registers.

NOTE—The code violation, ES, SES, LOSW, and UAS in SHDSL are modulo counters. The absolute value of the counter is meaningless, however the difference in between two consecutive readings provides the change in code violation/ES/SES/LOSW/UAS. If there are no changes in the performance registers, message ID 139 rather than 140 will be sent by the 2BASE-TL-R. It only contains the SNR value and none of the other parameters.

63.3 2BASE-TL PMD functional specifications

The 2BASE-TL PMD (and MDI) is specified by incorporating the SHDSL standard, ITU-T Recommendation G.991.2 (02/2001) with the changes specified in G.991.2 Amendment 1 (11/2001), by reference, with the modifications noted below. This standard provides support for voice-grade twisted pair. For improved legibility in this clause, ITU-T Recommendation G.991.2 and G.991.2 Amendment 1, will henceforth be referred to as G.991.2.

63.3.1 General exceptions

The 2BASE-TL PMD is precisely the PMD specified in G.991.2, with the following general modifications:

a) There are minor terminology differences between this standard and G.991.2 that do not cause ambiguity. The terminology used in 2BASE-TL was chosen to be consistent with other IEEE 802 standards, rather than with G.991.2. Terminology is both defined and consistent within each standard. Special note should be made of the interpretations shown in Table 63–4.
b) The 2BASE-TL PMD does not support the optional "four-wire mode". Operation over multiple pairs is optional; if implemented, multi-pair operation shall comply to the specifications in 61.2.2.
c) The 2BASE-TL PMD does not support "plesiochronous mode".
d) The 2BASE-TL PMD shall be octet oriented; hence, the bit oriented parameter i defined for Equation (63–1) shall be equal to 0 in all cases.
e) The 2BASE-TL PMD shall support the use of the 32-TCPAM constellation for specific rates (see 63.3.2.1).
f) The 2BASE-TL PMD shall support the use of the enhanced SHDSL[18] extended bandwidths.

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[18] "Enhanced SHDSL" refers to 32TC-PAM modulation and higher values of n as defined in Equation (63–2) and Equation (63–4), which are not part of ITU-T Recommendation G.991.2.

Table 63–4—Interpretation of general G.991.2 terms and concepts

G.991.2 term or concept	Interpretation for 2BASE-TL
PMS-TC	PMA
STU-C, LT	2BASE-TL-O
STU-R, NT	2BASE-TL-R
Transmission medium dependent interface, U-interface	MDI

63.3.2 Specific requirements and exceptions

The 2BASE-TL PMD (including MDI) shall comply to the requirements of G.991.2 Section 5 (Transport Capacity), Section 6 (PMD Layer Functional Characteristics), Section 10 (Clock Architecture), Section 11 (Electrical Characteristics), Section 12 (Conformance Testing) with the exceptions listed below. The 2BASE-TL PMD supports the requirements of G.991.2 Annex A (Regional Requirements - Region 1) and Annex B (Regional Requirements - Region 2) with the exception of performance requirements, which are replaced by Annex 63B. Where there is conflict between specifications in G.991.2 and those in this standard, those of this standard shall prevail.

Implementation of optional specifications in G.991.2 is not required for compliance with this standard. Reference Section 8 (TPS-TC Layer Functional Characteristics), Reference Annex D (Signal Regenerator Operation), Reference Annex E (Application-specific TPS-TC Framing), and Reference Appendices I, II, and III are out of scope for the 2BASE-TL PMD.

63.3.2.1 Replacement of section 5, "Transport Capacity"

This recommendation specifies a two-wire operational mode for 2BASE-TL transceivers that is capable of supporting user (payload) data rates from 192 kb/s to 3.840 Mb/s, using the 16-TCPAM constellation, and 768 kb/s to 5.696 Mb/s, using the 32-TCPAM constellation. The allowed rates r (in kb/s), using the 16-TCPAM constellation, are given by Equation (63–1):

$$r = n \times 64 + i \times 8 \qquad (63\text{–}1)$$

where

$$3 \le n \le 60\,. \qquad (63\text{–}2)$$

The allowed rates r (in kb/s), using the 32-TCPAM constellation, are given by Equation (63–3):

$$r = n \times 64 + i \times 8 \qquad (63\text{–}3)$$

where

$$12 \le n \le 89 \qquad (63\text{–}4)$$

In all cases, i is restricted to the value of 0. See 63.3.2.4, 63.3.2.5 and 63.3.2.6 for details of specific regional requirements.

63.3.2.2 Changes to section 6, "PMD Layer Functional Characteristics"

Referenced as is, with the exception of subsection 6.4 (G.994.1 Preactivation Sequence), which is supplanted by 61.4.

Section 6.1.2.3 is superseded by the following text:

Mapper:

The $K + 1$ bits $Y_K(m)$, ..., $Y_1(m)$, and $Y_0(m)$ shall be mapped to a level $x(m)$. In section 6.1.2.3 of G.991.2, the mapper function is specified for 16-TCPAM. This text extends that mapping to include both 16- and 32-TCPAM encodings. Table 63–5 shows the bit to level mapping for 16 and 32 level mapping.

Table 63–5—Mapping of bits to PAM levels

Y_4(m)	Y_3(m)	Y_2(m)	Y_1(m)	Y_0(m)	32-PAM (5 Bits)	16-PAM (4 Bits)
0	0	0	0	0	–31/32	–15/16
0	0	0	0	1	–29/32	–13/16
0	0	0	1	0	–27/32	–11/16
0	0	0	1	1	–25/32	–9/16
0	0	1	0	0	–23/32	–7/16
0	0	1	0	1	–21/32	–5/16
0	0	1	1	0	–19/32	–3/16
0	0	1	1	1	–17/32	–1/16
0	1	1	0	0	–15/32	1/16
0	1	1	0	1	–13/32	3/16
0	1	1	1	0	–11/32	5/16
0	1	1	1	1	–9/32	7/16
0	1	0	0	0	–7/32	9/16
0	1	0	0	1	–5/32	11/16
0	1	0	1	0	–3/32	13/16
0	1	0	1	1	–1/32	15/16
1	1	0	0	0	1/32	—
1	1	0	0	1	3/32	—
1	1	0	1	0	5/32	—
1	1	0	1	1	7/32	—
1	1	1	0	0	9/32	—
1	1	1	0	1	11/32	—

Table 63–5—Mapping of bits to PAM levels *(continued)*

$Y_4(m)$	$Y_3(m)$	$Y_2(m)$	$Y_1(m)$	$Y_0(m)$	32-PAM (5 Bits)	16-PAM (4 Bits)
1	1	1	1	0	13/32	—
1	1	1	1	1	15/32	—
1	0	1	0	0	17/32	—
1	0	1	0	1	19/32	—
1	0	1	1	0	21/32	—
1	0	1	1	1	23/32	—
1	0	0	0	0	25/32	—
1	0	0	0	1	27/32	—
1	0	0	1	0	29/32	—
1	0	0	1	1	31/32	—

63.3.2.3 Changes to section 10, “Clock Architecture”

Referenced as is, with the exception of Reference Table 10-1, which is replaced by Table 63–6.

Table 63–6—Clock synchronization configurations

Mode number	2BASE-TL-O symbol clock reference	2BASE-TL-R symbol clock reference	Example application	Mode
3a	Transmit data clock	Received symbol clock	Main application is synchronous transport in both directions.	Synchronous

63.3.2.4 Changes to Annex A, “Regional Requirements—Region 1”

63.3.2.4.1 General Changes

Referenced as is, with the exception of optional support for asymmetric PSD masks. Asymmetric PSD masks are not supported by 2BASE-TL.

Section A.5.3 “Span Powering” is out of scope.

63.3.2.4.2 Additional requirement: wetting current

The 2BASE-TL-R shall be capable of sustaining 20 mA of wetting (sealing) current. The maximum rate of change of the wetting current shall be no more than 20 mA per second.

NOTE—The -R device cannot be guaranteed to operate correctly if more than 20 mA (tip to ring) is sourced.

63.3.2.5 Changes to Annex B, “Regional Requirements—Region 2”

63.3.2.5.1 General changes

Referenced as is, with the exception of optional support for asymmetric PSD masks. Asymmetric PSD masks are not supported by 2BASE-TL.

Section B.5.3. “Span Powering” is out of scope.

The RL_{min} value of section B.5.2 is modified from 14 to 12 dB for the purpose of 2BASE-TL.

63.3.2.5.2 Additional requirement: wetting current

The 2BASE-TL-R shall be capable of sustaining 20 mA of wetting (sealing) current. The maximum rate of change of the wetting current shall be no more than 20 mA per second.

NOTE—The -R device cannot be guaranteed to operate correctly if more than 20 mA (tip to ring) is sourced.

63.3.2.6 Changes to Annex C, “Regional Requirements – Region 3”

Referenced as is, with the exception of optional support for asymmetric PSD masks. Asymmetric PSD masks are not supported by 2BASE-TL.

63.4 Protocol implementation conformance statement (PICS) proforma for Clause 63, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 2BASE-TL[19]

63.4.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 63, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 2BASE-TL, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

63.4.2 Identification

63.4.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

63.4.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 63, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 2BASE-TL.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[19] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

63.4.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
2BPMA	SHDSL based PMA	63.2	The PMA based on the PMS-TC specified in ITU-T Recommendation G.991.2 is implemented.	M	Yes [ ]
2BPMD	SHDSL based PMD	63.3	The PMD based on the PMD specified in ITU-T Recommendation G.991.2 is implemented.	M	Yes [ ]

63.4.4 PICS proforma tables for the Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD) sublayers, type 2BASE-TL

63.4.4.1 SHDSL based PMA

Item	Feature	Subclause	Value/Comment	Status	Support
2BPMA-1	$\alpha(\beta)$-interface	63.1.4.1	The PMA_receive_synchronized is asserted when LOSW is “0” and deasserted when LOSW is “1”	M	Yes [ ]
2BPMA-2	The I-data flow	63.1.4.2.1	If data streams are implemented serially, the LSB of each octet (i.e., b_8 of Figure 61–16) is sent first.	M	Yes [ ]
2BPMA-3	Operation Channel	63.1.4.3	The OC-TC function of the PMA receives the EOC and overhead indicators over the OC-TC interface.	M	Yes [ ]
2BPMA-4	Operation Channel	63.1.4.3	The EOC and overhead indicators are included in the overhead sections of the 2BASE-TL PMA frames.	M	Yes [ ]
2BPMA-5	General exceptions	63.2.1	The 2BASE-TL PMA is octet oriented.	M	Yes [ ]
2BPMA-6	General exceptions	63.2.1	The bit oriented parameter i defined for Equation (63–1) and Equation (63–3) is equal to 0 in all cases.	M	Yes [ ]
2BPMA-7	Specific requirements and exceptions	63.2.2	The 2BASE-TL PMA complies to the requirements of G.991.2 Section 7.	M	Yes [ ]
2BPMA-8	Specific requirements and exceptions	63.2.2	The 2BASE-TL PMA complies to the requirements of G.991.2 Section 9.	M	Yes [ ]
2BPMA-9	Reference 7.1	63.2.2.1	2BASE-TL operates in synchronous mode. Bits stb1 and stb2 are present in every frame, and stb3 and stb4 are not present.	M	Yes [ ]
2BPMA-10	Reference 7.1	63.2.2.1	Since different frame synchronization algorithms require different values for the bits of the FSW, a provision has been made to allow the receiver to inform the far end transmitter of the particular values that are to be used for this field according to 61.4.	M	Yes [ ]

63.4.4.2 SHDSL based PMD

Item	Feature	Subclause	Value/Comment	Status	Support
2BPMD-1	General exceptions	63.3.1	The 2BASE-TL PMD is octet oriented.	M	Yes [ ]
2BPMD-2	General exceptions	63.3.1	The 2BASE-TL PMD supports the use of the 32-TCPAM constellation for specific rates.	M	Yes [ ]
2BPMD-4	General exceptions	63.3.1	The 2BASE-TL PMD supports the use of the enhanced SHDSL extended bandwidths.	M	Yes [ ]
2BPMD-5	General exceptions	63.3.1	The bit oriented parameter *i* defined for Equation (63–1) and Equation (63–3) is equal to 0 in all cases.	M	Yes [ ]
2BPMD-6	Specific requirements and exceptions	63.3.2	The 2BASE-TL PMD complies to the requirements of G.991.2 Section 5, Section 6, Section 10, Section 11, Section 12.	M	Yes [ ]
2BPMD-7	Specific requirements and exceptions	63.3.2	The 2BASE-TL PMD complies to at least one of the three regional annexes: Annex A, Annex B, or Annex C with the exception of performance, which is defined in Annex 63B.	M	Yes [ ]
2BPMD-8	Reference section 6	63.3.2.2	The 16 and 32 TC-PAM mappings are per Table 63–5.	M	Yes [ ]
2BPMD-9	Changes to Annex A/B	63.3.2.4.2 63.3.2.5.2	The DC resistance of the 2BASE-TL-R is 1000 ohms plus or minus 10%.	M	Yes [ ]
2BPMD-10	Changes to Annex A/B	63.3.2.4.2 63.3.2.5.2	The 2BASE-TL-R is capable of sustaining 20 mA of wetting (sealing) current.	M	Yes [ ]

64. Multipoint MAC Control

64.1 Overview

This clause deals with the mechanism and control protocols required in order to reconcile the P2MP topology into the Ethernet framework. The P2MP medium is a passive optical network (PON), an optical network with no active elements in the signal's paths from source to destination. The only interior elements used in a PON are passive optical components, such as optical fiber, splices, and splitters. When combined with the Ethernet protocol, such a network is referred to as Ethernet passive optical network (EPON).

P2MP is an asymmetrical medium based on a tree (or tree-and-branch) topology. The DTE connected to the trunk of the tree is called optical line terminal (OLT) and the DTEs connected at the branches of the tree are called optical network units (ONU). The OLT typically resides at the service provider's facility, while the ONUs are located at the subscriber premises.

In the downstream direction (from the OLT to an ONU), signals transmitted by the OLT pass through a 1:N passive splitter (or cascade of splitters) and reach each ONU. In the upstream direction (from the ONUs to the OLT), the signal transmitted by an ONU would only reach the OLT, but not other ONUs. To avoid data collisions and increase the efficiency of the subscriber access network, ONU's transmissions are arbitrated. This arbitration is achieved by allocating a transmission window (grant) to each ONU. An ONU defers transmission until its grant arrives. When the grant arrives, the ONU transmits frames at wire speed during its assigned time slot.

A simplified P2MP topology example is depicted in Figure 64–1. Clause 67 provides additional examples of P2MP topologies.

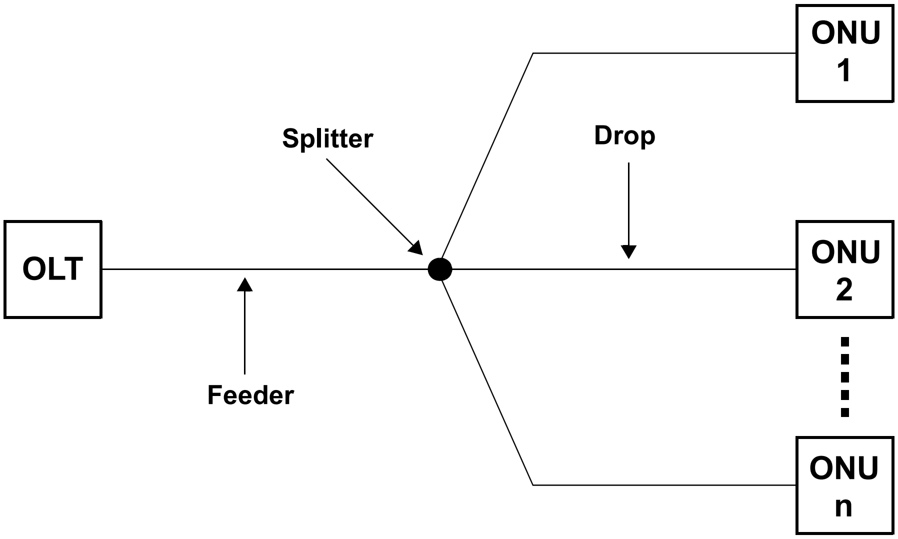


Figure 64–1—PON topology example

Topics dealt with in this clause include allocation of upstream transmission resources to different ONUs, discovery and registration of ONUs into the network, and reporting of congestion to higher layers to allow for dynamic bandwidth allocation schemes and statistical multiplexing across the PON.

This clause does not deal with topics including bandwidth allocation strategies, authentication of end-devices, quality-of-service definition, provisioning, or management.

This clause specifies the multipoint control protocol (MPCP) to operate an optical multipoint network by defining a Multipoint MAC Control sublayer as an extension of the MAC Control sublayer defined in Clause 31, and supporting current and future operations as defined in Clause 31 and annexes.

Each PON consists of a node located at the root of the tree assuming the role of OLT, and multiple nodes located at the tree leaves assuming roles of ONUs. The network operates by allowing only a single ONU to transmit in the upstream direction at a time. The MPCP located at the OLT is responsible for timing the different transmissions. Reporting of congestion by the different ONUs may assist in optimally allocating the bandwidth across the PON.

Automatic discovery of end stations is performed, culminating in registration through binding of an ONU to an OLT port by allocation of a Logical Link ID (see LLID in 65.1.3.3.2), and dynamic binding to a MAC connected to the OLT.

The Multipoint MAC Control functionality shall be implemented for subscriber access devices containing point-to-multipoint Physical Layer devices defined in Clause 60.

64.1.1 Goals and objectives

The goals and objectives of this clause are the definition of a point-to-multipoint Ethernet network utilizing an optical medium.

Specific objectives met include the following:

a) Support of Point-to-Point Emulation (P2PE) as specified
b) Support multiple LLIDs and MAC Clients at the OLT
c) Support a single LLID per ONU
d) Support a mechanism for single copy broadcast
e) Flexible architecture allowing dynamic allocation of bandwidth
f) Use of 32 bit timestamp for timing distribution
g) MAC Control based architecture
h) Ranging of discovered devices for improved network performance
i) Continuous ranging for compensating round trip time variation

64.1.2 Position of Multipoint MAC Control within the IEEE 802.3 hierarchy

Multipoint MAC Control defines the MAC control operation for optical point-to-multipoint networks. Figure 64–2 depicts the architectural positioning of the Multipoint MAC Control sublayer with respect to the MAC and the MAC Control client. The Multipoint MAC Control sublayer takes the place of the MAC Control sublayer to extend it to support multiple clients and additional MAC control functionality.

Multipoint MAC Control is defined using the mechanisms and precedents of the MAC Control sublayer. The MAC Control sublayer has extensive functionality designed to manage the real-time control and manipulation of MAC sublayer operation. This clause specifies the extension of the MAC Control mechanism to manipulate multiple underlying MACs simultaneously. This clause also specifies a specific protocol implementation for MAC Control.

The Multipoint MAC Control sublayer is specified such that it can support new functions to be implemented and added to this standard in the future. MultiPoint Control Protocol (MPCP), the management protocol for P2MP is one of these protocols. Non-real-time, or quasi-static control (e.g., configuration of MAC operational parameters) is provided by Layer Management. Operation of the Multipoint MAC Control sublayer is transparent to the MAC.

As depicted in Figure 64–2, the layered system instantiates multiple MAC entities, using a single Physical Layer. The individual MAC instances offer a Point-to-point emulation service between the OLT and the ONU. An additional MAC is instantiated to communicate to all ONUs at once. This instance takes maximum advantage of the broadcast nature of the downstream channel by sending a single copy of a frame that is received by all ONUs. This MAC instance is referred to as single copy broadcast (SCB).

The ONU only requires one MAC instance since frame filtering operations are done at the RS layer before reaching the MAC. Therefore, MAC and layers above are emulation-agnostic at the ONU (see 65.1.3.3).

Although Figure 64–2 and supporting text describe multiple MACs within the OLT, a single unicast MAC address may be used by the OLT. Within the EPON Network, MACs are uniquely identified by their LLID which is dynamically assigned by the registration process.

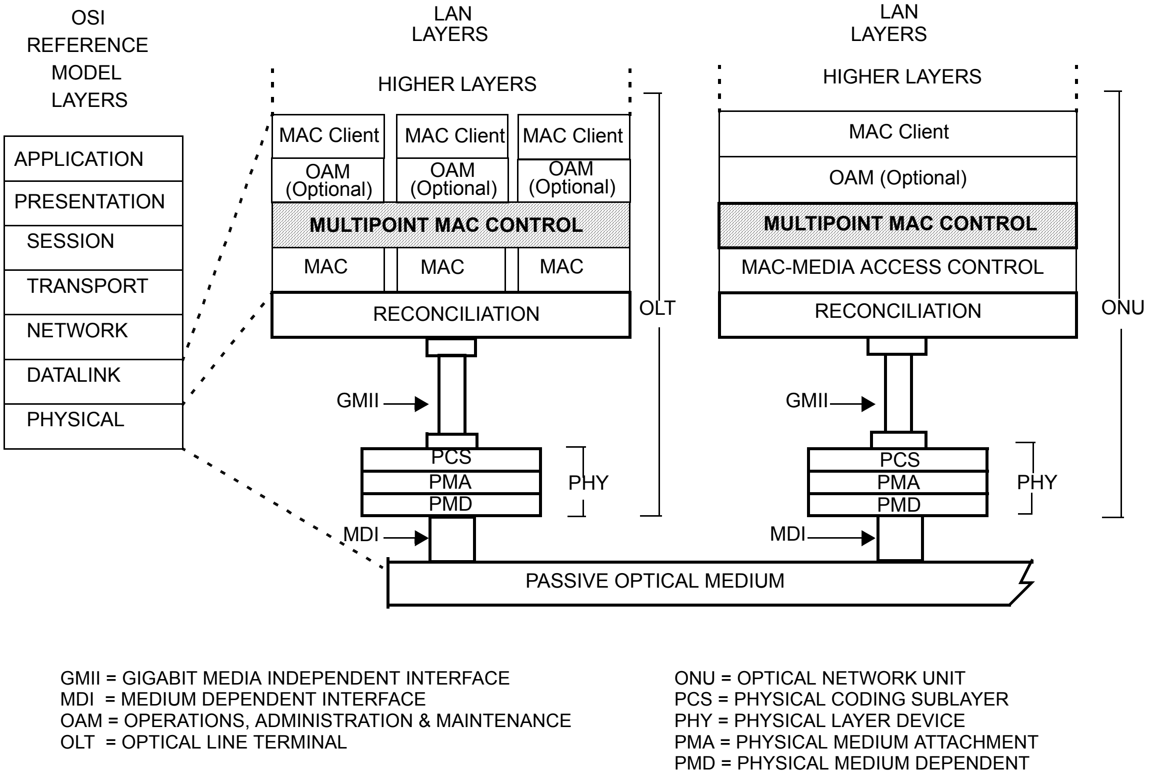


Figure 64–2—Relationship of Multipoint MAC Control and the OSI protocol stack

64.1.3 Functional block diagram

Figure 64–3 provides a functional block diagram of the Multipoint MAC Control architecture.

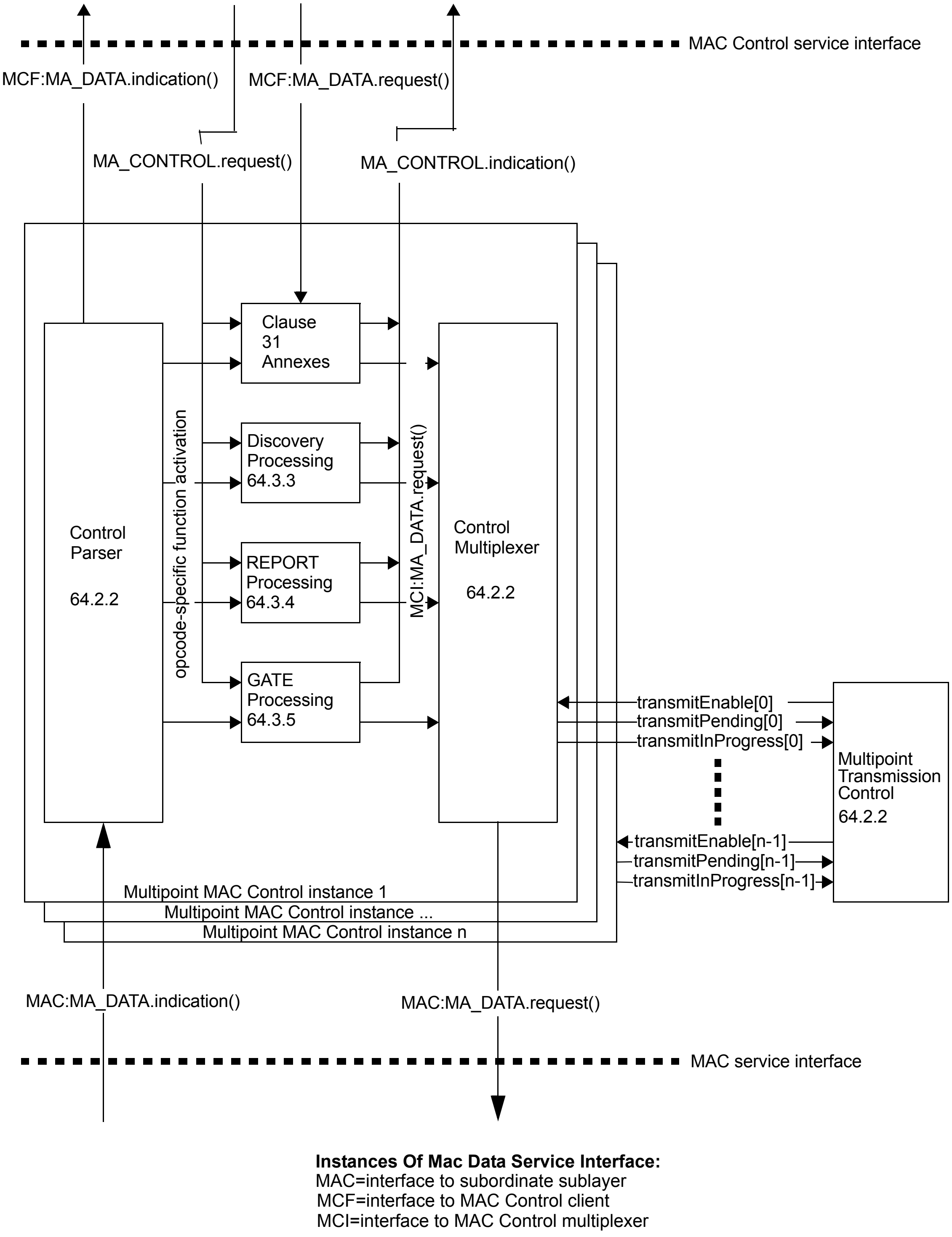


Figure 64–3—Multipoint MAC Control functional block diagram

64.1.4 Service interfaces

The MAC Client communicates with the Control Multiplexer using the standard service interface specified in 2.3. Multipoint MAC Control communicates with the underlying MAC sublayer using the standard service interface specified in 4A.3.2. Similarly, Multipoint MAC Control communicates internally using primitives and interfaces consistent with definitions in Clause 31.

64.1.5 State diagram conventions

The body of this standard comprises state diagrams, including the associated definitions of variables, constants, and functions. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

The notation used in the state diagrams follows the conventions of 21.5. State diagram timers follow the conventions of 14.2.3.2 augmented as follows:

a) [start x_timer, y] sets expiration of *y* to timer *x_timer*.
b) [stop x_timer] aborts the timer operation for *x_timer* asserting *x_timer_not_done* indefinitely.

The state diagrams use an abbreviation MACR as a shorthand form for MA_CONTROL.request and MACI as a shorthand form for MA_CONTROL.indication.

The vector notations used in the state diagrams for bit vector use 0 to mark the first received bit and so on (for example data[0:15]), following the conventions of 3.1 for bit ordering. When referring to an octet vector, 0 is used to mark the first received octet and so on (for example m_sdu[0..1]).

$a < b$: A function that is used to compare two (cyclic) time values. Returned value is true when b is larger than a allowing for wrap around of a and b. The comparison is made by subtracting b from a and testing the MSB. When MSB(a-b) = 1 the value true is returned, else false is returned. In addition, the following functions are defined in terms of $a < b$:
$a > b$ is equivalent to $!(a < b \text{ or } a = b)$
$a \geq b$ is equivalent to $!(a < b)$
$a \leq b$ is equivalent to $!(a > b)$

64.2 Multipoint MAC Control operation

As depicted in Figure 64–3, the Multipoint MAC Control functional block comprises the following functions:

a) *Multipoint Transmission Control*. This block is responsible for synchronizing Multipoint MAC Control instances associated with the Multipoint MAC Control. This block maintains the Multipoint MAC Control state and controls the multiplexing functions of the instantiated MACs.
b) *Multipoint MAC Control Instance n*. This block is instantiated for each MAC and respective MAC and MAC Control clients associated with the Multipoint MAC Control. It holds all the variables and state associated with operating all MAC Control protocols for the instance.
c) *Control Parser*. This block is responsible for parsing MAC Control frames, and interfacing with Clause 31 entities, the opcode specific blocks, and the MAC Client.
d) *Control Multiplexer*. This block is responsible for selecting the source of the forwarded frames.
e) *Clause 31 Annexes*. This block holds MAC Control actions as defined in Clause 31 annexes for support of legacy and future services.
f) *Discovery, Report and Gate Processing*. These blocks are responsible for handling the MPCP in the context of the MAC.

64.2.1 Principles of Multipoint MAC Control

As depicted in Figure 64–3, Multipoint MAC Control sublayer may instantiate multiple Multipoint MAC Control instances in order to interface multiple MAC and MAC Control clients above with multiple MACs below. A unique unicast MAC instance is used at the OLT to communicate with each ONU. The individual MAC instances utilize the point-to-point emulation service between the OLT and the ONU as defined in 65.1.

At the ONU, a single MAC instance is used to communicate with a MAC instance at the OLT. In that case, the Multipoint MAC Control contains only a single instance of the Control Parser/Multiplexer function.

Multipoint MAC Control protocol supports several MAC and client interfaces. Only a single MAC interface and Client interface is enabled for transmission at a time. There is a tight mapping between a MAC service interface and a Client service interface. In particular, the assertion of the MAC:MA_DATA.indication primitive in MAC *j* leads to the assertion of the MCF:MA_DATA.indication primitive to Client *j*. Conversely, the assertion of the request service interface in Client *i* leads to the assertion of the MAC:MA_DATA.request primitive of MAC *i*. Note that the Multipoint MAC sublayer need not receive and transmit packets associated with the same interface at the same time. Thus the Multipoint MAC Control acts like multiple MAC Controls bound together with common elements.

The scheduling algorithm is implementation dependent, and is not specified for the case where multiple transmit requests happen at the same time.

The reception operation is as follows. The Multipoint MAC Control instances generate MAC:MA_DATA.indication service primitives continuously to the underlying MAC instances. Since these MACs are receiving frames from a single PHY only one frame is passed from the MAC instances to Multipoint MAC Control. The MAC instance responding to the MAC:MA_DATA.indication is referred to as the enabled MAC, and its service interface is referred to as the enabled MAC interface. The MAC passes to the Multipoint MAC Control sublayer all valid frames. Invalid frames, as specified in 3.4, are not passed to the Multipoint MAC Control sublayer in response to a MAC:MA_DATA.indication service primitive.

The enabling of a transmit service interface is performed by the Multipoint MAC Control instance in collaboration with the Multipoint Transmission Control. Frames generated in the MAC Control are given priority over MAC Client frames, in effect, prioritizing the MA_CONTROL primitive over the MCF:MA_DATA primitive, and for this purpose MCF:MA_DATA.request primitives may be delayed, discarded or modified in order to perform the requested MAC Control function. For the transmission of this frame, the Multipoint MAC Control instance enables forwarding by the MAC Control functions, but the MAC Client interface is not enabled. The reception of a frame in a MAC results in generation of the MAC:MA_DATA.indication primitive on that MAC's interface. Only one receive MAC interface will be enabled at any given time since there is only one PHY interface.

The information of the enabled interfaces is stored in the controller state variables, and accessed by the Multiplexing Control block.

The Multipoint MAC Control sublayer uses the services of the underlying MAC sublayer to exchange both data and control frames.

Receive operation (MAC:MA_DATA.indication) at each instance:

a) A frame is received from the underlying MAC.
b) The frame is parsed according to Length/Type field
c) MAC Control frames are demultiplexed according to opcode and forwarded to the relevant processing functions
d) Data frames (see 31.5.1) are forwarded to the MAC Client by asserting MCF:MA_DATA.indication primitives

Transmit operation (MAC:MA_DATA.request) at each instance:

e) The MAC Client signals a frame transmission by asserting MCF:MA_DATA.request, or

f) A protocol processing block attempts to issue a frame, as a result of a previous MA_CONTROL.request or as a result of an MPCP event that generates a frame.
g) When allowed to transmit by the Multipoint Transmission Control block, the frame is forwarded.

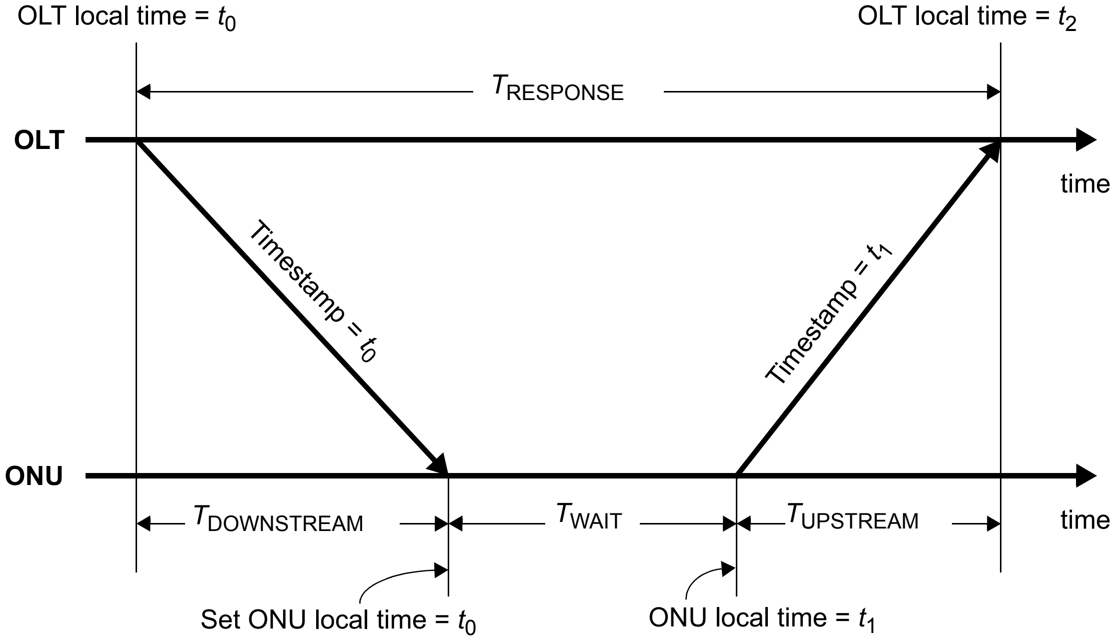
64.2.1.1 Ranging and Timing Process

Both the OLT and the ONU have 32-bit counters that increment every 16 ns. These counters provide a local time stamp. When either device transmits an MPCPDU, it maps its counter value into the timestamp field. The time of transmission of the first octet of the MPCPDU frame from the MAC Control to the MAC is taken as the reference time used for setting the timestamp value.

When the ONU receives MPCPDUs, it sets its counter according to the value in the timestamp field in the received MPCPDU.

When the OLT receives MPCPDUs, it uses the received timestamp value to calculate or verify a round trip time between the OLT and the ONU. The RTT is equal to the difference between the timer value and the value in the timestamp field. The calculated RTT is notified to the client via the MA_CONTROL.indication primitive. The client can use this RTT for the ranging process.

A condition of *timestamp drift error* occurs when the difference between OLT's and ONU's clocks exceeds some predefined threshold. This condition can be independently detected by the OLT or an ONU. The OLT detects this condition when an absolute difference between new and old RTT values measured for a given ONU exceeds the value of guardThresholdOLT (see 64.2.2.1), as shown in Figure 64–10. An ONU detects the timestamp drift error condition when absolute difference between a timestamp received in an MPCPDU and the localTime counter exceeds guardThresholdONU (see 64.2.2.1), as is shown in Figure 64–11.



$T_{DOWNSTREAM}$ = downstream propagation delay

$T_{UPSTREAM}$ = upstream propagation delay

T_{WAIT} = wait time at ONU = $t_1 - t_0$

$T_{RESPONSE}$ = response time at OLT = $t_2 - t_0$

$$RTT = T_{DOWNSTREAM} + T_{UPSTREAM} = T_{RESPONSE} - T_{WAIT} = (t_2 - t_0) - (t_1 - t_0) = t_2 - t_1$$

Figure 64–4—Round trip time calculation

64.2.2 Multipoint transmission control, Control Parser, and Control Multiplexer

The purpose of the multipoint transmission control is to allow only one of the multiple MAC clients to transmit to its associated MAC and subsequently to the RS layer at one time by only asserting one transmitEnable signal at a time.

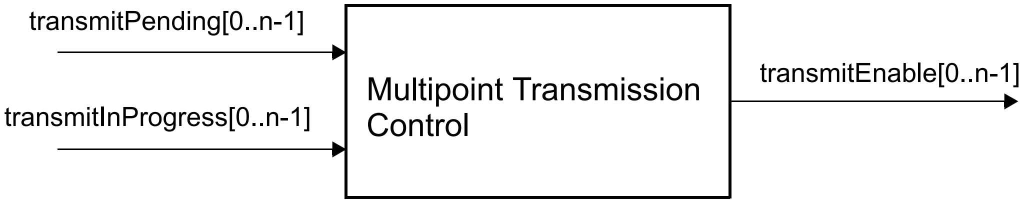


Figure 64–5—Multipoint Transmission Control Service Interfaces

Multipoint MAC Control Instance n function block communicates with the Multipoint Transmission Control using transmitEnable[n], transmitPending[n], and transmitInProgress[n] state variables (see Figure 64–3).

The Control Parser is responsible for opcode independent parsing of MAC frames in the reception path. By identifying MAC Control frames, demultiplexing into multiple entities for event handling is possible. Interfaces are provided to existing Clause 31 entities, functional blocks associated with MPCP, and the MAC Client.

The Control Multiplexer is responsible for forwarding frames from the MAC Control opcode-specific functions and the MAC Client to the MAC. Multiplexing is performed in the transmission direction. Given multiple MCF:MA_DATA.request service primitives from the MAC Client, and MA_CONTROL.request primitives from the MAC Control Clients, a single MAC:MA_DATA.request service primitive is generated for transmission. At the OLT, multiple MAC instances share the same Multipoint MAC Control, as a result, the transmit block is enabled based on an external control signal housed in Multipoint Transmission Control for transmission overlap avoidance. At the ONU the Gate Processing functional block interfaces for upstream transmission administration.

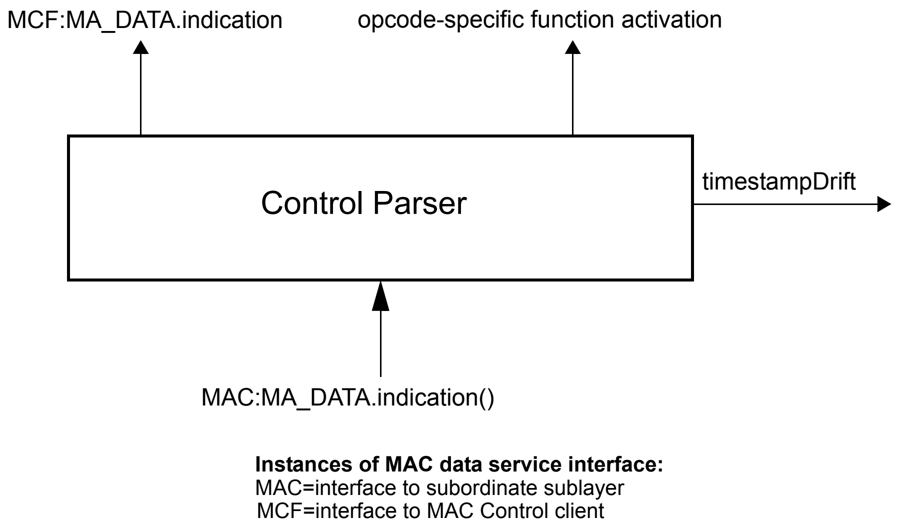
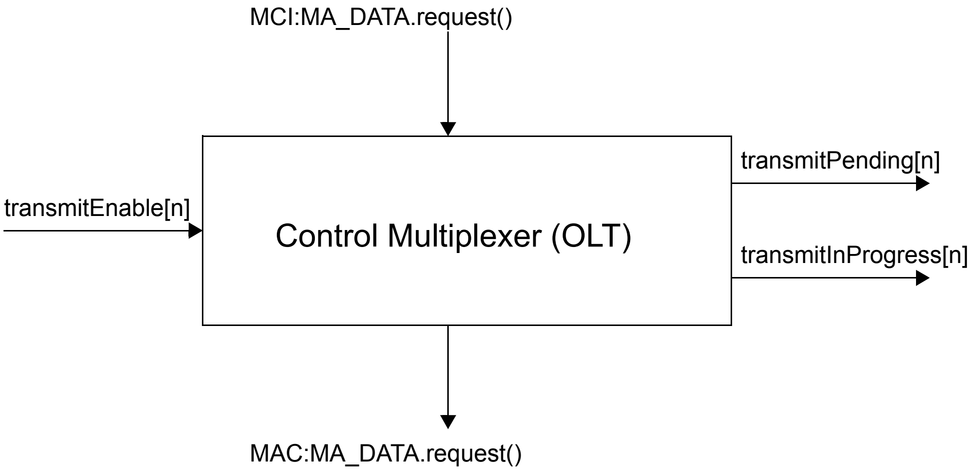


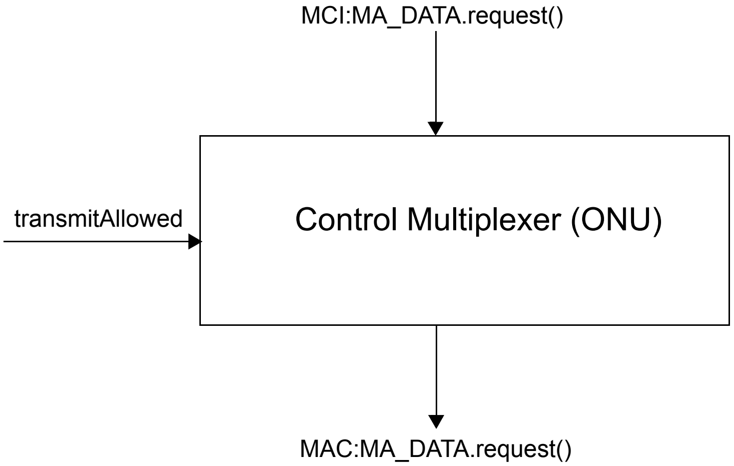
Figure 64–6—Control Parser service interfaces



Instances of MAC data service interface:
MAC=interface to subordinate sublayer
MCI=interface to MAC Control multiplexer

NOTE—MAC:MA_DATA.request primitive may be issued from multiple MAC Control processing blocks.

Figure 64–7—OLT Control Multiplexer service interfaces



Instances of MAC data service interface:
MAC=interface to subordinate sublayer
MCI=interface to MAC Control multiplexer

NOTE—MAC:MA_DATA.request primitive may be issued from multiple MAC Control processing blocks.

Figure 64–8—ONU Control Multiplexer service interfaces

64.2.2.1 Constants

defaultOverhead

This constant holds the size of packet transmission overhead. This overhead is measured in units of time quanta.

TYPE:	integer
VALUE:	6

guardThresholdOLT

This constant holds the maximal amount of drift allowed for a timestamp received at the OLT. This value is measured in units of time_quantum (16 bit times).

TYPE:	integer
VALUE:	12

guardThresholdONU

This constant holds the maximal amount of drift allowed for a timestamp received at the ONU. This value is measured in units of time_quantum (16 bit times)

TYPE:	integer
VALUE:	8

MAC_Control_type

The value of the Length/Type field as defined in 31.4.1.3.

TYPE:	integer
VALUE:	0x8808

tailGuard

This constant holds the value used to reserve space at the end of the upstream transmission at the ONU in addition to the size of last MAC service data unit (m_sdu) in units of octets. Space is reserved for the MAC overheads including: preamble, SFD, DA, SA, Length/Type, FCS, and the End of Packet Delimiter (EPD). The sizes of the above listed MAC overhead items are described in 3.1.1. The size of the EPD is described in 36.2.4.14.

TYPE:	integer
VALUE:	29

time_quantum

The unit of time_quantum is used by all mechanisms synchronized to the advancement of the localTime variable. All variables that represent counters and time intervals are defined using time_quantum. Each time_quantum is 16 ns.

TYPE:	integer
VALUE:	16

tqSize

This constant represents time_quantum in octet transmission times.

TYPE:	integer
VALUE:	2

64.2.2.2 Counters

localTime

This variable holds the value of the local timer used to control MPCP operation. This variable is advanced by a timer at 62.5 MHz, and counts in time_quanta. At the OLT the counter shall track the transmit clock, while at the ONU the counter shall track the receive clock. For accuracy of receive clock, see 65.3.1.2. It is reloaded with the received timestamp value (from the OLT) by the Control Parser (see Figure 64–11). Changing the value of this variable while running using Layer Management is highly undesirable and is unspecified.

TYPE:	32 bit unsigned

64.2.2.3 Variables

BEGIN

This variable is used when initiating operation of the functional block state diagram. It is set to true following initialization and every reset.

TYPE: Boolean

data_rx

This variable represents a 0-based bit array corresponding to the payload of a received MPCPDU. This variable is used to parse incoming MPCPDU frames.

TYPE: bit array

data_tx

This variable represents a 0-based bit array corresponding to the payload of an MPCPDU being transmitted. This variable is used to access payload of outgoing MPCPDU frames, for example to set the timestamp value.

TYPE: bit array

fecEnabled

This variable represents whether the FEC function is enabled. If FEC function is enabled, this variable equals true, otherwise it equals false.

TYPE: Boolean

newRTT

This variable temporary holds a newly-measured Round Trip Time to the ONU. The new RTT value is represented in units of time_quanta.

TYPE: 16 bit unsigned

nextTxTime

This variable represents a total transmission time of next packet and is used to check whether the next packet fits in the remainder of ONU’s transmission window. The value of nextTxTime includes packet transmission time, tailGuard defined in 64.2.2.1, and FEC parity data overhead, if FEC is enabled. This variable is measured in units of time quanta.

TYPE: 16 bit unsigned

opcode_rx

This variable holds an opcode of the last received MPCPDU.

TYPE: 16 bit unsigned

opcode_tx

This variable holds an opcode of an outgoing MPCPDU.

TYPE: 16 bit unsigned

RTT

This variable holds the measured Round Trip Time to the ONU. The RTT value is represented in units of time_quanta.

TYPE: 16 bit unsigned

stopTime

This variable holds the value of the localTime counter corresponding to the end of the nearest grant. This value is set by the Gate Processing function as described in 64.3.5.

TYPE: 32 bit unsigned

timestamp

This variable holds the value of timestamp of the last received MPCPDU frame.

TYPE: 32 bit unsigned

timestampDrift

This variable is used to indicate whether an error is signaled as a result of uncorrectable timestamp drift.

TYPE: Boolean

transmitAllowed

This variable is used to control PDU transmission at the ONU. It is set to true when the transmit path is enabled, and is set to false when the transmit path is being shut down. transmitAllowed changes its value according to the state of the Gate Processing functional block.

TYPE: Boolean

transmitEnable[j]

These variables are used to control the transmit path in a Multipoint MAC Control instance at the OLT. Setting them to on indicates that the selected instance is permitted to transmit a frame. Setting it to off inhibits the transmission of frames in the selected instance. Only one of transmitEnable[j] should be set to on at a time.

TYPE: Boolean

transmitInProgress[j]

This variable indicates that the Multipoint MAC Control instance *j* is in a process of transmitting a frame.

TYPE: Boolean

transmitPending[j]

This variable indicates that the Multipoint MAC Control instance *j* is ready to transmit a frame.

TYPE: Boolean

64.2.2.4 Functions

abs(n)

This function returns the absolute value of the parameter n.

Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

FEC_Overhead(length)

This function calculates the size of additional overhead to be added by the FEC encoder while encoding a frame of size length. Parameter length represents the size of an entire frame including preamble, SFD, DA, SA, Length/Type, and FCS. As specified in 65.2.3, FEC encoder adds 16 parity octets for each block of 239 data octets. Additionally, 26 code-groups are required to accommodate IPG and longer start-of-frame and end-of-frame sequences, which are used to allow reliable packet boundary detection in presence of high bit error ratio. The function returns the value of FEC overhead in units of time quanta. The following formula is used to calculate the overhead:

$$FEC\_Overhead = 13 + \left\lceil \frac{length}{239} \right\rceil \times 8$$

NOTE—The notation $\lceil x \rceil$ represents a *ceiling* function, which returns the value of its argument *x* rounded up to the nearest integer.

select

This function selects the next Multipoint MAC Control instance allowed to initiate transmission of a frame. The function returns an index to the transmitPending array for which the value is not false. The selection criteria in the presence of multiple active elements in the list is implementation dependent.

SelectFrame()

This function enables the interface, which has a pending frame. If multiple interfaces have frames waiting at the same time, only one interface will be enabled. The selection criteria is not specified, except for the case when some of the pending frames have Length/Type = MAC_Control. In this case, one of the interfaces with a pending MAC Control frame shall be enabled.

sizeof(sdu)

This function returns the size of the sdu in octets.

transmissionPending()

This function returns true if any of the Multipoint MAC Control instances has a frame waiting to be transmitted. The function can be represented as

transmissionPending() = transmitPending[0] +
transmitPending[1] +
... +
transmitPending[n-1]

where n is the total number of Multipoint MAC Control instances.

64.2.2.5 Timers

packet_initiate_timer

This timer is used to delay frame transmission from MAC Control to avoid variable MAC delay while MAC enforces IPG after a previous frame. In addition, when FEC is enabled, this timer increases interframe spacing just enough to accommodate the extra parity data to be added by the FEC encoder.

64.2.2.6 Messages

MAC:MA_DATA.indication(DA, SA, m_sdu, receiveStatus)

The service primitive is defined in 31.3.

MCF:MA_DATA.indication(DA, SA, m_sdu, receiveStatus)

The service primitive is defined in 31.3.

MAC:MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 31.3. The action invoked by this service primitive is not considered to end until the transmission of the frame by the MAC has concluded. The ability of the MAC control layer to determine this is implementation dependent.

MCF:MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 31.3.

64.2.2.7 State Diagrams

The Multipoint transmission control function in the OLT shall implement state diagram shown in Figure 64–9. Control parser function in the OLT shall implement state diagram shown in Figure 64–10. Control parser function in the ONU shall implement state diagram shown in Figure 64–11. Control multiplexer function in the OLT shall implement state diagram shown in Figure 64–12. Control multiplexer function in the ONU shall implement state diagram shown in Figure 64–13.

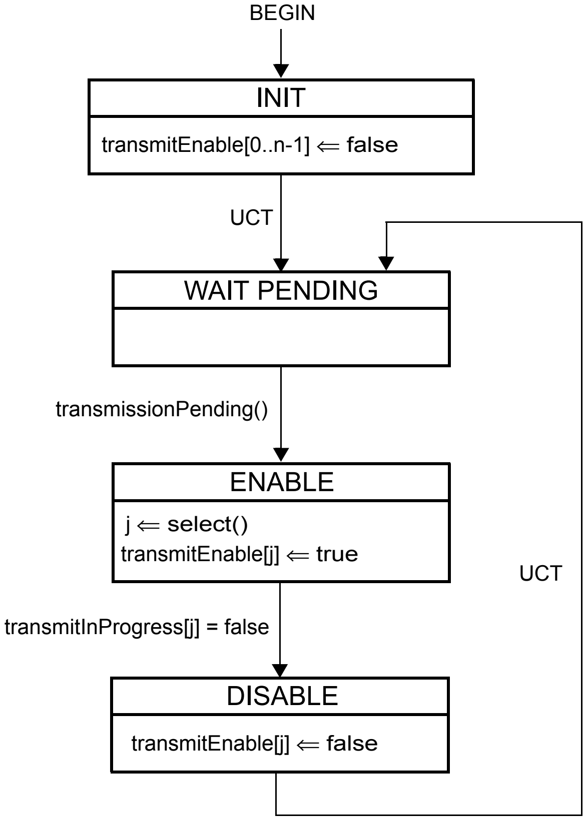
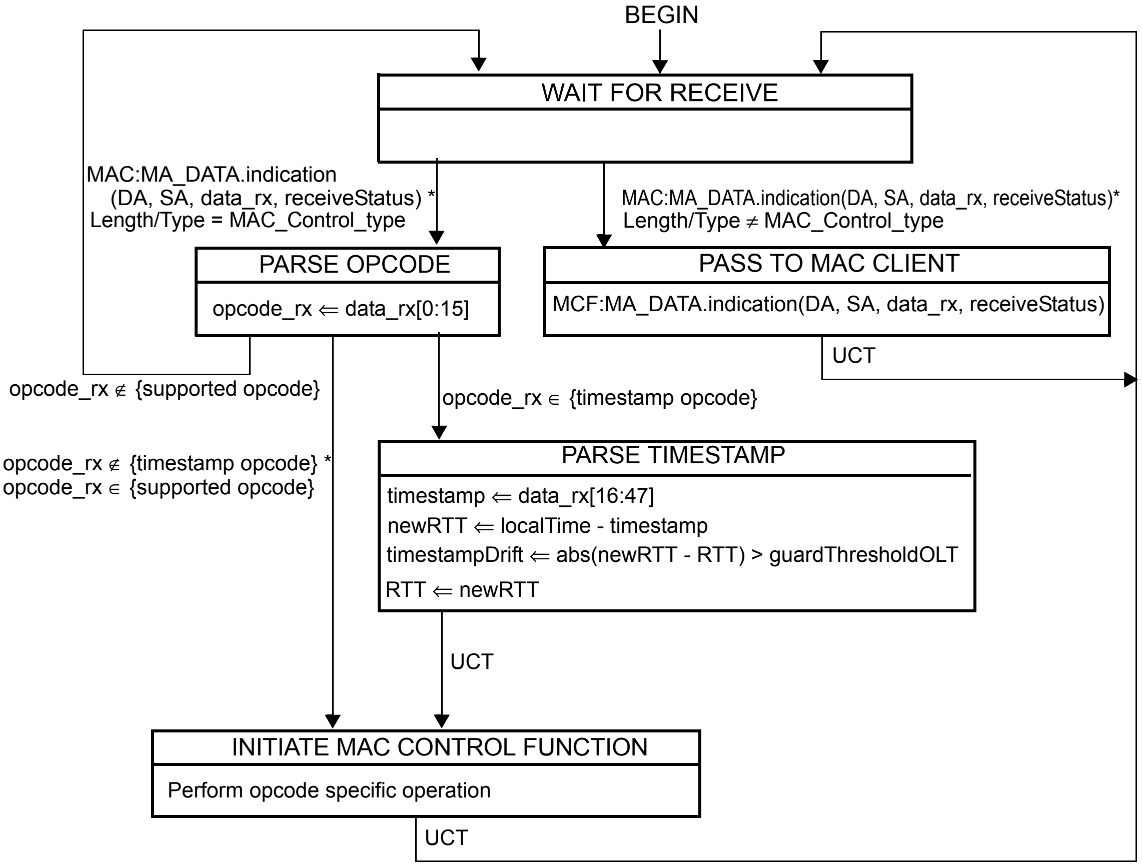


Figure 64–9—OLT Multipoint Transmission Control state diagram

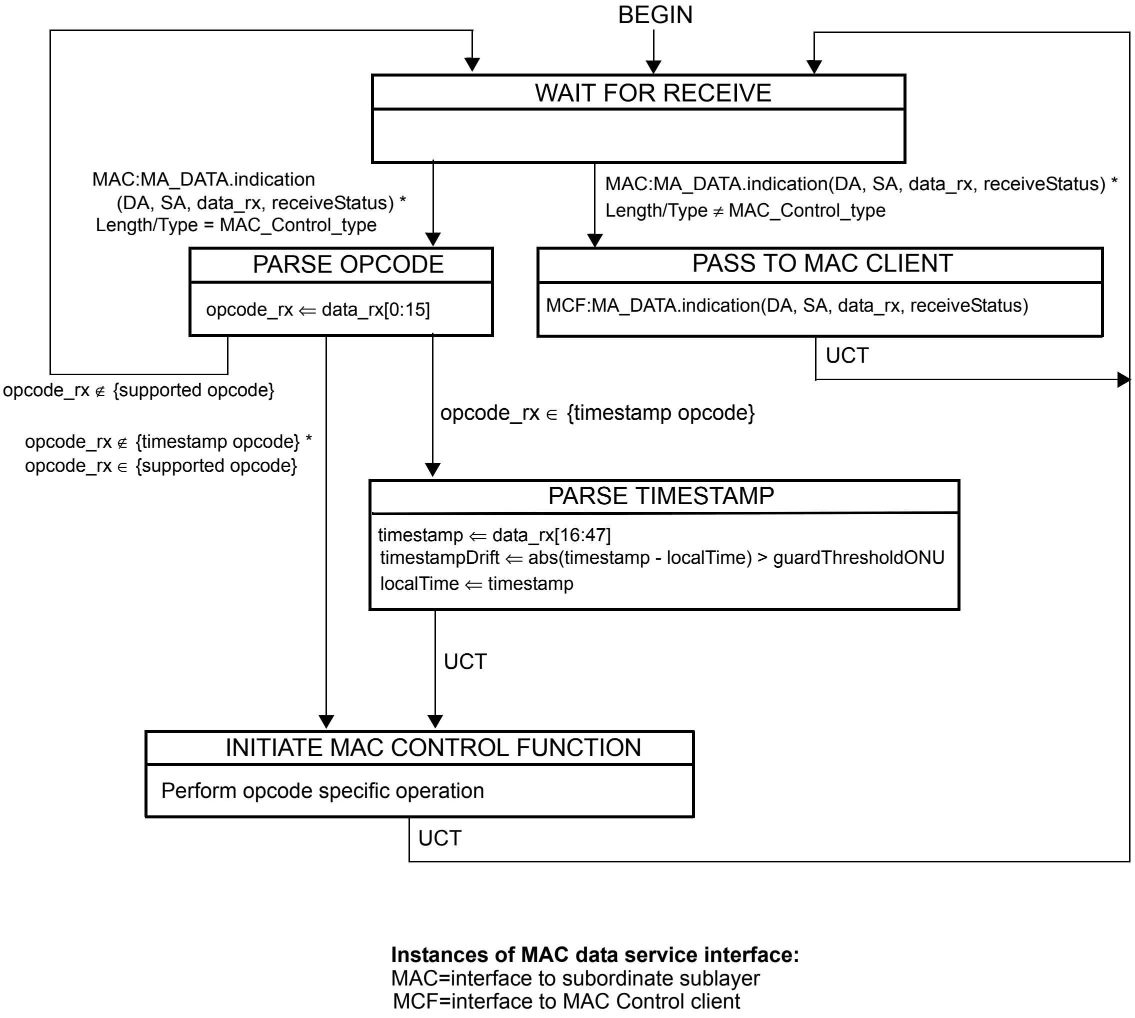


Instances of MAC data service interface:
MAC=interface to subordinate sublayer
MCF=interface to MAC Control client

NOTE—The opcode-specific operation is launched as a parallel process by the MAC Control sublayer, and not as a synchronous function. Progress of the generic MAC Control Receive state diagram (as shown in this figure) is not implicitly impeded by the launching of the opcode specific function.

Refer to Annex 31A for list of supported opcodes and timestamp opcodes.

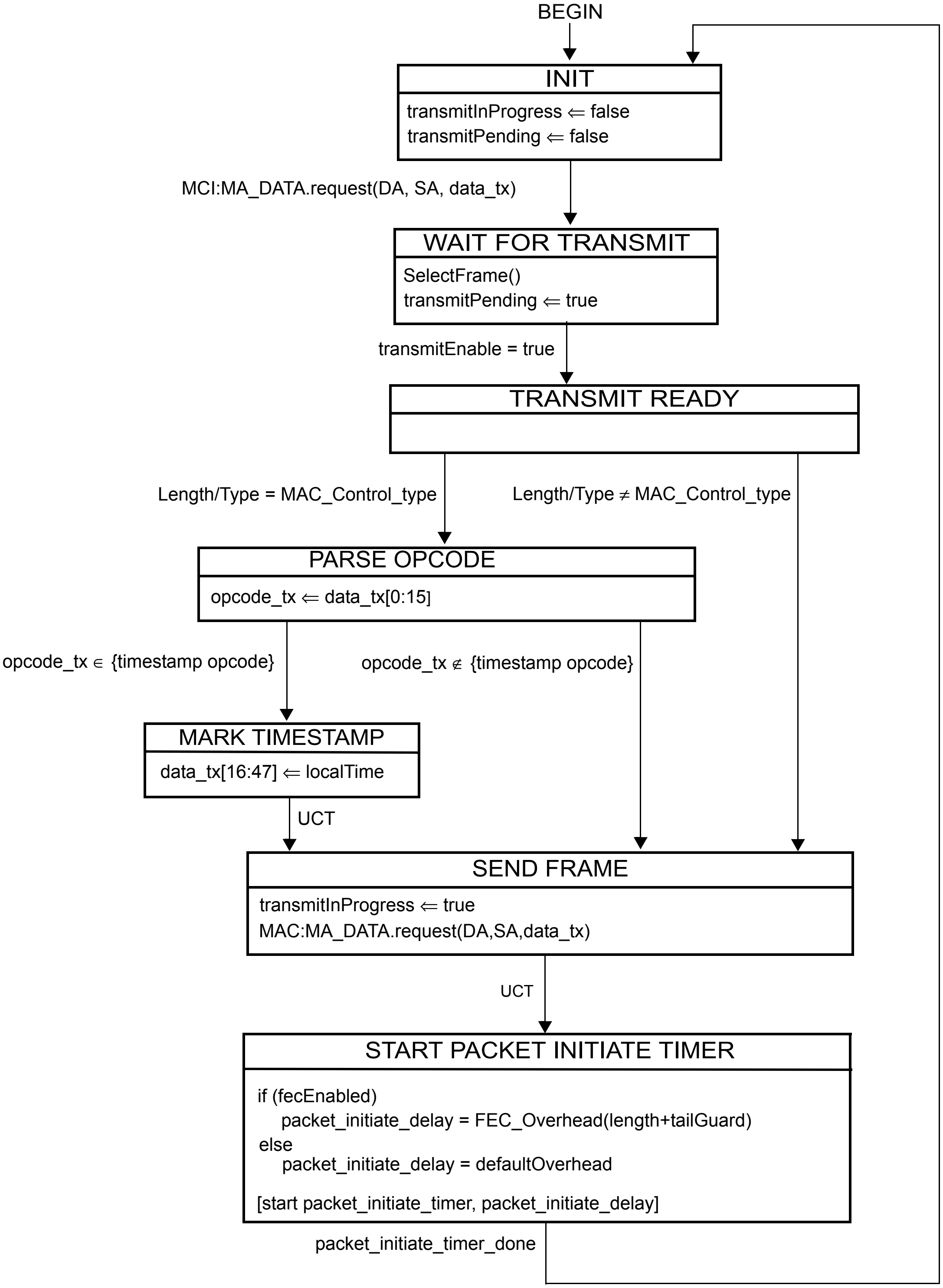
Figure 64–10—OLT Control Parser state diagram



NOTE—The opcode-specific operation is launched as a parallel process by the MAC Control sublayer, and not as a synchronous function. Progress of the generic MAC Control Receive state diagram (as shown in this figure) is not implicitly impeded by the launching of the opcode specific function.

Refer to Annex 31A for list of supported opcodes and timestamp opcodes.

Figure 64–11—ONU Control Parser state diagram



Instances of MAC data service interface:
MAC=interface to subordinate sublayer
MCI=interface to MAC Control multiplexer

Figure 64–12—OLT Control Multiplexer state diagram

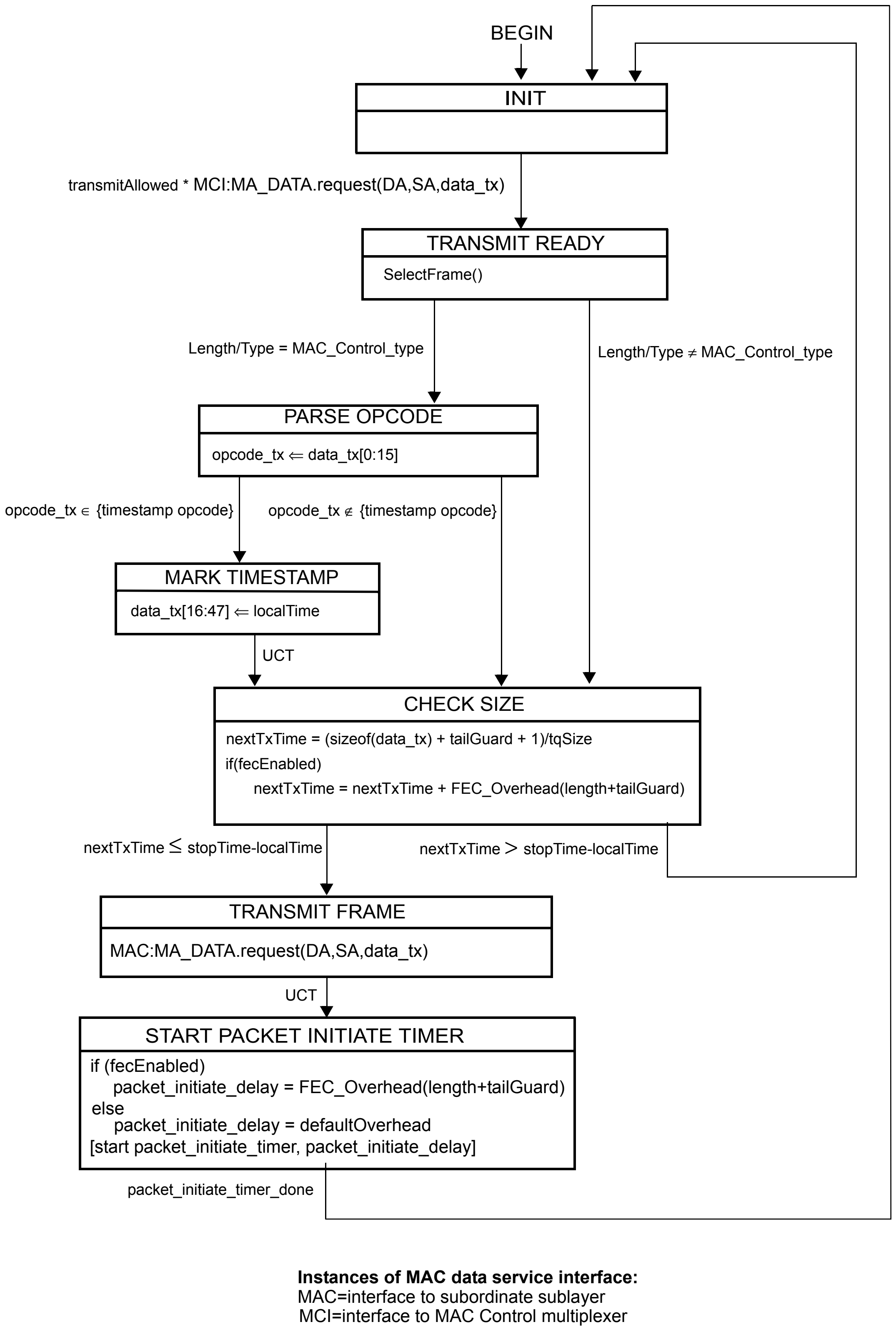


Figure 64–13—ONU Control Multiplexer state diagram

64.3 Multipoint Control Protocol (MPCP)

As depicted in Figure 64–3, the Multipoint MAC Control functional block comprises the following functions:

a) *Discovery Processing*. This block manages the discovery process, through which an ONU is discovered and registered with the network while compensating for RTT.
b) *Report Processing*. This block manages the generation and collection of report messages, through which bandwidth requirements are sent upstream from the ONU to the OLT.
c) *Gate Processing*. This block manages the generation and collection of gate messages, through which multiplexing of multiple transmitters is achieved.

As depicted in Figure 64–3, the layered system may instantiate multiple MAC entities, using a single Physical Layer. Each instantiated MAC communicates with an instance of the opcode specific functional blocks through the Multipoint MAC Control. In addition some global variables are shared across the multiple instances. Common state control is used to synchronize the multiple MACs using MPCP procedures. Operation of the common state control is generally considered outside the scope of this document.

64.3.1 Principles of Multipoint Control Protocol

Multipoint MAC Control enables a MAC Client to participate in a point-to-multipoint optical network by allowing it to transmit and receive frames as if it was connected to a dedicated link. In doing so, it employs the following principles and concepts:

a) A MAC client transmits and receives frames through the Multipoint MAC Control sublayer.
b) The Multipoint MAC Control decides when to allow a frame to be transmitted using the client interface Control Multiplexer.
c) Given a transmission opportunity, the MAC Control may generate control frames that would be transmitted in advance of the MAC Client's frames, utilizing the inherent ability to provide higher priority transmission of MAC Control frames over MAC Client frames.
d) Multiple MACs operate on a shared medium by allowing only a single MAC to transmit upstream at any given time across the network using a time-division multiple access (TDMA) method.
e) Such gating of transmission is orchestrated through the Gate Processing function.
f) New devices are discovered in the network and allowed transmission through the Discovery Processing function.
g) Fine control of the network bandwidth distribution can be achieved using feedback mechanisms supported in the Report Processing function.
h) The operation of P2MP network is asymmetrical, with the OLT assuming the role of master, and the ONU assuming the role of slave.

64.3.2 Compatibility considerations

64.3.2.1 PAUSE operation

Even though MPCP is compatible with flow control, optional use of flow control may not be efficient in the case of large propagation delay. If flow control is implemented, then the timing constraints in Annex 31B supplement the constraints found at 64.3.2.4.

NOTE—MAC at an ONU can receive frames from unicast channel and SCB channel. If the SCB channel is used to broadcast data frames to multiple ONUs, the ONU's MAC may continue receiving data frames from SCB channel even after the ONU has issued a PAUSE request to its unicast remote-end.

64.3.2.2 Optional Shared LAN Emulation

By combining P2PE, suitable filtering rules at the ONU, and suitable filtering and forwarding rules at the OLT, it is possible to emulate an efficient shared LAN. Support for shared LAN emulation is optional, and requires an additional layer above the MAC, which is out of scope for this document. Thus, shared LAN emulation is introduced here for informational purposes only.

Specific behavior of the filtering layer at the RS is specified in 65.1.3.3.2.

64.3.2.3 Multicast and single copy broadcast support

In the downstream direction, the PON is a broadcast medium. In order to make use of this capability for forwarding broadcast frames from the OLT to multiple recipients without multiple duplication for each ONU, the SCB and multicast LLID support is introduced.

The OLT has at least one MAC associated with every ONU. In addition one more MAC at the OLT is marked as the SCB MAC. Moreover, the OLT has a multicast MAC associated with each defined multicast LLID. The SCB MAC handles all downstream broadcast traffic, but is never used in the upstream direction for client traffic, except for client registration. Similarly, the multicast MACs handle downstream multicast traffic, but are never used in the upstream direction for client traffic. Optional higher layers may be implemented to perform selective broadcast and multicast of frames. Such layers may require additional MACs (multicast MACs) to be instantiated in the OLT for some or all ONUs increasing the total number of MACs beyond the number of ONUs + 1.

When connecting the SCB MAC or a multicast MAC to an IEEE 802.1D bridge port it is possible that loops may be formed due to the broadcast or multicast nature of the associated LLIDs. Thus it is recommended that this MAC not be connected to an IEEE 802.1D bridge port.

SCB channel configuration as well as filtering and marking of frames for support of SCB is defined in 65.1.3.3.2.

64.3.2.4 Delay requirements

The MPCP protocol relies on strict timing based on distribution of timestamps. A compliant implementation needs to guarantee a constant delay through the MAC and PHY in order to maintain the correctness of the timestamping mechanism. The actual delay is implementation dependent, however, a complying implementation shall maintain a delay variation of no more than 16 bit times through the implemented MAC stack.

The OLT shall not grant less than 1024 time_quanta into the future, in order to allow the ONU processing time when it receives a gate message. The ONU shall process all messages in less than this period. The OLT shall not issue more than one message every 1024 time_quanta to a single ONU. The unit of time_quantum is defined as 16 ns.

64.3.3 Discovery Processing

Discovery is the process whereby newly connected or off-line ONUs are provided access to the PON. The process is driven by the OLT, which periodically makes available Discovery Time Windows during which off-line ONUs are given the opportunity to make themselves known to the OLT. The periodicity of these windows is unspecified and left up to the implementer. The OLT signifies that a discovery period is occurring by broadcasting a discovery gate message, which includes the starting time and length of the discovery window. Off-line ONUs, upon receiving this message, wait for the period to begin and then transmit a REGISTER_REQ message to the OLT. Discovery windows are unique in that they are the only times where multiple ONUs can access the PON simultaneously, and transmission overlap can occur. In order to reduce transmission overlaps, a contention algorithm is used by all ONUs. Measures are taken to reduce the probability for overlaps by artificially simulating a random distribution of distances from the OLT. Each ONU shall wait a random amount of time before transmitting the REGISTER_REQ message that is shorter than the length of the discovery time window. It should be noted that multiple valid REGISTER_REQ messages can be received by the OLT during a single discovery time period. Included in the REGISTER_REQ message is the ONU's MAC address and number of maximum pending grants. Upon receipt of a valid REGISTER_REQ message, the OLT registers the ONU, allocating and assigning new port identities (LLIDs), and bonding corresponding MACs to the LLIDs.

The next step in the process is for the OLT to transmit a Register message to the newly discovered ONU, which contains the ONU's LLID, and the OLT's required synchronization time. Also, the OLT echoes the maximum number of pending grants. The OLT now has enough information to schedule the ONU for access to the PON and transmits a standard GATE message allowing the ONU to transmit a REGISTER_ACK. Upon receipt of the REGISTER_ACK, the discovery process for that ONU is complete, the ONU is registered and normal message traffic can begin. It is the responsibility of Layer Management to perform the MAC bonding, and start transmission from/to the newly registered ONU. The discovery message exchange is illustrated in Figure 64–14.

There may exist situations when the OLT requires that an ONU go through the discovery sequence again and reregister. Similarly, there may be situations where an ONU needs to inform the OLT of its desire to deregister. The ONU can then reregister by going through the discovery sequence. For the OLT, the REGISTER message may indicate a value, Reregister or Deregister, that if either is specified will force the receiving ONU into reregistering. For the ONU, the REGISTER_REQ message contains the Deregister bit that signifies to the OLT that this ONU should be deregistered.

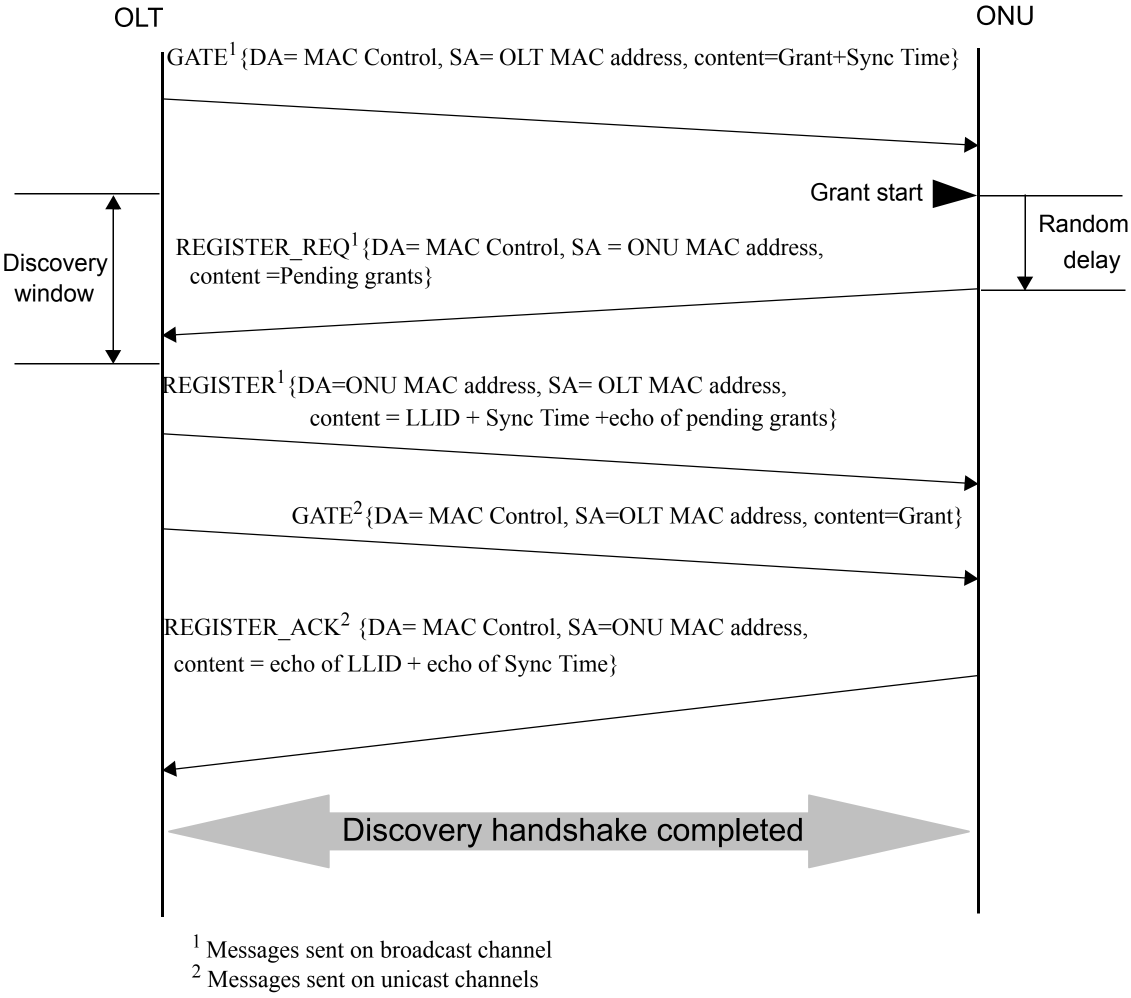


Figure 64–14—Discovery Handshake Message Exchange

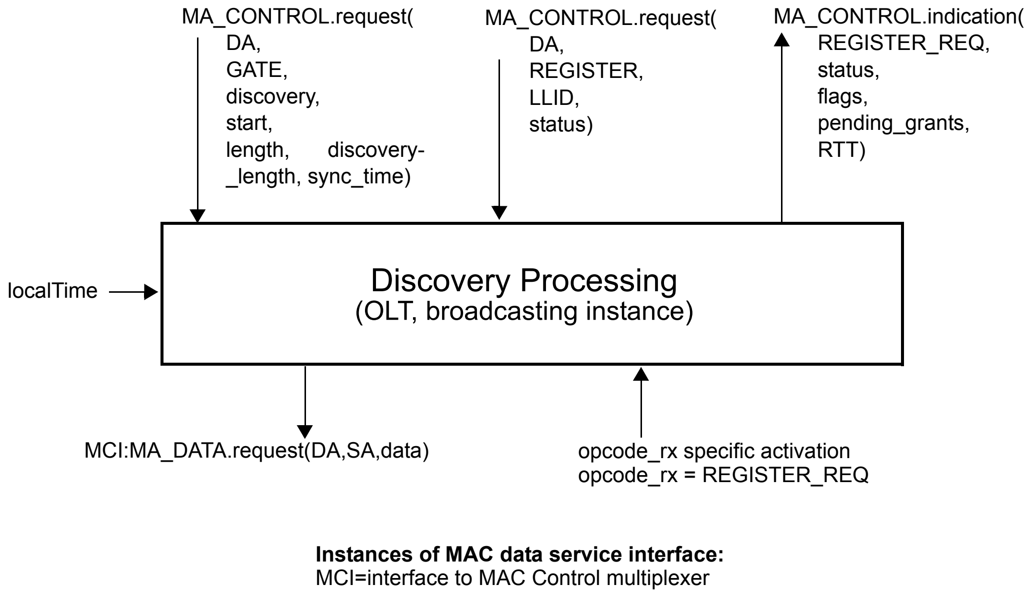


Figure 64–15—Discovery Processing service interfaces (OLT, broadcasting instance)

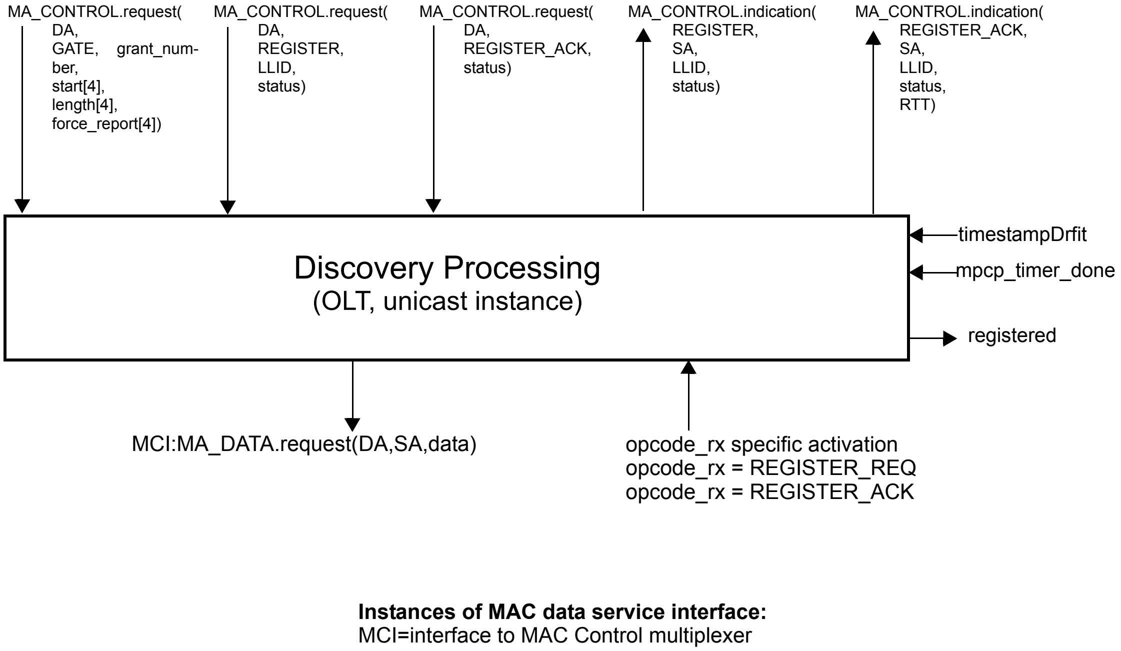


Figure 64–16—Discovery Processing service interfaces (OLT, unicasting instance)

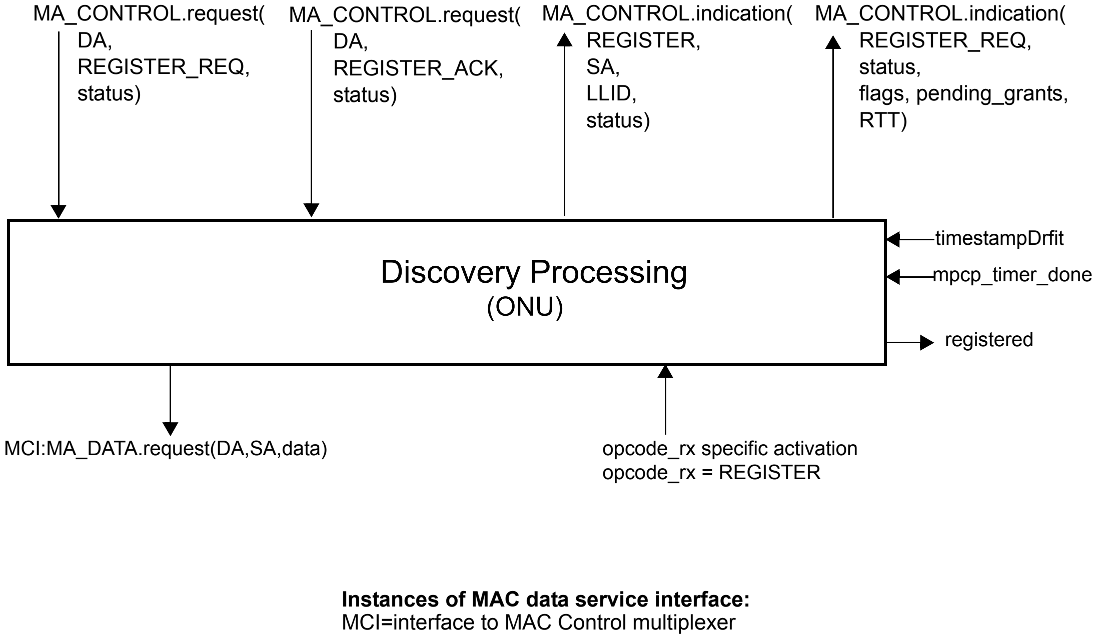


Figure 64–17—Discovery Processing service interfaces (ONU)

64.3.3.1 Constants

No constants defined.

64.3.3.2 Variables

BEGIN
  This variable is defined in 64.2.2.3.

data_rx
  This variable is defined in 64.2.2.3.

data_tx
  This variable is defined in 64.2.2.3.

grantEndTime
  This variable holds the time at which the OLT expects the ONU grant to complete. Failure of a REGISTER_ACK message from an ONU to arrive at the OLT before grantEndTime is a fatal error in the discovery process, and causes registration to fail for the specified ONU, who may then retry to register. The value of grantEndTime is measured in units of time_quantum.
  TYPE: 32-bit unsigned

insideDiscoveryWindow
  This variable holds the current status of the discovery window. It is set to true when the discovery window opens, and is set to false when the discovery window closes.
  TYPE: Boolean

localTime

This variable is defined in 64.2.2.2.

opcode_rx

This variable is defined in 64.2.2.3.

opcode_tx

This variable is defined in 64.2.2.3.

pendingGrants

This variable holds the maximum number of pending grants that an ONU is able to queue.

TYPE: 16 bit unsigned

registered

This variable holds the current result of the Discovery Process. It is set to true once the discovery process is complete and registration is acknowledged.

TYPE: Boolean

syncTime

This variable holds the time required to stabilize the receiver at the OLT. It counts time_quanta units from the point where transmission output is stable to the point where synchronization has been achieved. The value of syncTime includes gain adjustment interval ($T_{receiver\_settling}$), clock synchronization interval (T_{CDR}), and code-group alignment interval ($T_{code\_group\_align}$), as specified in 60.9.13.2. The OLT conveys the value of syncTime to ONUs in Discovery GATE and REGISTER messages. During the synchronization time only IDLE patterns can be transmitted by an ONU.

TYPE: 16 bit unsigned

timestampDrift

This variable is defined in 64.2.2.3.

64.3.3.3 Functions

None.

64.3.3.4 Timers

discovery_window_size_timer

This timer is used to wait for the event signaling the end of the discovery window.

VALUE: The timer value is set dynamically based on the parameters received in a DISCOVERY GATE message.

mpcp_timer

This timer is used to measure the arrival rate of MPCP frames in the link. Failure to receive frames is considered a fatal fault and leads to deregistration.

64.3.3.5 Messages

MA_DATA.indication(DA, SA, m_sdu, receiveStatus)

The service primitive is defined in 2.3.2.

MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 2.3.2.

MA_CONTROL.request(DA, GATE, discovery, start, length, discovery_length, sync_time)

The service primitive used by the MAC Control client at the OLT to initiate the Discovery Process. This primitive takes the following parameters:

DA:	multicast or unicast MAC address.
GATE:	opcode for GATE MPCPDU as defined in Table 31A–1.
discovery:	flag specifying that the given GATE message is to be used for discovery only.

start: start time of the discovery window.
length: length of the grant given for discovery.
discovery_length: length of the discovery window process.
sync_time: the time interval required to stabilize the receiver at the OLT.

MA_CONTROL.request(DA, GATE, grant_number, start[4], length[4], force_report[4])

This service primitive is used by the MAC Control client at the OLT to issue the GATE message to an ONU. This primitive takes the following parameters:

DA: multicast MAC Control address as defined in Annex 31B.
GATE: opcode for GATE MPCPDU as defined in Table 31A–1.
grant_number: number of grants issued with this GATE message. The number of grants ranges from 0 to 4.
start[4]: start times of the individual grants. Only the first grant_number elements of the array are used.
length[4]: lengths of the individual grants. Only the first grant_number elements of the array are used.
force_report[4]: flags indicating whether a REPORT message should be generated in the corresponding grant. Only the first grant_number elements of the array are used.

MA_CONTROL.request(DA, REGISTER_REQ, status)

The service primitive used by a client at the ONU to request the Discovery Process to perform a registration. This primitive takes the following parameters:

DA: multicast MAC Control address as defined in Annex 31B.
REGISTER_REQ: opcode for REGISTER_REQ MPCPDU as defined in Table 31A–1.
status: This parameter takes on the indication supplied by the flags field in the REGISTER_REQ MPCPDU as defined in Table 64–3.

MA_CONTROL.indication(REGISTER_REQ, status, flags, pending_grants, RTT)

The service primitive issued by the Discovery Process to notify the client and Layer Management that the registration process is in progress. This primitive takes the following parameters:

REGISTER_REQ: opcode for REGISTER_REQ MPCPDU as defined in Table 31A–1.
status: This parameter holds the values incoming or retry. Value incoming is used at the OLT to signal that a REGISTER_REQ message was received successfully. The value retry is used at the ONU to signal to the client that a registration attempt failed and will be repeated.
flags: This parameter holds the contents of the flags field in the REGISTER_REQ message. This parameter holds a valid value only when the primitive is generated by the Discovery Process is in the OLT.
pending_grants: This parameters holds the contents of the pending_grants field in the REGISTER_REQ message. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

RTT:	The measured round trip time to/from the ONU is returned in this parameter. RTT is stated in time_quanta units. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

MA_CONTROL.request(DA, REGISTER, LLID, status, pending_grants)

The service primitive used by the MAC Control client at the OLT to initiate acceptance of an ONU. This primitive takes the following parameters:

DA:	Unicast MAC address or multicast MAC Control address as defined in Annex 31B.
REGISTER:	opcode for REGISTER MPCPDU as defined in Table 31A–1.
LLID:	This parameter holds the logical link identification number assigned by the MAC Control client.
status:	This parameter takes on the indication supplied by the flags field in the REGISTER MPCPDU as defined in Table 64–4.
pending_grants:	This parameters echoes back the pending_grants field that was previously received in the REGISTER_REQ message.

MA_CONTROL.indication(REGISTER, SA, LLID, status)

This service primitive is issued by the Discovery Process at the OLT or an ONU to notify the MAC Control client and Layer Management of the result of the change in registration status. This primitive takes the following parameters:

REGISTER:	opcode for REGISTER MPCPDU as defined in Table 31A–1.
SA	This parameter represents is the MAC address of the OLT.
LLID	This parameter holds the logical link identification number assigned by the MAC Control client.
status	This parameter holds the value of accepted/denied/deregistered/reregistered.

MA_CONTROL.request(DA, REGISTER_ACK, status)

This service primitive is issued by the MAC Control clients at the ONU and the OLT to acknowledge the registration. This primitive takes the following parameters:

DA:	multicast MAC Control address as defined in Annex 31B.
REGISTER_ACK:	opcode for REGISTER_ACK MPCPDU as defined in Table 31A–1.
status:	This parameter takes on the indication supplied by the flags field in the REGISTER MPCPDU as defined in Table 64–5.

MA_CONTROL.indication(REGISTER_ACK, SA, LLID, status, RTT)

This service primitive is issued by the Discovery Process at the OLT to notify the client and Layer Management that the registration process has completed. This primitive takes the following parameters:

REGISTER_ACK:	opcode for REGISTER_ACK MPCPDU as defined in Table 31A–1.
SA	This parameter represents the MAC address of the reciprocating device (ONU address at the OLT, and OLT address at the ONU).
LLID	This parameter holds the logical link identification number assigned by the MAC Control client.

status	This parameter holds the value of accepted/denied/reset/deregistered.
RTT	The measured round trip time to/from the ONU is returned in this parameter. RTT is stated in time_quanta units. This parameter holds a valid value only when the invoking Discovery Process is in the OLT

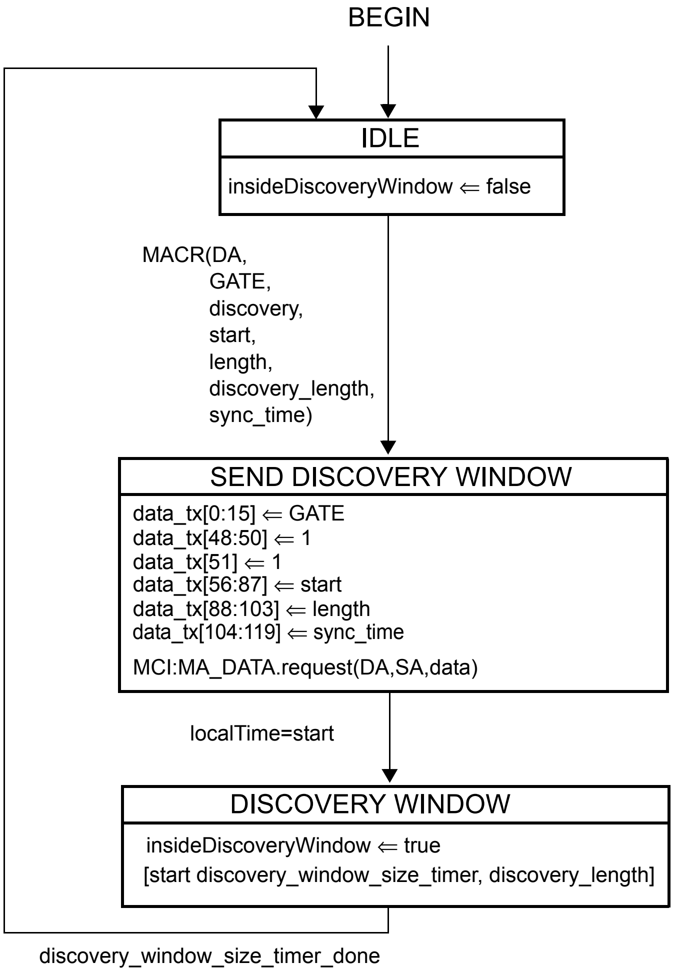
Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

64.3.3.6 State Diagram

Discovery process in the OLT shall implement the discovery window setup state diagram shown in Figure 64–18, request processing state diagram as shown in Figure 64–19, register processing state diagram as shown in Figure 64–20, and final registration state diagram as shown in Figure 64–21. The discovery process in the ONU shall implement registration state diagram as shown in Figure 64–22.

Instantiation of state diagrams as described in Figure 64–18, Figure 64–19, and Figure 64–20 is performed only at the Multipoint MAC Control instance attached to the broadcast LLID. Instantiation of state diagrams as described in Figure 64–21 and Figure 64–22 is performed for every Multipoint MAC Control instance, except the instance attached to the broadcast channel.



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 64–18—Discovery Processing OLT Window Setup state diagram

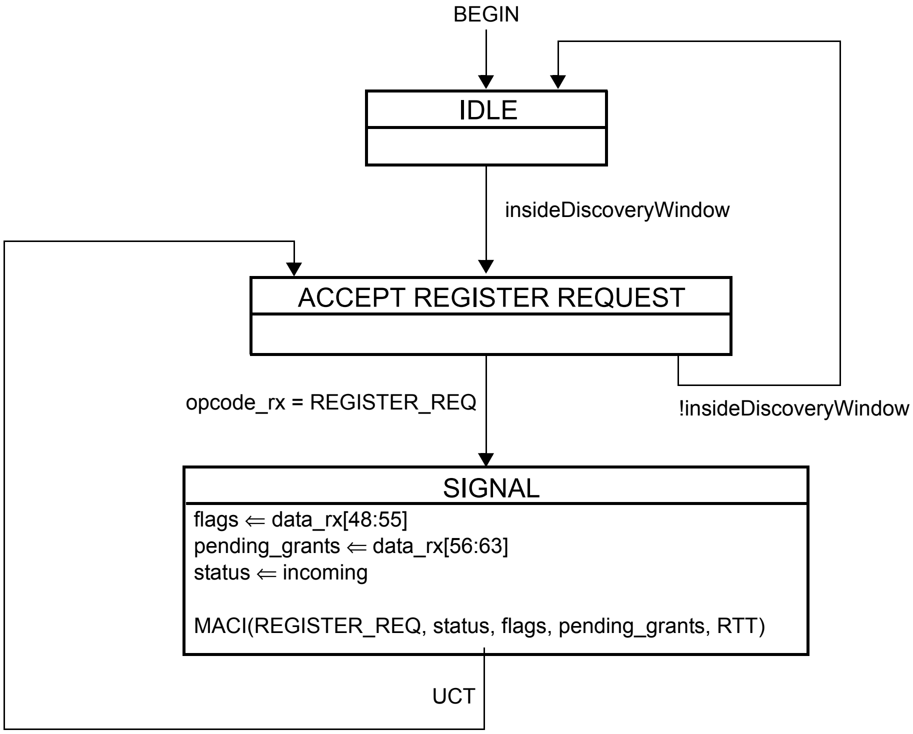


Figure 64–19—Discovery Processing OLT Process Requests State Diagram

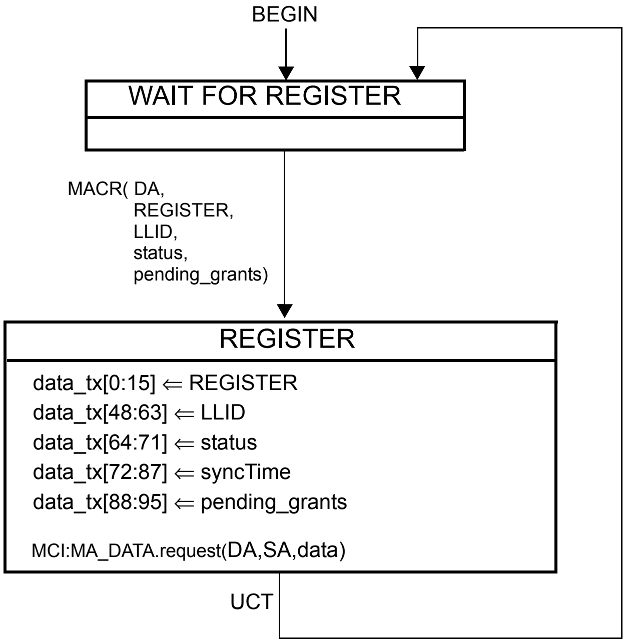
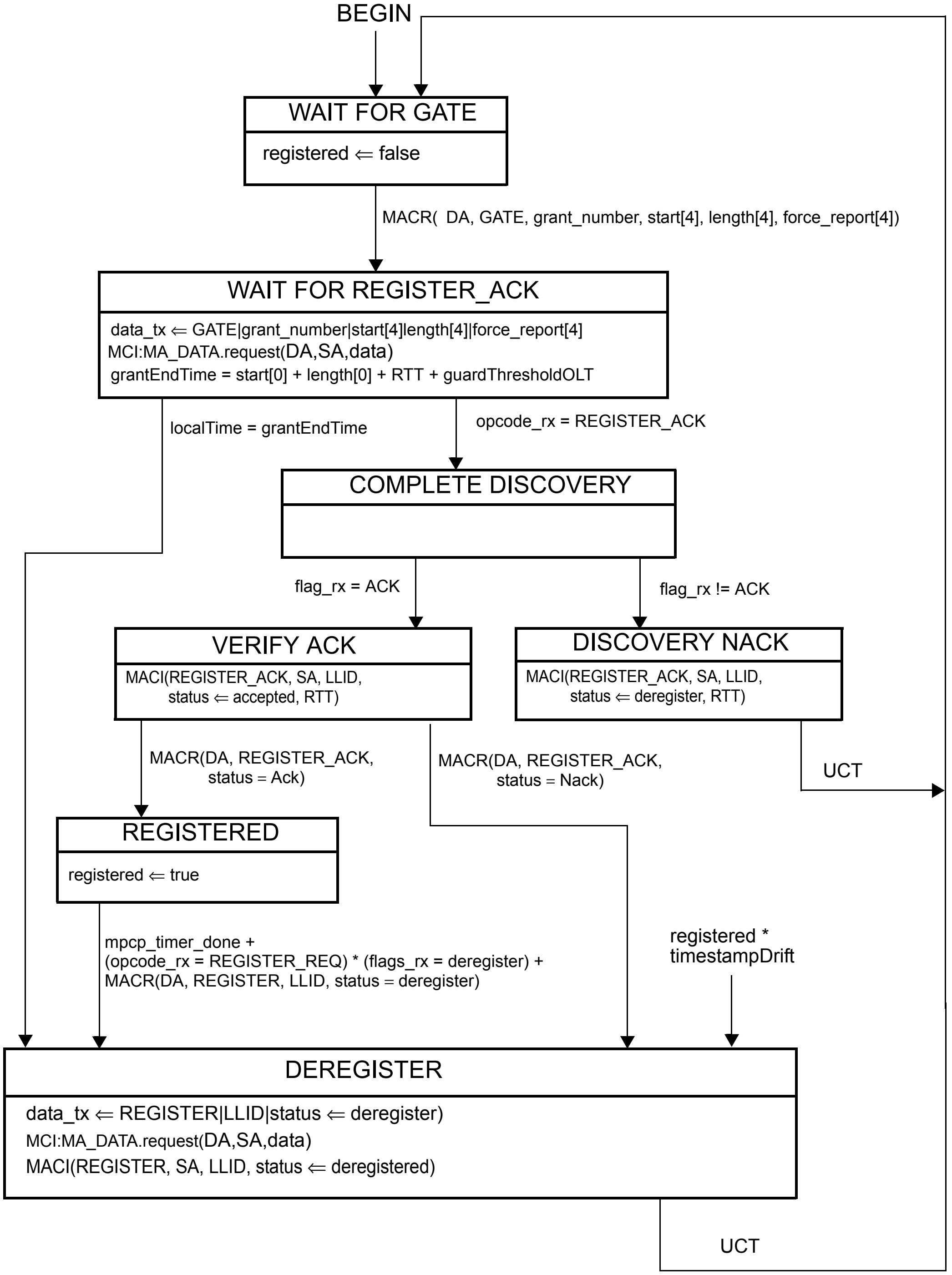


Figure 64–20—Discovery Processing OLT Register State Diagram



NOTE—The MAC Control Client issues the grant following the REGISTER message, taking the ONU processing delay of REGISTER message into consideration.

Figure 64–21—Discovery Processing OLT Final Registration State Diagram

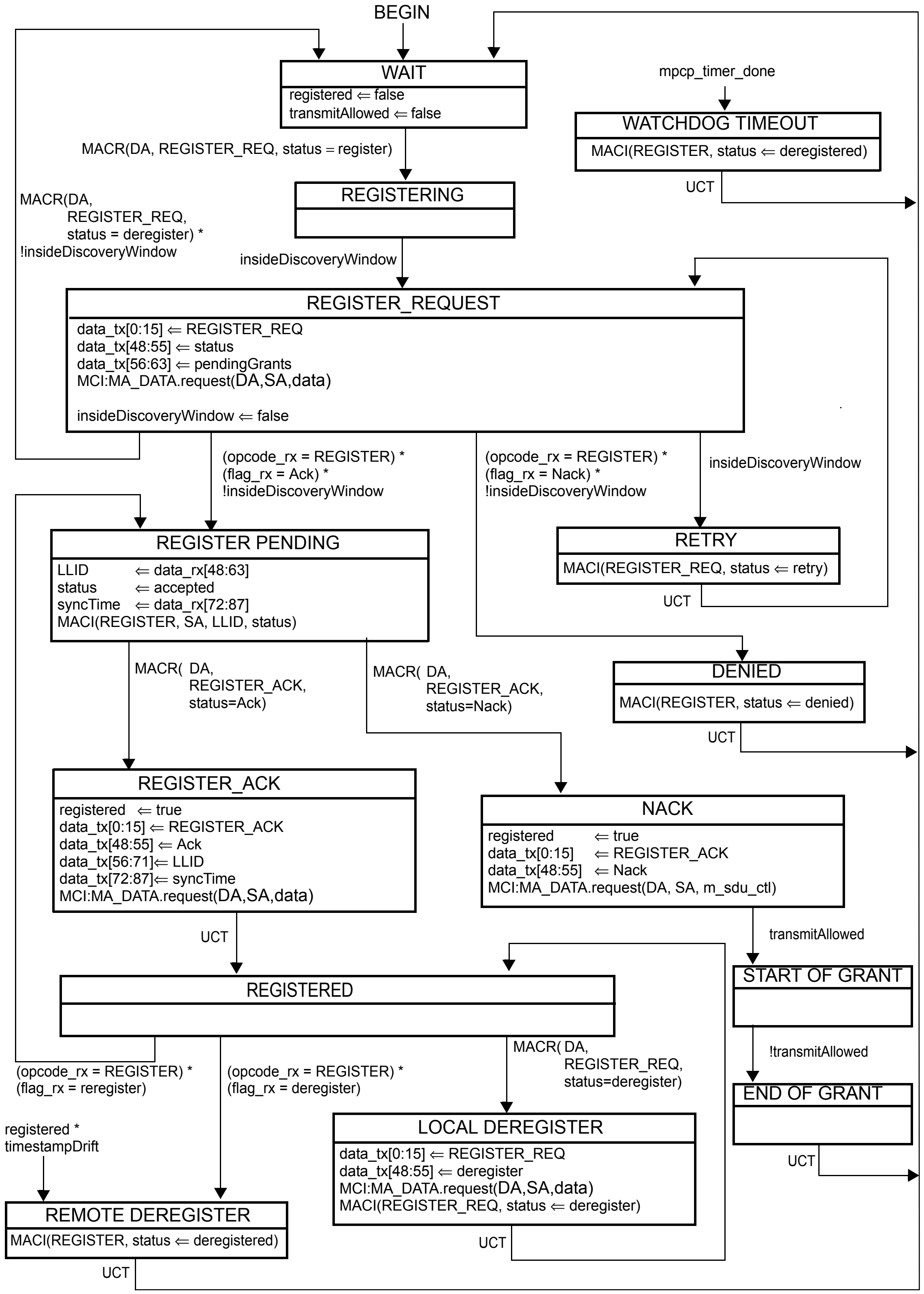


Figure 64–22—Discovery Processing ONU Registration State Diagram

64.3.4 Report Processing

The Report Processing functional block has the responsibility of dealing with queue report generation and termination in the network. Reports are generated by higher layers and passed to the MAC Control sublayer by the MAC Control clients. Status reports are used to signal bandwidth needs as well as for arming the OLT watchdog timer.

Reports shall be generated periodically, even when no request for bandwidth is being made. This keeps a watchdog timer in the OLT from expiring and deregistering the ONU. For proper operation of this mechanism the OLT shall grant the ONU periodically.

The Report Processing functional block, and its MPCP protocol elements are designed for use in conjunction with an IEEE 802.1P capable bridge.

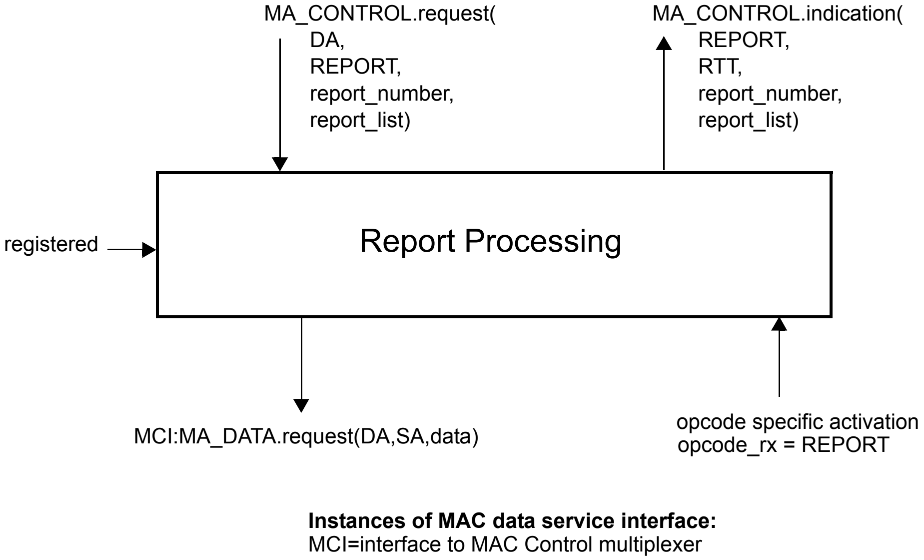


Figure 64–23—Report Processing service interfaces

64.3.4.1 Constants

None

64.3.4.2 Variables

BEGIN

This variable is used when initiating operation of the functional block state diagram. It is set to true following initialization and every reset.

TYPE: Boolean

data_rx

This variable is defined in 64.2.2.3.

data_tx

This variable is defined in 64.2.2.3.

mpcp_timeout

This variable represents the maximum allowed interval of time between two MPCPDU messages. Failure to receive at least one frame within this interval is considered a fatal fault and leads to deregistration. This variable is expressed in units of time_quanta.

TYPE	32-bit unsigned
VALUE	03-B9-AC-A0 (1 s, default value)

opcode_rx

This variable is defined in 64.2.2.3.

opcode_tx

This variable is defined in 64.2.2.3.

registered

This variable is defined in 64.3.3.2.

report_timeout

This variable represents the maximum allowed interval of time between two REPORT messages generated by the ONU, expressed in units of time_quanta.

TYPE	32-bit unsigned
VALUE	00-2F-AF-08 (50 ms, default value)

64.3.4.3 Functions

None.

64.3.4.4 Timers

report_periodic_timer

ONUs are required to generate REPORT MPCPDUs with a periodicity of less than report_timeout value. This timer counts down time remaining before a forced generation of a REPORT message in an ONU.

mpcp_timer

This timer is defined in 64.3.3.4.

64.3.4.5 Messages

MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 2.3.2.

MA_CONTROL.request(DA, REPORT, report_number, report_list)

This service primitive is used by a MAC Control client to request the Report Process at the ONU to transmit a queue status report. This primitive may be called at variable intervals, independently of the granting process, in order to reflect the time varying aspect of the network. This primitive uses the following parameters:

DA:	multicast MAC Control address as defined in Annex 31B.
REPORT:	opcode for REPORT MPCPDU as defined in Table 31A–1.
report_number:	the number of queue status report sets located in report list. The report_number value ranges from 0 to a maximum of 13.

report_list:	the list of queue status reports. A queue status report consists of two fields: valid and status. The parameter valid, is a Boolean array with length of 8, ‘0’ or false indicates that the corresponding status field is not present (the length of status field is 0), while ‘1’ or true indicates that the corresponding status field is present (the length of status field is 2 octets). The index of the array is meant to reflect the same numbered priority queue in the IEEE 802.1P nomenclature. The parameter status is an array of 16-bit unsigned integer values. This array consists only of entries whose corresponding bit in field valid is set to true.

MA_CONTROL.indication(REPORT, RTT, report_number, report_list)

The service primitive issued by the Report Process at the OLT to notify the MAC Control client and higher layers the queue status of the MPCP link partner. This primitive may be called multiple times, in order to reflect the time-varying aspect of the network. This primitive uses the following parameters:

REPORT:	opcode for REPORT MPCPDU as defined in Table 31A–1.
RTT:	this parameter holds an updated round trip time value which is recalculated following each REPORT message reception.
report_number:	the number of queue status report sets located in report list. The report_number value ranges from 0 to a maximum of 13.
report_list:	the list of queue status reports. A queue status report consists of two fields: valid and status. The parameter valid, is a Boolean array with length of 8, ‘0’ or false indicates that the corresponding status field is not present (the length of status field is 0), while ‘1’ or true indicates that the corresponding status field is present (the length of status field is 2 octets). The index of the array is meant to reflect the same numbered priority queue in the 802.1P nomenclature. The parameter status is an array of 16-bit unsigned integer values. This array consists only of entries whose corresponding bit in field valid is set to true.

Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

64.3.4.6 State Diagram

The report process in the OLT shall implement the report processing state diagram as shown in Figure 64–24. The report process in the ONU shall implement the report processing state diagram as shown in Figure 64–25. Instantiation of state diagrams as described is performed for Multipoint MAC Control instances attached to unicast LLIDs only.

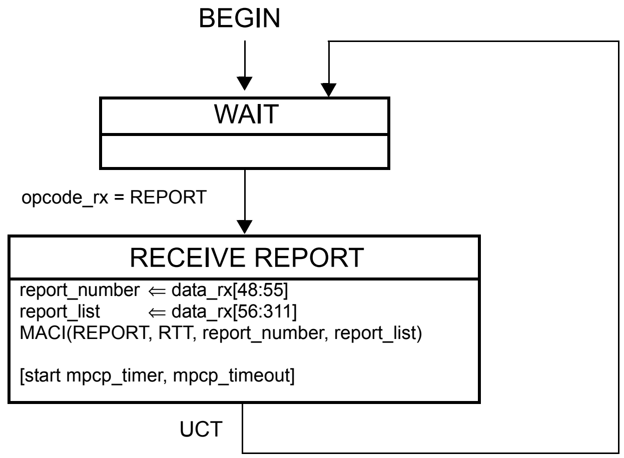
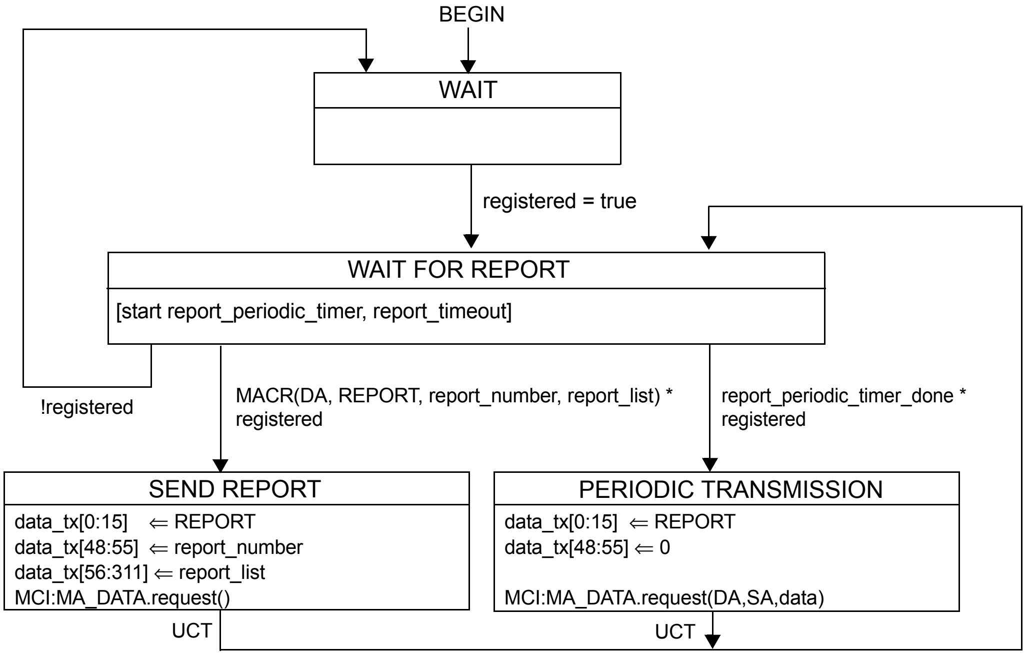


Figure 64–24—Report Processing State Diagram at OLT



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 64–25—Report Processing state diagram at ONU

64.3.5 Gate Processing

A key concept pervasive in Multipoint MAC Control is the ability to arbitrate a single transmitter out of a plurality of ONUs. The OLT controls an ONU's transmission by the assigning of grants.

The transmitting window of an ONU is indicated in GATE message where start time and length are specified. An ONU will begin transmission when its localTime counter matches start_time value indicated in the GATE message. An ONU will conclude its transmission with sufficient margin to ensure that the laser is turned off before the grant length interval has elapsed.

Multiple outstanding grants may be issued to each ONU. The OLT shall not issue more than the maximal supported maximal outstanding grants as advertised by the ONU during registration (see pending grants in 64.3.6.3).

In order to maintain the watchdog timer at the ONU, grants are periodically generated. For this purpose empty GATE messages may be issued periodically.

When registered, the ONU ignores all gate messages where the discovery flag is set.

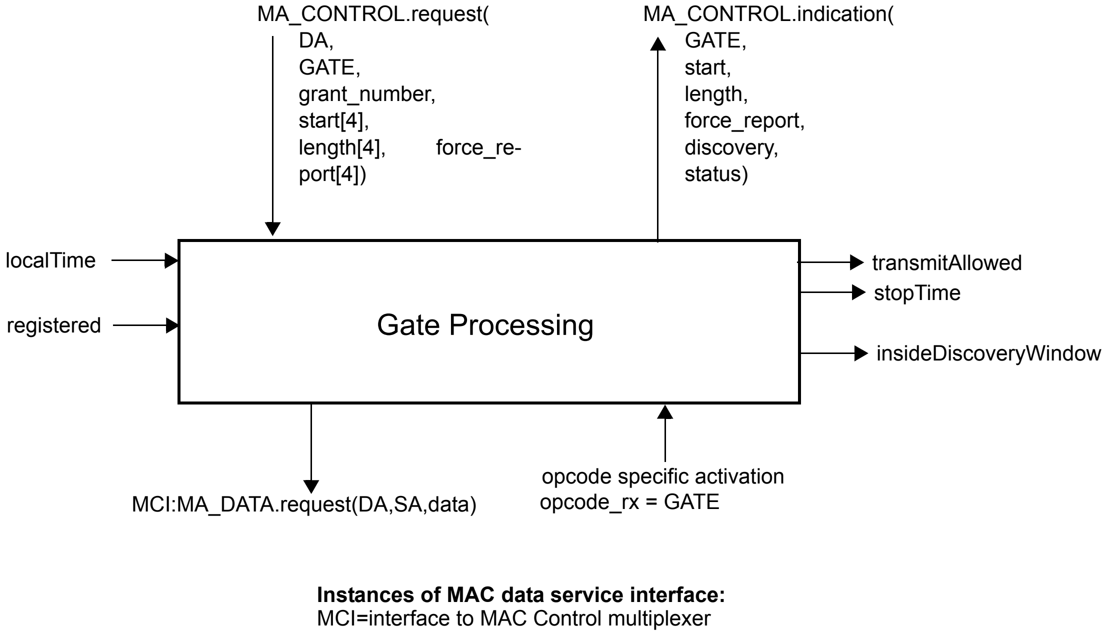


Figure 64–26—Gate Processing service interface

64.3.5.1 Constants

discoveryGrantLength

This constant represents the duration of ONU's transmission during discovery attempt. The value of discoveryGrantLength includes MPCPDU transmission time and tailGuard as defined in 64.2.2.1. discoveryGrantLength is represented in units of time_quanta.

TYPE: 32 bit unsigned
VALUE: 00-00-00-26 (608 ns)

laserOffTime

This constant holds the time required to terminate the laser. It counts in time_quanta units the time period required for turning off the PMD, as specified in 60.9.13.1.

TYPE: 32 bit unsigned
VALUE: 00-00-00-20 (512 ns)

laserOnTime

This constant holds the time required to initiate the PMD. It counts in time_quanta units the time period required for turning on the PMD, as specified in 60.9.13.1.

TYPE: 32 bit unsigned
VALUE: 00-00-00-20 (512 ns)

max_future_grant_time

This constant holds the time limiting the future time horizon for a valid incoming grant.

TYPE: 32 bit unsigned
VALUE: 03-B9-AC-A0 (1 s)

min_processing_time

This constant is the time required for the ONU processing time.

TYPE: 32 bit unsigned
VALUE: 00-00-04-00 (16.384 us)

tqSize

This constant is defined in 64.2.2.1.

64.3.5.2 Variables

BEGIN

This variable is used when initiating operation of the functional block state diagram. It is set to true following initialization and every reset.

TYPE: Boolean

counter

This variable is used as a loop iterator counting the number of incoming grants in a GATE message.

TYPE: integer

currentGrant

This variable is used for local storage of a pending grant state during processing. It is dynamically set by the Gate Processing functional block and is not exposed.

The state is a structure field composed of multiple subfields.

TYPE: structure {
    DA 48 bit unsigned, a.k.a MAC address type
    start 32 bit unsigned
    length 16 bit unsigned
    force_report Boolean
    discovery Boolean}

data_rx

This variable is defined in 64.2.2.3.

data_tx

This variable is defined in 64.2.2.3.

effectiveLength

This variable is used for temporary storage of a normalized net time value. It holds the net effective length of a grant normalized for elapsed time, and compensated for the periods required to turn the laser on and off, and waiting for receiver lock.

TYPE: 32 bit unsigned

fecEnabled

This variable is defined in 64.2.2.3.

gate_timeout

This variable represents the maximum allowed interval of time between two GATE messages generated by the OLT to the same ONU, expressed in units of time_quanta.

TYPE	32-bit unsigned
VALUE	00-2F-AF-08 (50 ms, default value)

grantList

This variable is used for storage of the list of pending grants. It is dynamically set by the Gate Processing functional block and is not exposed. Each time a grant is received it is added to the list.

The list elements are structure fields composed of multiple subfields.

The list is indexed by the start subfield in each element for quick searches.

TYPE: list of elements having the structure define in currentGrant

insideDiscoveryWindow

This variable is defined in 64.3.3.2.

maxDelay

This variable holds the maximum delay that can be applied by an ONU before sending the REGISTER MPCPDU. This delay is calculated such that the ONU would have sufficient time to transmit the REGISTER message and its associated overhead (FEC parity date, end-of-frame sequence, etc.) and terminate the laser before the end of the discovery grant.

TYPE 16 bit unsigned

nextGrant

This variable is used for local storage of a pending grant state during processing. It is dynamically set by the Gate Processing functional block and is not exposed. The content of the variable is the next grant to become active.

TYPE: element having same structure as defined in currentGrant

nextStopTime

This variable holds the value of the localTime counter corresponding to the end of the next grant.

TYPE: 32 bit unsigned

registered

This variable is defined in 64.3.3.2.

stopTime

This variable is defined in 64.2.2.3.

syncTime

This variable is defined in 64.3.3.2.

transmitAllowed

This variable is defined in 64.2.2.3.

64.3.5.3 Functions

empty(list)

This function is use to check whether the list is empty. When there are no elements queued in the list, the function returns true. Otherwise, a value of false is returned.

InsertInOrder(sorted_list, inserted_element)

This function is used to queue an element inside a sorted list. The queueing order is sorted. In the condition that the list is full the element may be discarded. The length of the list is dynamic and its maximal size equals the value advertised during registration as maximum number of pending grants.

IsBroadcast(grant)

This function is used to check whether its argument represents a broadcast grant, i.e., grant given to multiple ONUs. This is determined by the destination MAC address of the corresponding GATE message. The function returns the value true when MAC address is a global assigned MAC Control address as defined in Annex 31B, and false otherwise.

PeekHead(sorted_list)

This function is used to check the content of a sorted list. It returns the element at the head of the list without dequeuing the element.

Random(r)

This function is used to compute a random integer number uniformly distributed between 0 and r. The randomly generated number is then returned by the function.

RemoveHead(sorted_list)

This function is used to dequeue an element from the head of a sorted list. The return value of the function is the dequeued element.

64.3.5.4 Timers

gntStTmr

This timer is used to wait for the event signaling the start of a grant window.

VALUE: The timer value is dynamically set according to the signaled grant start time.

gntWinTmr

This timer is used to wait for the event signaling the end of a grant window.

VALUE: The timer value is dynamically set according to the signaled grant length.

gate_periodic_timer

The OLT is required to generate GATE MPCPDUs with a periodicity of less than gate_timeout value. This timer counts down time remaining before a forced generation of a GATE message in the OLT.

mpcp_timer

This timer is defined in 64.3.3.4.

rndDlyTmr

This timer is used to measure a random delay inside the discovery window. The purpose of the delay is to apriori reduce the probability of transmission overlap during the registration process, and thus lowering the expectancy of registration time in the PON.

VALUE: A random value less than the net discovery window size less the REGISTER_REQ MPCPDU frame size less the idle period and laser turn on and off delays less the preamble size less the IFG size. The timer value is set dynamically based on the parameters passed from the client.

64.3.5.5 Messages

MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 2.3.2.

MA_CONTROL.request(DA, GATE, grant_number, start[4], length[4], force_report[4])

This service primitive is defined in 64.3.3.5.

MA_CONTROL.indication(GATE, start, length, force_report, discovery, status)

This service primitive issued by the Gate Process at the ONU to notify the MAC Control client and higher layers that a grant is pending. This primitive is invoked multiple times when a single GATE message arrives with multiple grants. It is also generated at the start and end of each grant as it becomes active. This primitive uses the following parameters:

GATE:	opcode for GATE MPCPDU as defined in Table 31A–1.

start:	start time of the grant. This parameter is not present when the status value is deactive.
length:	length of the grant. This parameter is not present when the status value is deactive.
force_report:	flags indicating whether a REPORT message should be transmitted in this grant. This parameter is not present when the status value is deactive.
discovery:	This parameter holds the value true when the grant is to be used for the discovery process, and false otherwise. This parameter is not present when the status value is deactive.
status:	This parameter takes the value *arrive* on grant reception, *active* when a grant becomes active, and *deactive* at the end of a grant.

Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

64.3.5.6 State Diagrams

The gating process in the OLT shall implement the gate processing state diagram as shown in Figure 64–26. The gating process in the ONU shall implement the gate processing state diagram as shown in Figure 64–27. Instantiation of state diagrams as described is performed for all Multipoint MAC Control instances.

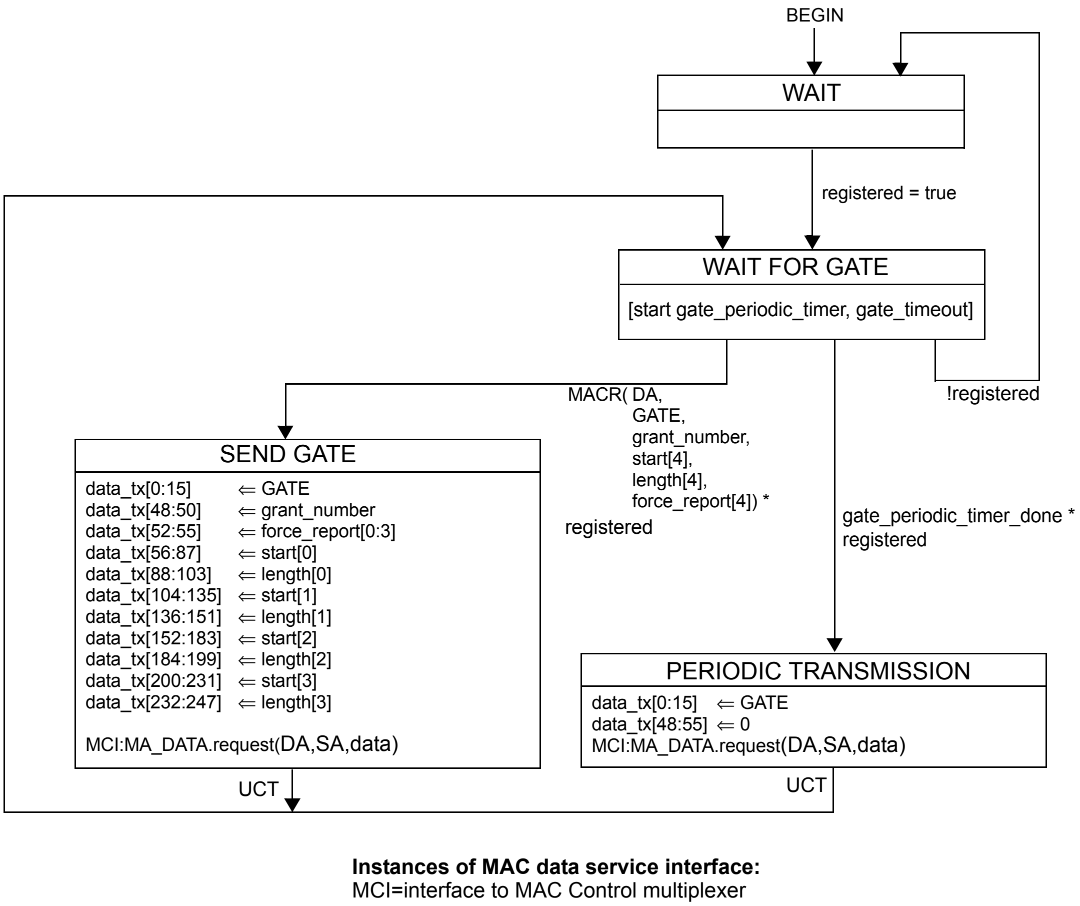


Figure 64–27—Gate Processing state diagram at OLT

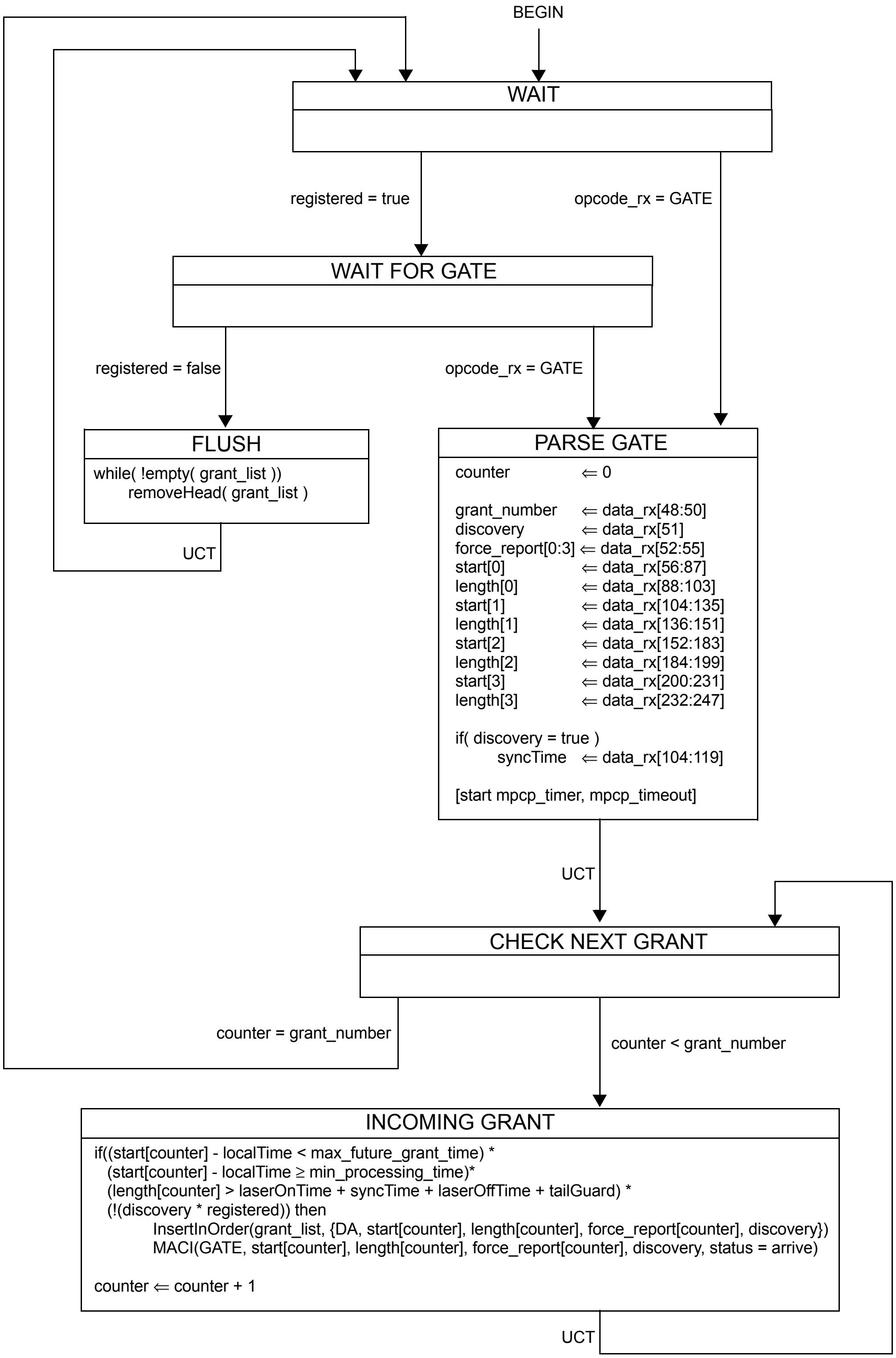


Figure 64–28—Gate Processing ONU Programing State Diagram

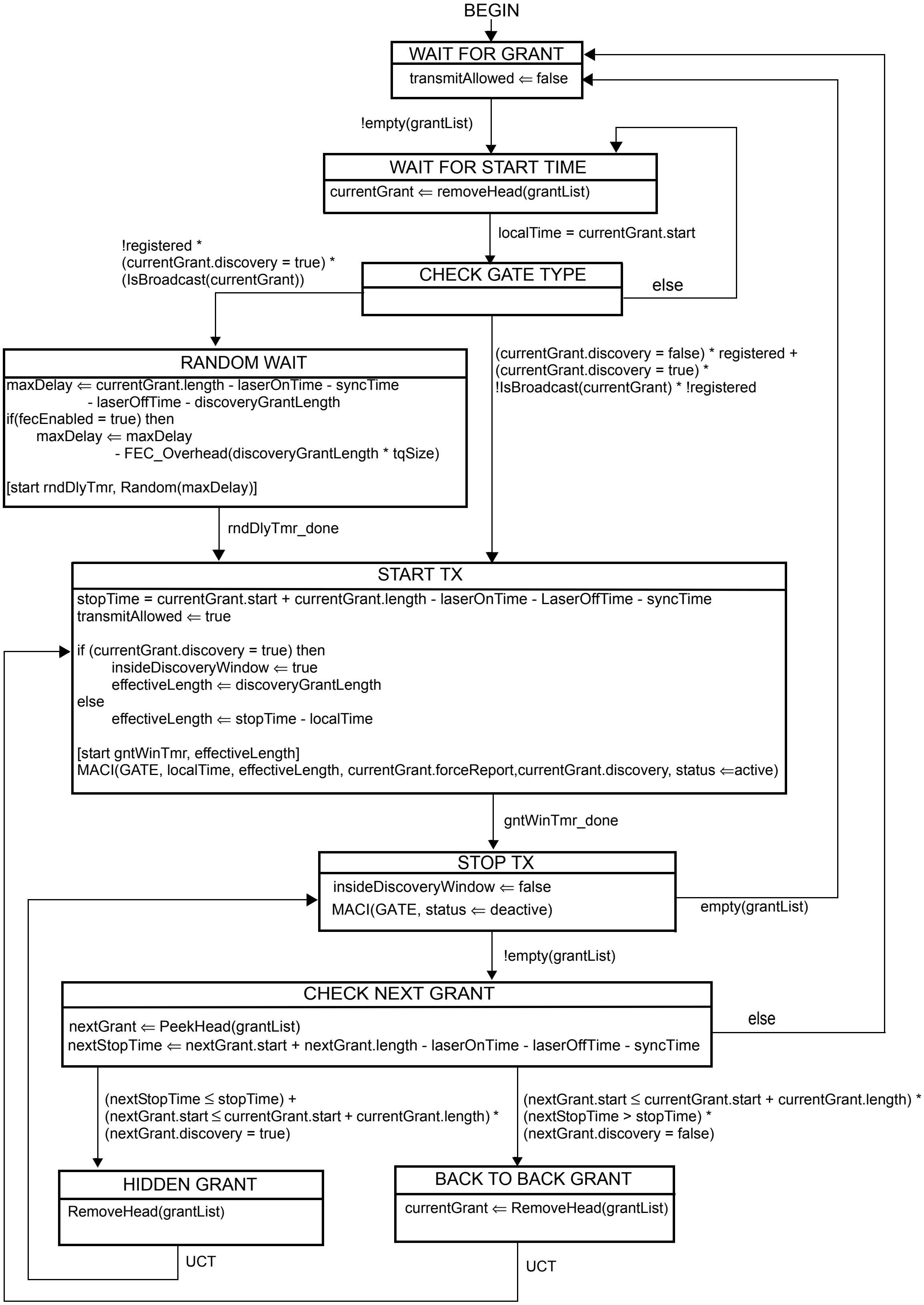


Figure 64–29—Gate Processing ONU Activation State Diagram

64.3.6 MPCPDU structure and encoding

The MPCPDU structure shall be as shown in Figure 64–30, and is further defined in the following definitions:

a) Destination Address (DA). The DA in MPCPDU is the MAC Control Multicast address as specified in the annexes to Clause 31, or the individual MAC address associated with the port to which the MPCPDU is destined.
b) Source Address (SA). The SA in MPCPDU is the individual MAC address associated with the port through which the MPCPDU is transmitted. For MPCPDUs originating at the OLT end, this can be the address any of the individual MACs. These MACs may all share a single unicast address, as explained in 64.1.2.
c) Length/Type. The Length/Type in MPCPDU carries the MAC_Control_Type field value as specified in 31.4.1.3.
d) Opcode. The opcode identifies the specific MPCPDU being encapsulated. Values are defined in Table 31A–1.
e) Timestamp. The timestamp field conveys the content of the localTime register at the time of transmission of the MPCPDUs. This field is 32 bits long, and counts 16 bit transmissions. The timestamp counts time in 16 bit time granularity.
f) Data/Reserved/PAD. These 40 octets are used for the payload of the MPCPDUs. When not used they would be filled with zeros on transmission, and be ignored on reception.
g) FCS. This field is the Frame Check Sequence, typically generated by the underlying MAC.

Based on the MAC instance used to generate the specific MPCPDU, the appropriate LLID shall be generated by the RS.

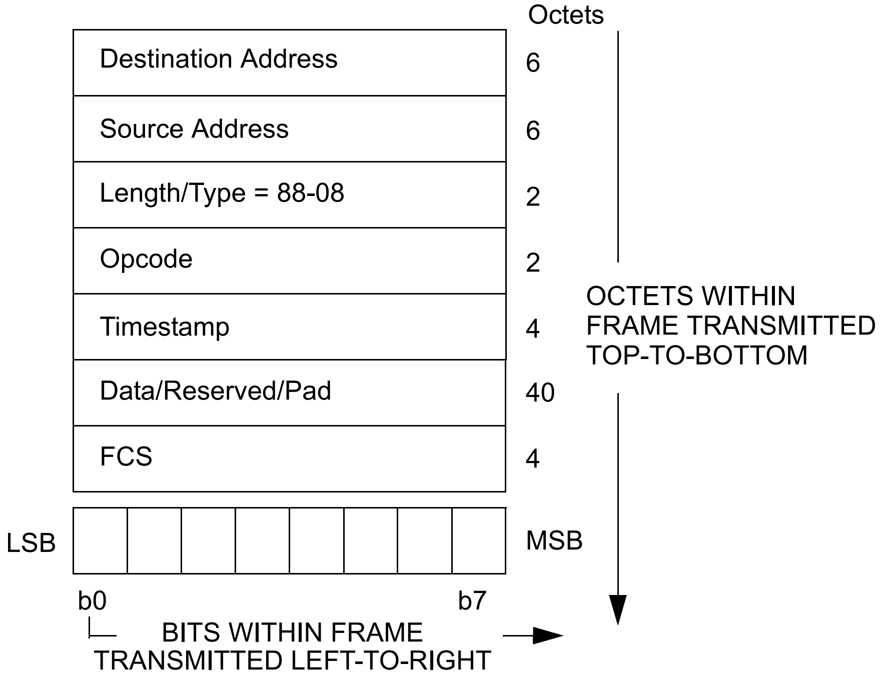


Figure 64–30—Generic MPCPDU

64.3.6.1 GATE description

The purpose of GATE message is to grant transmission windows to ONUs for both discovery messages and normal transmission. Up to four grants can be included in a single GATE message. The number of grants can also be set to zero for using the GATE message as an MPCP keep alive from OLT to the ONU.

The GATE MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the GATE MPCPDU is 0x0002.
b) Flags. This is an 8 bit flag register that holds the following flags: The Number of grants field contains the number of grants, composed of valid Length, Start Time pairs in this MPCPDU. This is a number between 0 and 4. Note: when Number of grants is set to 0, sole purpose of message is conveying of timestamp to ONU.
   The Discovery flag field indicates that the signaled grants would be used for the discovery process, in which case a single grant shall be issued in the gate message.
   The Force Report flag fields ask the ONU to issue a REPORT message related to the corresponding grant number at the corresponding transmission opportunity indicated in this GATE.
c) Grant #n Length. Length of the signaled grant, this is an 16 bit unsigned field. The length is counted in 16 bit time increments. There are 4 Grants that are possibly packed into the GATE MPCPDU. The laserOnTime, syncTime, and laserOffTime are included in and thus consume part of Grant #n Length.
d) Grant #n Start Time. Start time of the grant, this is an 32 bit unsigned field. The start time is compared to the local clock, to correlate the start of the grant. Transmitted values shall satisfy the condition Grant #n Start Time < Grant #n + 1 Start Time for consecutive grants within the same GATE MPCPDU.
e) Sync Time. This is an unsigned 16 bit value signifying the required synchronization time of the OLT receiver. During the synchronization time the ONU shall send IDLE code-pairs. The value is counted in 16 bit time increments. The advertised value includes synchronization requirement on all receiver elements including PMD, PMA and PCS. This field is present only when the gate is a discovery gate, as signaled by the Discovery flag and is not present otherwise.

Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception when constructing a complying MPCP protocol implementation. The size of this field depends on the used Grant #n Length/Start Time entry-pairs, and varies in length from 13–39 accordingly. The GATE MPCPDU shall be generated by a MAC Control instance mapped to an active ONU, and as such shall be marked with a unicast type of LLID, except when the discovery flag is set where the MAC Control instance is mapped to all ONUs and such frame is marked by the broadcast LLID.

Table 64–1—GATE MPCPDU Number of grants/Flags Fields

Bit	Flag Field	Values
0-2	Number of grants	0–4
3	Discovery	0—Normal GATE 1—Discovery GATE
4	Force Report Grant 1	0—No action required 1—A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 1
5	Force Report Grant 2	0—No action required 1—A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 2
6	Force Report Grant3	0—No action required 1—A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 3
7	Force Report Grant 4	0—No action required 1—A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 4

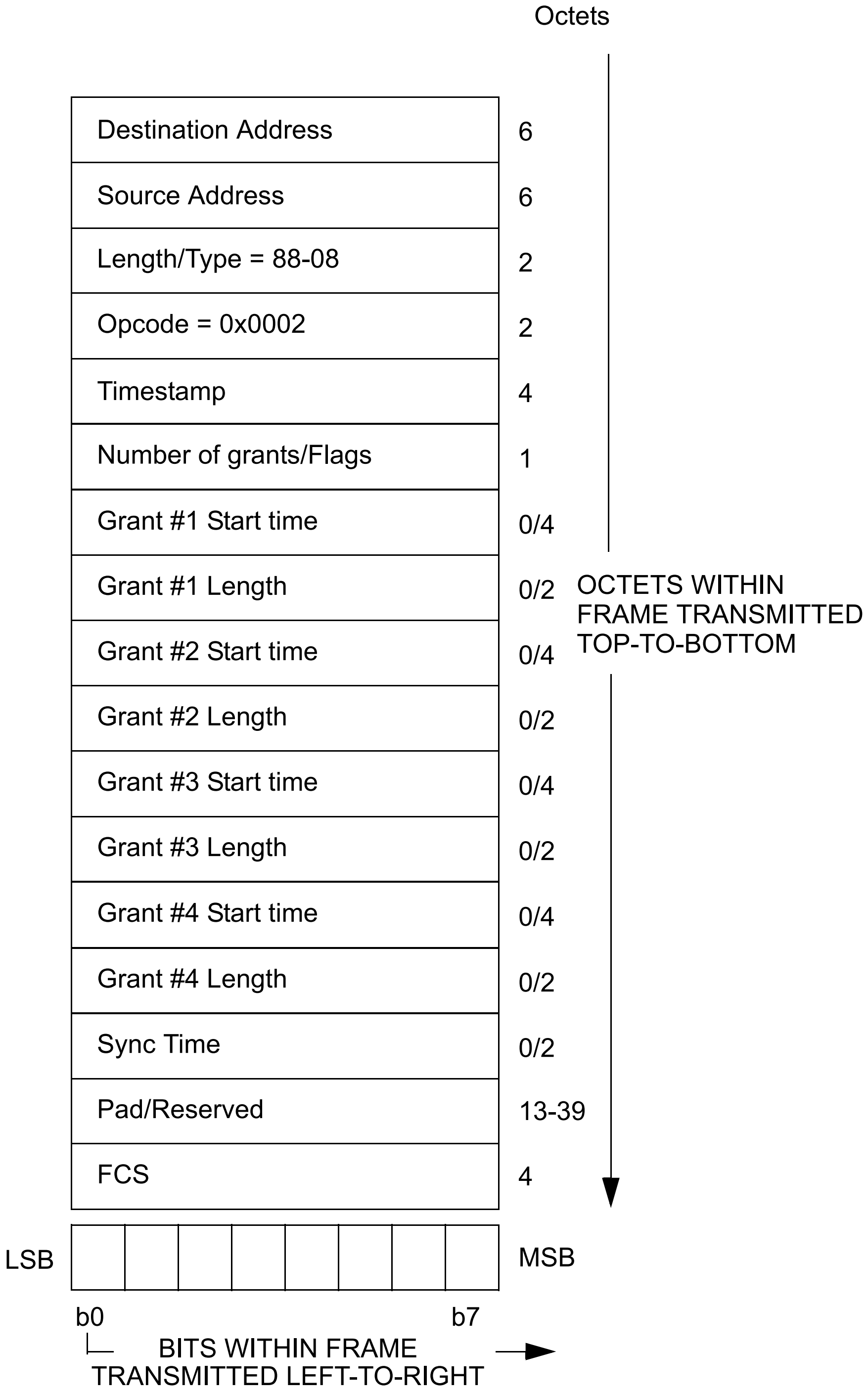


Figure 64–31—GATE MPCPDU

64.3.6.2 REPORT description

REPORT messages have several functionalities. Time stamp in each REPORT message is used for round trip (RTT) calculation. In the REPORT messages ONUs indicate the upstream bandwidth needs they request per IEEE 802.1Q priority queue. REPORT messages are also used as keep-alives from ONU to OLT. ONUs issue REPORT messages periodically in order to maintain link health at the OLT as defined in 64.3.4. In addition, the OLT may specifically request a REPORT message.

The REPORT MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

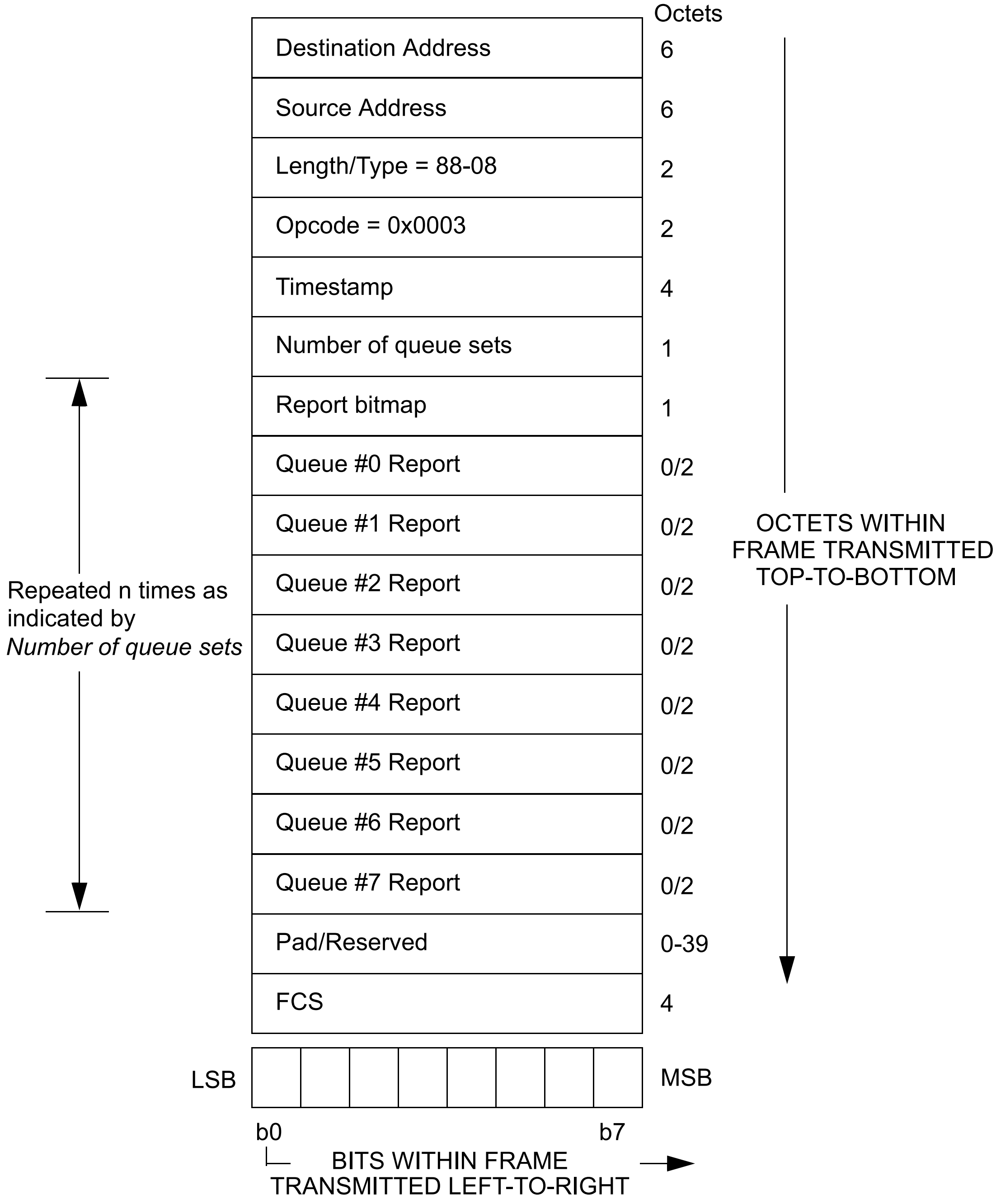
a) Opcode. The opcode for the REPORT MPCPDU is 0x0003.
b) Number of Queue Sets. This field specifies the number of requests in the REPORT message. A REPORT frame may hold multiple sets of Report bitmap and Queue #n as specified in the Number of Queue Sets field
c) Report bitmap. This is an 8 bit flag register that indicates which queues are represented in this REPORT MPCPDU.

Table 64–2—REPORT MPCPDU Report bitmap fields

Bit	Flag Field	Values
0	Queue 0	0—queue 0 report is not present 1—queue 0 report is present
1	Queue 1	0—queue 1 report is not present 1—queue 1 report is present
2	Queue 2	0—queue 2 report is not present 1—queue 2 report is present
3	Queue 3	0—queue 3 report is not present 1—queue 3 report is present
4	Queue 4	0—queue 4 report is not present 1—queue 4 report is present
5	Queue 5	0—queue 5 report is not present 1—queue 5 report is present
6	Queue 6	0—queue 6 report is not present 1—queue 6 report is present
7	Queue 7	0—queue 7 report is not present 1—queue 7 report is present

d) Queue #n Report. This value represents the length of queue# n at time of REPORT message generation. The reported length shall be adjusted to account for the necessary inter-frame spacing and FEC parity data overhead, if FEC is enabled. The Queue #n Report field is an unsigned 16 bit integer representing transmission request in units of time quanta. This field is present only when the corresponding flag in the Report bitmap is set.
e) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception when constructing a complying MPCP protocol implementation. The size of this field depends on the used Queue Report entries, and accordingly varies in length from 0 to 39.

The REPORT MPCPDU shall be generated by a MAC Control instance mapped to an active ONU, and as such shall be marked with a unicast type of LLID.



	Octets
Destination Address	6
Source Address	6
Length/Type = 88-08	2
Opcode = 0x0003	2
Timestamp	4
Number of queue sets	1
Report bitmap	1
Queue #0 Report	0/2
Queue #1 Report	0/2
Queue #2 Report	0/2
Queue #3 Report	0/2
Queue #4 Report	0/2
Queue #5 Report	0/2
Queue #6 Report	0/2
Queue #7 Report	0/2
Pad/Reserved	0-39
FCS	4

Figure 64–32—REPORT MPCPDU

64.3.6.3 REGISTER_REQ description

The REGISTER_REQ MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the REGISTER_REQ MPCPDU is 0x0004.
b) Flags. This is an 8 bit flag register that indicates special requirements for the registration.

.

Table 64–3—REGISTER_REQ MPCPDU Flags fields

Value	Indication	Comment
0	Reserved	Ignored on reception.
1	Register	Registration attempt for ONU.
2	reserved	Ignored on reception.
3	Deregister	This is a request to deregister the ONU. Subsequently, the MAC is deallocated and the LLID may be reused.
4–255	Reserved	Ignored on reception.

c) Pending grants. This is an unsigned 8 bit value signifying the maximum number of future grants the ONU is configured to buffer. The OLT should not grant the ONU more than this maximum number of Pending grants vectors comprised of {start, length, force_report, discovery} into the future.

d) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception when constructing a complying MPCP protocol implementation.

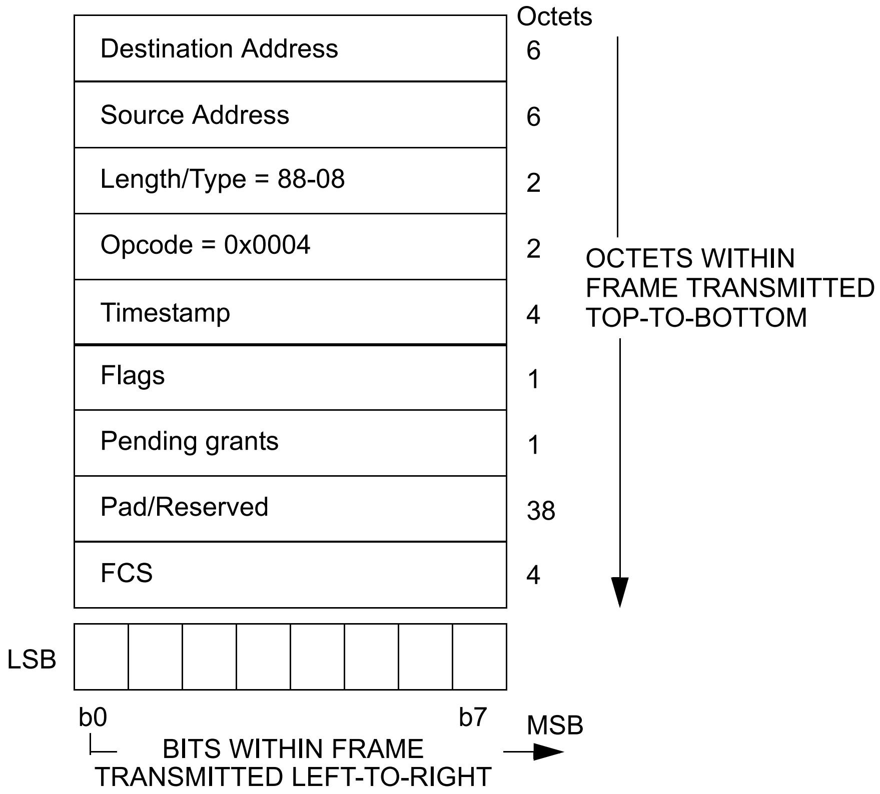


Figure 64–33—REGISTER_REQ MPCPDU

The REGISTER_REQ MPCPDU shall be generated by a MAC Control instance mapped to an undiscovered ONU, and as such shall be marked with a broadcast type of LLID.

64.3.6.4 REGISTER description

The REGISTER MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) DA. The destination address used shall be an individual MAC address.
b) Opcode. The opcode for the REGISTER MPCPDU is 0x0005.
c) Assigned Port. This field holds a 16 bit unsigned value reflecting the LLID of the port assigned following registration.
d) Flags. this is an 8 bit flag register that indicates special requirements for the registration.

Table 64–4—REGISTER MPCPDU Flags field

Value	Indication	Comment
0	Reserved	Ignored on reception.
1	Reregister	The ONU is explicitly asked to re-register.
2	Deregister	This is a request to deallocate the port and free the LLID. Subsequently, the MAC is deallocated.
3	Ack	The requested registration is successful.
4	Nack	The requested registration attempt is denied by the higher-layer-entity.
5–255	Reserved	Ignored on reception.

e) Sync Time. This is an unsigned 16 bit value signifying the required synchronization time of the OLT receiver. During the synchronization time the ONU transmits only IDLE code-pairs. The value is counted in 16 bit time increments. The advertised value includes synchronization requirement on all receiver elements including PMD, PMA and PCS.
f) Echoed pending grants. This is an unsigned 8 bit value signifying the number of future grants the ONU may buffer before activating. The OLT should not grant the ONU more than this number of grants into the future.
g) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception when constructing a complying MPCP protocol implementation.

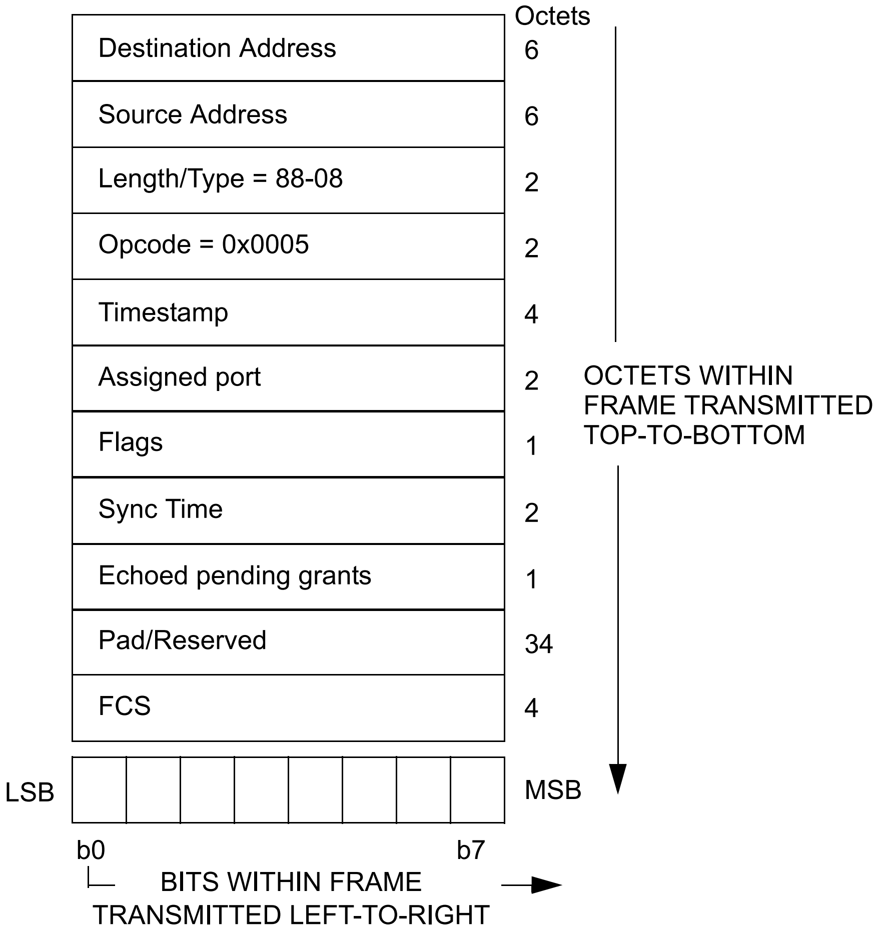


Figure 64–34—REGISTER MPCPDU

The REGISTER MPCPDU shall be generated by a MAC Control instance mapped to all ONUs and such frame is marked by the broadcast LLID.

64.3.6.5 REGISTER_ACK description

The REGISTER_ACK MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the REGISTER_ACK MPCPDU is 0x0006.
b) Flags. This is an 8-bit flag register that indicates special requirements for the registration.Echoed assigned port. This field holds a 16 bit unsigned value reflecting the LLID of the port assigned following registration.
c) Echoed Sync Time. This is an unsigned 16 bit value echoing the required synchronization time of the OLT receiver as previously advertised (see 64.3.6.4).
d) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored at reception when constructing a complying MPCP protocol implementation.

.

Table 64–5—REGISTER_ACK MPCPDU Flags fields

Value	Indication	Comment
0	Nack	The requested registration attempt is denied by the higher-layer-entity.
1	Ack	The registration process is successfully acknowledged.
2–255	Reserved	Ignored on reception.

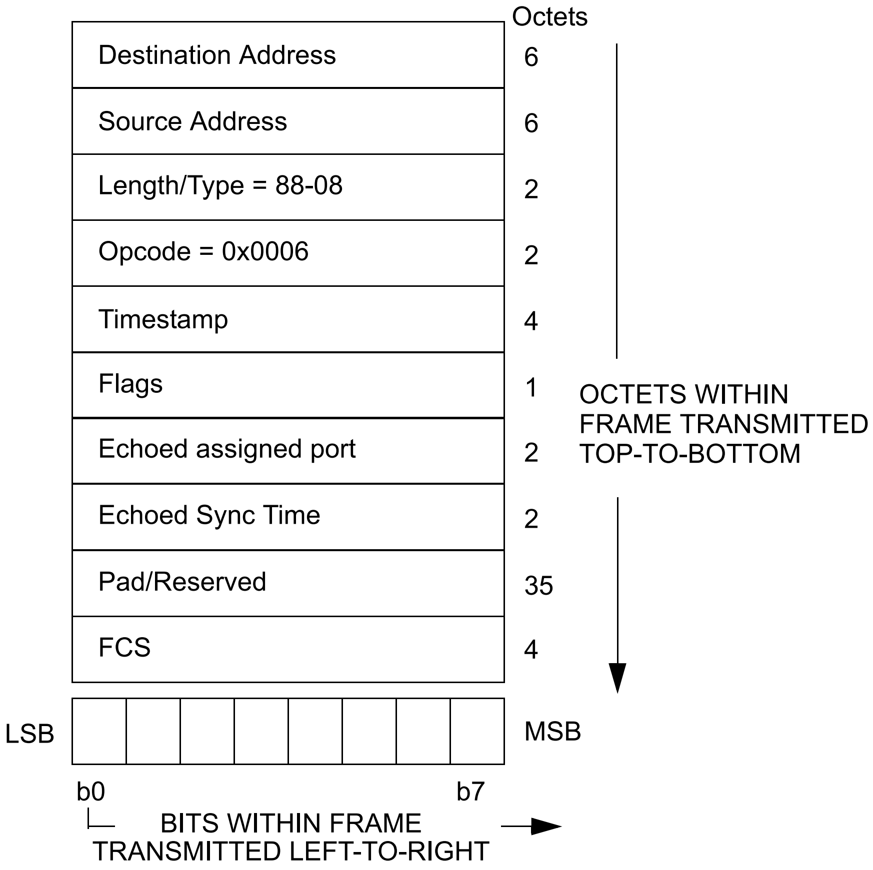


Figure 64–35—REGISTER_ACK MPCPDU

The REGISTER_ACK MPCPDU shall be generated by a MAC Control instance mapped to an active ONU, and as such shall be marked with a unicast type of LLID.

64.4 Protocol implementation conformance statement (PICS) proforma for Clause 64, Multipoint MAC Control[20]

64.4.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 64 Multipoint MAC Control, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

64.4.2 Identification

64.4.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

64.4.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 64, Multipoint MAC Control
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[20] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

64.4.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*OLT	OLT functionality	64.1	Device supports functionality required for OLT	O/1	Yes [ ] No [ ]
*ONU	ONU functionality	64.1	Device supports functionality required for ONU	O/1	Yes [ ] No [ ]

64.4.4 PICS proforma tables for Multipoint MAC Control

64.4.4.1 Compatibility Considerations

Item	Feature	Subclause	Value/Comment	Status	Support
CC1	Delay through MAC and PHY	64.3.2.4	Maximum delay variation of 16 ns (1 time_quantum)	M	Yes [ ]
CC2	OLT grant time delays	64.3.2.4	Not grant nearer than 1024 time_quanta into the future	OLT:M	Yes [ ]
CC3	ONU processing delays	64.3.2.4	Must process all messages in less than 1024 time_quanta	ONU:M	Yes [ ]
CC4	OLT grant issuance	64.3.2.4	Not grant more than one message every 1024 time_quanta	OLT:M	Yes [ ]

64.4.4.2 Multipoint MAC Control

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	OLT localTime	64.2.2.2	Track transmit clock	OLT:M	Yes [ ]
OM2	ONU localTime	64.2.2.2	Track receive clock	ONU:M	Yes [ ]
OM3	Random wait for transmitting REGISTER_REQ messages	64.3.3	Shorter than length of discovery time window	ONU:M	Yes [ ]
OM4	Periodic report generation	64.3.4	Reports are generated periodically	ONU:M	Yes [ ]
OM5	Periodic granting	64.3.4	Grants are issued periodically	OLT:M	Yes [ ]
OM6	Issuing of grants	64.3.5	Not issue more than maximal supported grants	OLT:M	Yes [ ]

64.4.4.3 State diagrams

Item	Feature	Subclause	Value/Comment	Status	Support
SM1	Multipoint Transmission Control	64.2.2.7	Meets the requirements of Figure 64–9	M	Yes [ ]
SM2	OLT Control Parser	64.2.2.7	Meets the requirements of Figure 64–10	M	Yes [ ]
SM3	ONU Control Parser	64.2.2.7	Meets the requirements of Figure 64–11	M	Yes [ ]
SM4	OLT Control Multiplexer	64.2.2.7	Meets the requirements of Figure 64–12	OLT:M	Yes [ ]
SM5	ONU Control Multiplexer	64.2.2.7	Meets the requirements of Figure 64–13	OLT:M	Yes [ ]
SM6	Discovery Processing OLT Window Setup	64.3.3.6	Meets the requirements of Figure 64–18	OLT:M	Yes [ ]
SM7	Discovery Processing OLT Process Requests	64.3.3.6	Meets the requirements of Figure 64–19	OLT:M	Yes [ ]
SM8	Discovery Processing OLT Register	64.3.3.6	Meets the requirements of Figure 64–20	ONU:M	Yes [ ]
SM9	Discovery Processing OLT Final Registration	64.3.3.6	Meets the requirements of Figure 64–21	OLT:M	Yes [ ]
SM10	Discovery Processing ONU Registration	64.3.3.6	Meets the requirements of Figure 64–22	ONU:M	Yes [ ]
SM11	Report Processing at OLT	64.3.4.6	Meets the requirements of Figure 64–24	OLT:M	Yes [ ]
SM12	Report Processing at ONU	64.3.4.6	Meets the requirements of Figure 64–25	ONU:M	Yes [ ]
SM13	Gate Processing at OLT	64.3.5.6	Meets the requirements of Figure 64–27	OLT:M	Yes [ ]
SM14	Gate Processing at ONU	64.3.5.6	Meets the requirements of Figure 64–28	ONU:M	Yes [ ]
SM15	Gate Processing ONU Activation	64.3.5.6	Meets the requirements of Figure 64–29	ONU:M	Yes [ ]

64.4.4.4 MPCP

Item	Feature	Subclause	Value/Comment	Status	Support
MP1	MPCPDU structure	64.3.6	As in Figure 64–30	M	Yes [ ]
MP2	LLID for MPCPDU	64.3.6	RS generates LLID for MPCPDU	M	Yes [ ]
MP3	Grants during discovery	64.3.6.1	Single grant in GATE message during discovery	OLT:M	Yes [ ]
MP4	Grant start time	64.3.6.1	Grants within one GATE MPCPDU are sorted by their Start time values	OLT:M	Yes [ ]
MP5	TX during synchronization	64.3.6.1	Transmit IDLE code groups	ONU:M	Yes [ ]
MP6	GATE generation	64.3.6.1	GATE generated for active ONU except during discovery	OLT:M	Yes [ ]
MP7	GATE LLID	64.3.6.1	Unicast LLID except for discovery	OLT:M	Yes [ ]
MP8	REPORT issuing	64.3.6.2	Issues REPORT periodically	ONU:M	Yes [ ]
MP9	REPORT generation	64.3.6.2	Generated by active ONU	ONU:M	Yes [ ]
MP10	REPORT LLID	64.3.6.2	REPORT has unicast LLID	ONU:M	Yes [ ]
MP11	REGISTER_REQ generation	64.3.6.3	Generated by undiscovered ONU	ONU:M	Yes [ ]
MP12	REGISTER_REQ LLID	64.3.6.3	Use broadcast LLID	ONU:M	Yes [ ]
MP13	REGISTER DA address	64.3.6.4	Use individual MAC address	OLT:M	Yes [ ]
MP14	REGISTER generation	64.3.6.4	Generated for all ONUs	OLT:M	Yes [ ]
MP15	REGISTER_ACK generation	64.3.6.5	Generated by active ONU	ONU:M	Yes [ ]
MP16	REGISTER_ACK LLID	64.3.6.5	Use unicast LLID	ONU:M	Yes [ ]

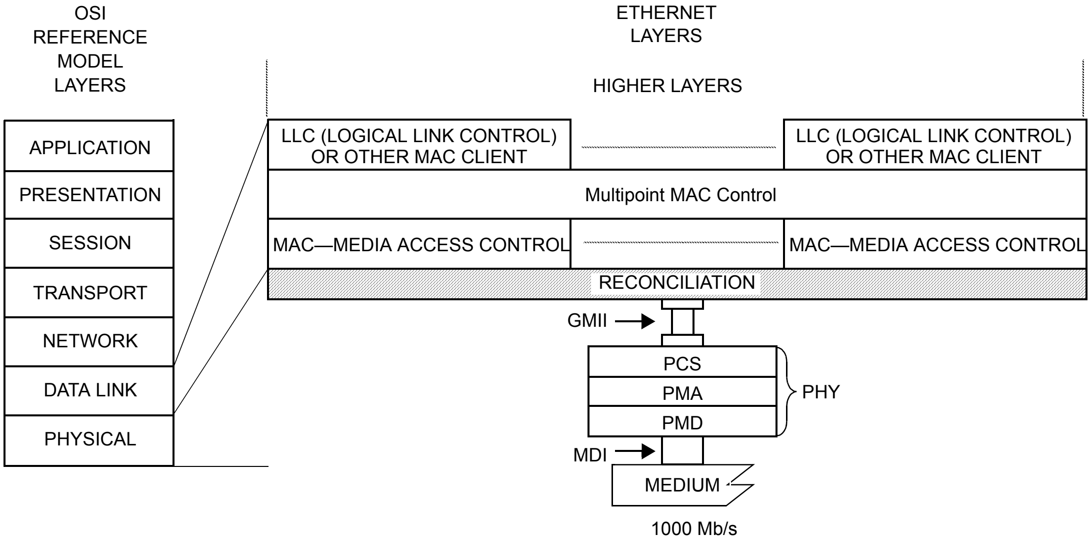
65. Extensions of the Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS) / Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction

This clause describes functions for use in a 1000BASE-PX point-to-multipoint (P2MP) networks. This is an optical multipoint network that connects multiple DTEs using a single shared fiber. The architecture is asymmetrical, based on a tree and branch topology utilizing passive optical splitters. This type of network requires that the Multipoint MAC Control sublayer exists above the MACs, as described in Clause 64.

65.1 Extensions of the Reconciliation Sublayer (RS) for point-to-point emulation

65.1.1 Overview

This subclause extends Clause 35 to enable multiple data link layers to interface with a single Physical Layer. The number of MACs supported is limited only by the implementation. It is acceptable for only one MAC to be connected to this Reconciliation Sublayer. Figure 65–1 shows the relationship of this RS to the ISO/IEC OSI reference model. The mapping of GMII signals to PLS service primitives is described in 35.2.1.



GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
PHY = PHYSICAL LAYER DEVICE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 65–1—RS location in the OSI protocol stack

65.1.2 Principle of operation

A successful registration process, described in 64.3.3, results in the assignment of values to the MODE and LLID variables associated with a MAC. This may be one of many MACs in an Optical Line Terminal (OLT) or a single MAC in an Optical Network Unit (ONU). The MODE and LLID variables are used to identify a packet transmitted from that MAC and how received packets are directed to that MAC. The PCS of OLT shall operate in unidirectional mode as defined in 66.2.2.

As described in 64.1.2, multiple MACs within an OLT are bound to a single GMII, while at the ONU a single MAC is bound to the GMII. The multipoint control protocol (MPCP) ensures that only one MAC is transmitting at any one time. Correspondingly, only one PLS_DATA.request primitive is active at any time. The active PLS_DATA.request is mapped to the GMII signals, TXD<7:0>, TX_EN, TX_ER, and

GTX_CLK. The RS replaces octets of preamble with the values of the transmitting MAC's MODE and LLID variables.

In the receive direction, these MODE and LLID values, embedded within the preamble, identify the MAC to which this frame should be directed. The RS establishes a temporal mapping of the GMII signals, RXD<7:0>, RX_ER, RX_CLK, and RX_DV, to the correct PLS_DATA.indication and PLS_DATA_VALID.indication primitives.

65.1.3 Functional specifications

The variables below provide a mapping between MODE and LLID variables and multiple MACs. While the usage of this mapping is less interesting in the ONU, it is critical in the OLT. This mapping is used to replace transmitted preambles with MODE and LLID fields as well as to steer received packets to the appropriate MAC.

65.1.3.1 Variables

enable
  Value: Boolean
  This variable shall be TRUE for an ONU MAC. For an OLT MAC, this variable is defined as below:
    TRUE when management has assigned a value to mode and logical_link_id. Indicates the MAC is enabled to receive frames.
    FALSE when the MAC is not in use.

mode
  Value: 1 bit
  This variable shall be 0 for an ONU MAC and may be 0 or 1 for an OLT MAC.
  When the LLID is used to emulate a single copy broadcast or multicast channel, this variable will be set to 1. When emulating a unicast channel, this variable will be set to 0.

logical_link_id
  Value: 15 bits
  This variable shall be set to the broadcast value of 0x7FFF for the unregistered ONU MAC.
  Enabled OLT MACs may use any value for this variable. If the optional multicast LLID feature is supported, the OLT may use a multicast_link_id along with the mode bit 0.
  Registered ONU MACs may use any value other than 0x7FFF or a multicast_link_id for this variable.

multicast_link_id
  Value: 15 bits
  Enabled OLT MACs that support the optional multicast LLID feature may use any value for this variable. This variable is used, along with a mode bit reset to 0, to derive the multicast LLID.

65.1.3.2 Transmit

The transmit function of this extended RS replaces some of the octets of the preamble as transmitted by the MAC with several fields: SLD (start of LLID delimiter), LLID and CRC8. The SLD field is used by the receiver function to locate the LLID and CRC8 fields. The LLID field identifies the source or destination MAC. The CRC8 field provides a level of integrity on the LLID field. Table 65–1 shows the replacement mapping.

Table 65–1—Preamble/SFD replacement mapping

Offset	Field	Preamble/SFD	Modified preamble/SFD
1	—	0x55	same
2	—	0x55	same
3	SLD	0x55	0xd5
4	—	0x55	same
5	—	0x55	same
6	LLID[15:8]	0x55	<mode, logical_link_id[14:8]>[a]

Table 65–1—Preamble/SFD replacement mapping *(continued)*

Offset	Field	Preamble/SFD	Modified preamble/SFD
7	LLID[7:0]	0x55	<logical_link_id[7:0]>[b]
8	CRC8	0xd5	The 8-bit CRC calculated over offsets 3 through 7

[a] mode maps to TXD[7], logical_link_id[14] maps to TXD[6], logical_link_id[8] maps to TXD[0]
[b] logical_link_id[7] maps to TXD[7], logical_link_id[0] maps to TXD[0]

65.1.3.2.1 SLD

The SLD field is one octet in length and replaces the third octet of the preamble.

NOTE—The 1000BASE-X PCS transmit function replaces the first octet of preamble with the /S/ code-group or it discards the first octet and replaces the second octet of preamble with the /S/ code-group. This decision is based upon the even or odd alignment of the PCS's transmit state diagram (see Figure 36–5). The 1000BASE-X PCS receive function replaces the /S/ code-group with an octet of preamble. The third octet of preamble is the first octet passed through the 1000BASE-X PHY without modification.

65.1.3.2.2 LLID

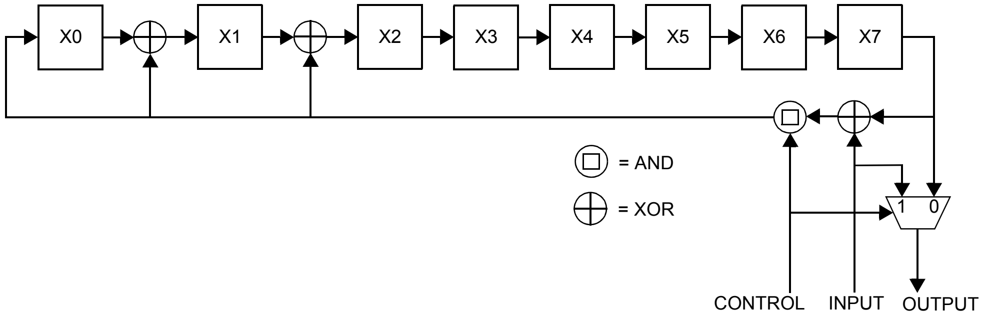
The LLID field is two octets in length and replaces the last two octets of preamble. The LLID field is a concatenation of the mode and logical_link_id variables for the associated MAC.

65.1.3.2.3 CRC-8

The CRC8 field contains an 8-bit cyclic redundancy check value. This value is computed as a function of the contents of the modified preamble beginning with the SLD field (offset 3) through the LLID field (offset 7). The encoding is defined by the generating polynomial shown in Equation (65–1):

$$G(x) = x^8 + x^2 + x + 1 \tag{65–1}$$

This CRC calculation shall produce the same result as the serial implementation shown in Figure 65–2. Before calculation begins, the shift register shall be initialized to the value 0x00. The content of the shift register is transmitted without inversion.



CONTROL = 1 when shifting the modified preamble and calculating the CRC
CONTROL = 0 when transmitting the CRC8 field

Figure 65–2—CRC8 field generation

65.1.3.3 Receive function

The receive function of this extended RS is responsible for the following functions:

a) Locate the SLD field.
b) Use the location of the SLD field to locate the CRC8 field and verify that the received value matches the CRC calculated using the received data.
c) Use the location of the SLD field to locate the LLID field and parse it to determine the destination MAC.
d) If the packet is not discarded due to incorrect CRC or unknown LLID, then replace the SLD and LLID fields with normal preamble and the CRC8 field with the SFD and transfer the packet to the appropriate MAC.
e) Otherwise, discard the entire packet, replacing it with normal inter-frame.

Table 65–2 shows the mapping of the modified preamble/SFD to RXD.

Table 65–2—Preamble/SFD replacement mapping

Signal	Bit values of octets received through GMII[a]								
RXD0	X	1[b]	1	1[c]	1	1	logical_link_id[8][d]	logical_link_id[0][e]	X7[f]	D0[g]
RXD1	X	0	0	0	0	0	logical_link_id[9]	logical_link_id[1]	X6	D1
RXD2	X	1	1	1	1	1	logical_link_id[10]	logical_link_id[2]	X5	D2
RXD3	X	0	0	0	0	0	logical_link_id[11]	logical_link_id[3]	X4	D3
RXD4	X	1	1	1	1	1	logical_link_id[12]	logical_link_id[4]	X3	D4
RXD5	X	0	0	0	0	0	logical_link_id[13]	logical_link_id[5]	X2	D5
RXD6	X	1	1	1	1	1	logical_link_id[14]	logical_link_id[6]	X1	D6
RXD7	X	0	0	1	0	0	mode	logical_link_id[7]	X0	D7
RX_DV	0	1	1	1	1	1	1	1	1	1

[a] Leftmost octet is the first received
[b] This octet may be missing per 1000BASE-X PCS transmit state diagram (see Figure 36–5)
[c] SLD field
[d] First octet of LLID field
[e] Second octet of LLID field
[f] CRC8 field
[g] D0 through D7 is the first octet of the PDU (first octet of the Destination Address)

65.1.3.3.1 SLD

Recall that the 1000BASE-X transmit function must maintain an even alignment for its Start_of_Packet delimiters. It may replace the first octet of preamble with the /S/ code-group and pass the second octet unchanged or it may discard the first octet of preamble and replace the second octet of preamble with the /S/ code-group. The SLD is transmitted in the third octet. These are the only two possibilities considered when parsing the incoming octet stream for the SLD. If the SLD field is not found then the packet shall be discarded. If the packet is transferred, the SLD shall be replaced with a normal preamble octet and the one or two octets preceding the SLD and the two octets following the SLD are passed without modification.

65.1.3.3.2 LLID

The third and fourth octets following the SLD contain the mode and logical_link_id values. These values are acted upon differently for OLTs and ONUs.

If the device is an OLT then the following comparison is made:

a) The received mode bit is ignored.
b) If the received logical_link_id value matches 0x7FFF and an enabled MAC exists with a logical_link_id variable with the same value then the comparison is considered a match to that MAC.

c) If the received logical_link_id value is any value other than 0x7FFF and an enabled MAC exists with a mode variable with a value of 0 and a logical_link_id variable with a value matching the received logical_link_id value then the comparison is considered a match to that MAC.

If the device is an ONU then the following comparison is made:

d) If the received mode bit is 0 and the received logical_link_id value matches the logical_link_id variable then the comparison is considered a match.
e) If the received mode bit is 1 and the received logical_link_id value does not match the logical_link_id variable, or the received logical_link_id matches 0x7FFF, then the comparison is considered a match.
f) If the device supports the multicast LLID feature, the received mode bit is 0 and the received logical_link_id value matches an assigned multicast_link_id, then the comparison is considered a match.

If no match is found, then the packet shall be discarded within the RS. If a match is found, then the packet is intended to be transferred. If the packet is transferred, then both octets of the LLID field shall be replaced with normal preamble octets.

65.1.3.3.3 CRC-8

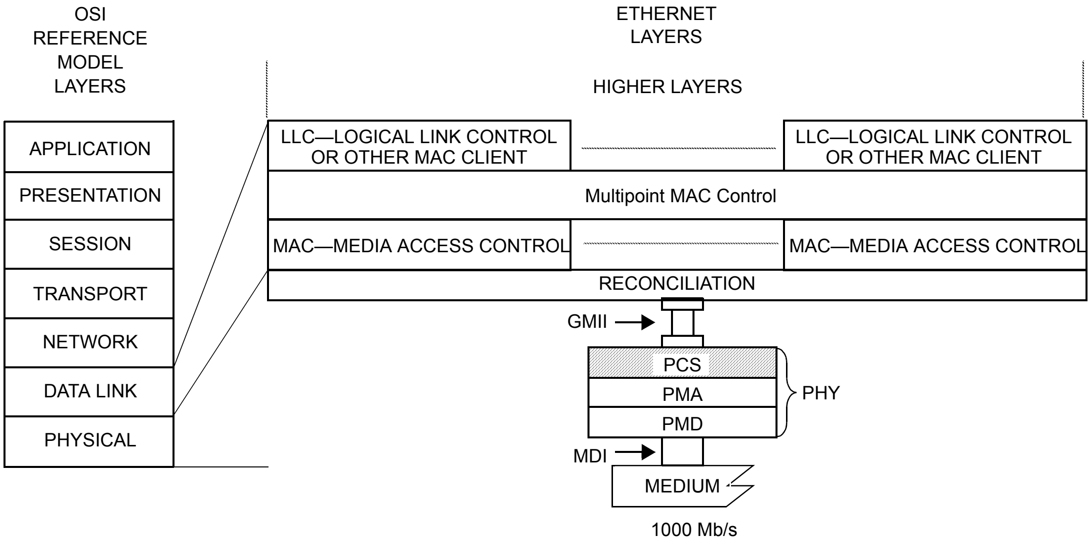
The octet following the LLID field contains the CRC8 field. The value of this field is compared against the calculated CRC of the received octets, beginning with the SLD field and ending with the last octet of the LLID field. If the received and calculated CRC values do not match, then the packet shall be discarded. If the values match then the packet is transferred. If the packet is transferred, then the CRC8 field shall be replaced with the SFD.

65.2 Extensions of the physical coding sublayer for data detection and forward error correction

65.2.1 Overview

This subclause extends the physical coding sublayer Clause 36 to support burst mode operation of the point-to-multipoint physical medium. This subclause also specifies an optional forward error correction (FEC) mechanism to increase the optical link budget or the fiber distance. Figure 65–3 shows the relationship between the extended PCS sublayer and the ISO/IEC OSI reference model. Auto-Negotiation, as defined in Clause 37, establishes a point-to-point handshaking mechanism for allowing 1000BASE-X devices to achieve a highest common denominator link. The P2MP aspect of a 1000BASE-PX network prohibits the use of the auto-negotiation protocol.

NOTE—Many implementations of the transmit and receive buffers might be dependent on the maximum length of frame supported. It is recommended that these frame buffers should be sized to accommodate maximum length envelope frames (see 3.2.7). It is also recommended that the FEC function should accommodate maximum length envelope frames, requiring up to 9 FEC code blocks per frame.



GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
PHY = PHYSICAL LAYER DEVICE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 65–3—PCS location in the OSI protocol stack

65.2.2 Burst-mode operation

To avoid spontaneous emission noise from near ONUs obscuring signal from a distant ONU, the ONUs' lasers should be turned off between their transmissions. To control the laser, the PCS is extended to detect the presence of transmitted data and generate the PMD_SIGNAL.request(tx_enable) primitive to turn the laser on and off at the correct times. This function is performed by the Data Detector shown in the functional block diagram in Figure 65–4.

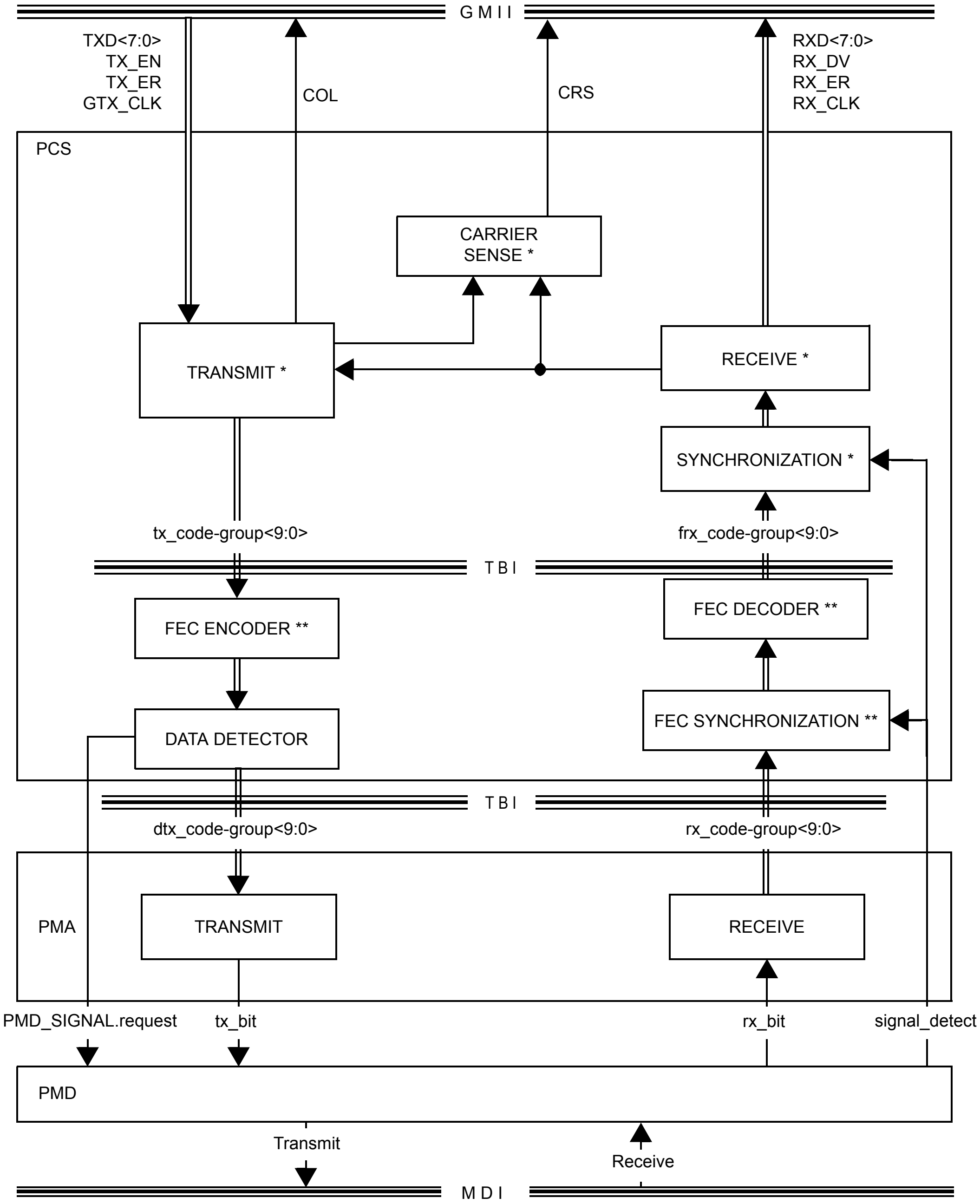
65.2.2.1 Principle of operation

The Data Detector contains a delay line (FIFO buffer) storing code-groups to be transmitted. The length of the FIFO buffer shall be chosen such that the delay introduced by the buffer together with any delay introduced by the PMA sublayer is long enough to turn the laser on and to allow a predefined number of idle characters to be transmitted. This number of idle characters is needed by the receiver to adjust its gain ($T_{receiver\_settling}$), synchronize its receiving clock (T_{CDR}), and complete the synchronization process (T_{sync}).

Upon initialization, the FIFO buffer is filled with /I/ ordered sets and the laser is turned off. When the first code-group that is not /I/ arrives at the buffer, the Data Detector sets the PMD_SIGNAL.request(tx_enable) primitive to the value ON, instructing the PMD sublayer to start the process of turning the laser on (see Figure 65–4).

When the buffer empties of data (i.e., contains only /I/ ordered sets), the Data Detector sets the PMD_SIGNAL.request(tx_enable) primitive to the value OFF, instructing the PMD sublayer to start the process of turning the laser off. Between packets, /I/ or /R/ ordered sets will arrive at the buffer. If the number of these /I/ or /R/ ordered sets is insufficient to fill the buffer then the laser is not turned off.

Figure 65–5 shows the relationship of filling the buffer and the generation of laser_control. In the OLT, the laser always remains turned on. Correspondingly, therefore the OLT's Data Detector does not need a delay line or buffer in the data path for this purpose.



* - legacy 1000BASE-X functions
** - optional FEC functions

Figure 65–4—PCS Extension functional block diagram

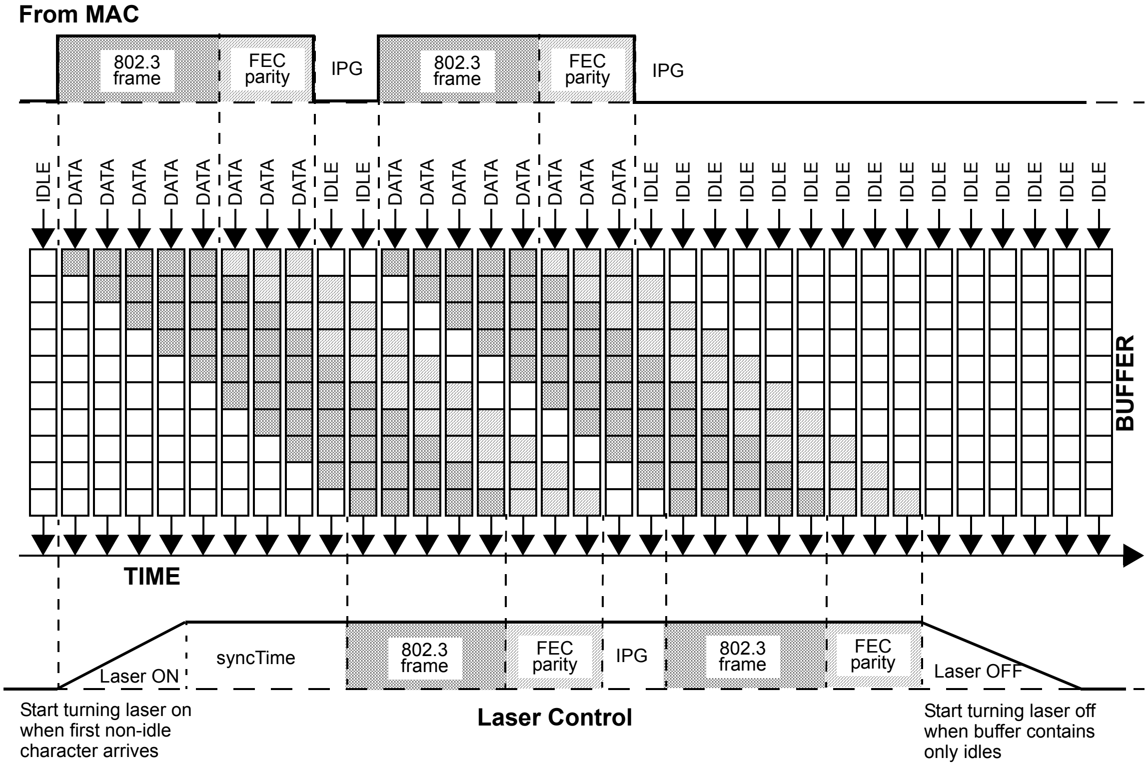


Figure 65–5—Laser control as a function of buffer fill

65.2.2.2 Detailed functions and state diagrams

The body of this clause comprises state diagrams, including the associated definitions of variables, constants, and functions. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation used in the state diagrams in this clause follows the conventions in 21.5. State diagram variables follow the conventions of 21.5.2 except when the variable has a default value. Variables in a state diagram with default values evaluate to the variable default in each state where the variable value is not explicitly set.

65.2.2.2.1 Variables

BEGIN

TYPE: Boolean

This variable is used when initiating operation of the state diagram. It is set to true following initialization and every reset.

DelayBound

TYPE: 16-bit unsigned

DEFAULT VALUE: 00-6A (106 code-groups = 848 ns)

This represents the delay sufficient to initiate the laser and to stabilize the receiver at the OLT. The default value of DelayBound is based on default values of laserOnTime (64.3.5.1) and SyncTime (64.3.3.2). This variable is only used by the ONU.

dtx_code-group

A 10-bit vector representing one code-group, as specified in Tables 36–1a through 36–2, which has been prepared for transmission by the Data Detector process. This vector is conveyed to the PMA as the parameter of a PMA_UNITDATA.request(dtx_code-group) service primitive. The element dtx_code-group<0> is the first bit transmitted and dtx_code-group<9> is the last bit transmitted.

laser_control

This variable represents the status of the laser. The value on corresponds to the laser being turned on, and the value off corresponds to laser being off.

TYPE: Boolean.

tx_code-group

A 10-bit vector of bits representing one code-group, as specified in Table 36–1a or Table 36–2, which has been prepared for transmission by the PCS Transmit process. The element tx_code-group<0> is the first tx_bit transmitted; tx_code-group<9> is the last tx_bit transmitted.

65.2.2.2.2 Functions

IsIdle(tx_code-group)

This function is used to determine whether tx_code-group is a code-group in /I/, the IDLE ordered set, or /C/, the Configuration ordered set. This function returns true if tx_code-group is /K28.5/ or any code-group that follows a /K28.5/ or any two consecutive /D/ code-groups that follow /K28.5/D21.5/ or /K28.5/D2.2/. Otherwise, the IsIdle function returns false.

FIFO.RemoveHead()

This function removes the first code-group from the FIFO buffer and advances all remaining code-groups one position ahead. This function returns the 10-bit vector representing the removed code-group.

FIFO.Append(tx_code-group)

This function appends a new 10-bit vector to the end of the FIFO buffer.

65.2.2.2.3 Messages

PMD_SIGNAL.request(tx_enable)

This primitive is used to turn the laser on and off at the PMD sublayer. In the OLT, this primitive shall always take the value ON. In the ONU, the value of this variable is controlled by the Data detector state diagram (see Figure 65–6).

PUDR

Alias for PMA_UNITDATA.request(tx_code-group<9:0>).

65.2.2.2.4 Counters

IdleLength

This counter represents the length of the consecutive interval of idles ending with the most recent tx_code-group. If the most recent tx_code-group represents a non-idle character, the IdleLength is reset to 0.

TYPE: 32-bit unsigned

65.2.2.3 State Diagrams

The Data Detector shall be implemented for an ONU as depicted in Figure 65–6, including compliance with the associated state variables as specified in 65.2.2.2.

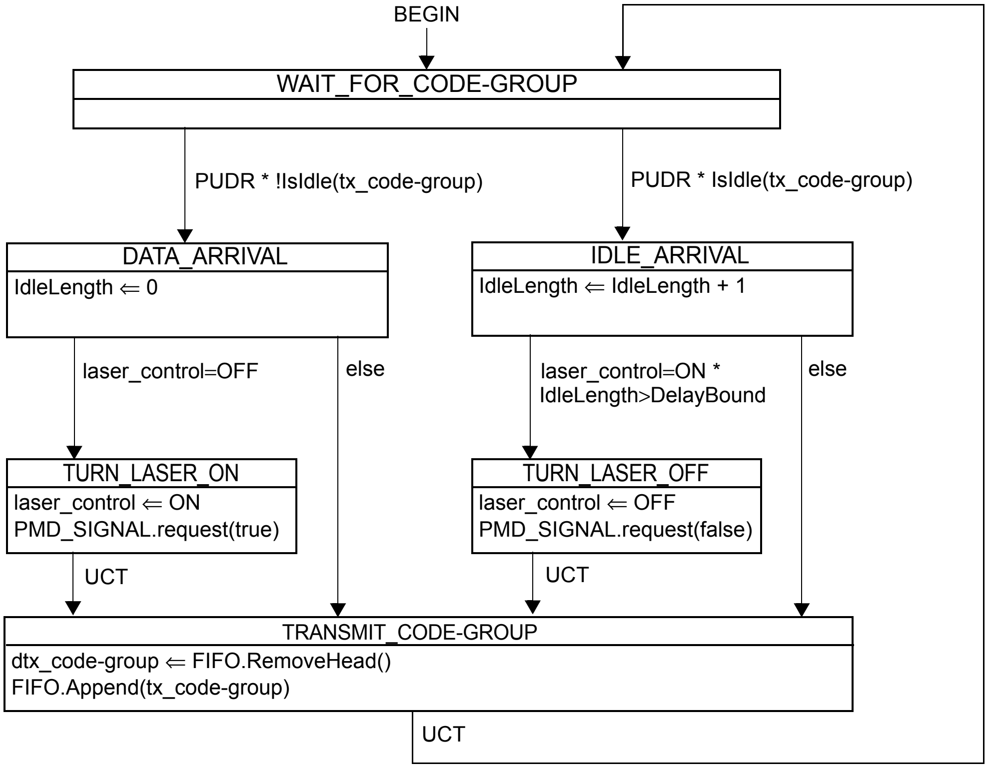


Figure 65–6—ONU data decoder state diagram

65.2.3 Forward error correction

This subclause specifies an optional forward error correction (FEC) mechanism to increase the optical link budget or the fiber distance. The FEC appends to the Ethernet frame additional data that is a result of a set of non-binary arithmetic functions (known as Galois arithmetic) performed on the data of the Ethernet frame. This additional data (known as the FEC parity octets) is used to correct errors at the receiving end of the link that may occur when the data is transferred through the link.

The FEC function comprises three functional blocks: FEC Encoder, FEC Decoder, and FEC Synchronization, as shown in Figure 65–4. These blocks have ten-bit interfaces (TBIs) to both sides and can be omitted for implementations not requiring FEC. Though the FEC functionality is optional, if implemented for operation over a multipoint optical link, it shall behave as specified in 65.2.3.

The following are the objectives of FEC:
a) Keep frame format compliant to 1000BASE-X PCS.
b) Support optional functionality.
c) Allow backwards compatibility with legacy 1000BASE-X devices.
d) Support BER objective of 10^{-12} at PCS.
e) Support BER objective of 10^{-4} at FEC sublayer.

65.2.3.1 FEC code

The FEC code specification, properties and performance analysis are specified in ITU-T G.975.

The FEC code used is a linear cyclic block code - the Reed-Solomon code (255,239,8) over the Galois Field of GF(2^8) - a non-binary code operating on 8-bit symbols. The code encodes 239 information symbols and adds 16 parity symbols. The code is systematic—meaning that the information symbols are not disturbed in any way in the encoder and the parity symbols are added separately to each block.

The code is the systematic form of the RS code based on the generating polynomial $G(x) = \prod_{i=0}^{15}(x-\alpha^i)$ where α is equal to 0x02 and is a root of the binary primitive polynomial $x^8+x^4+x^3+x^2+1$.

A codeword of the systematic code is presented by $D(x) + P(x) = G(x) * \mathrm{L}(x)$ where:

$D(x)$ is the data vector – $D(\mathrm{x})=\mathrm{D}_{238}X^{254} + ... + \mathrm{D}_0X^{16}$. D_{238} is the first data octet and D_0 is the last.

$P(x)$ is the parity vector – $P(x)=\mathrm{P}_{15}X^{15} + ... + \mathrm{P}_0$. P_{15} is the first parity octet and P_0 is the last.

A data octet (d_7, d_6, ..., d_1, d_0) is identified with the element: $\mathrm{d}_7*\alpha^7 + \mathrm{d}_6*\alpha^6 + ... \mathrm{d}_1*\alpha^1 + \mathrm{d}_0$ in GF(2^8), the finite field with 2^8 elements. The code has a correction capability of up to eight symbols.

NOTE—For the (255,239,8) Reed-Solomon code, the symbol size equals one octet. d_0 is identified as the LSB and d_7 is identified as the MSB bit in accordance with the conventions of 3.1.1.

The FEC decoder shall replace all octets in an uncorrectable block with /V/ to clearly propagate the error condition to the PCS.

65.2.3.2 FEC frame format

The frame format of an FEC coded Ethernet frame is herein described.

65.2.3.2.1 Placing parity octets

Ethernet packets are received from the PCS. The data is partitioned into 239-symbol frames (blocks), with the first block beginning with the first symbol after the /S/ code-group and the last block ending with the last symbol before the /T/ code-group. Each block is encoded using the (255,239,8) Reed-Solomon encoder, which results in an additional 16 parity symbols for each block. The block plus the associated 16 parity symbols form the 255 symbol Reed-Solomon codeword. The additional 16 parity symbols, which are generated from this encoding process for each block, are gathered and added at the end of the packet.

65.2.3.2.2 Shortened last block

When dividing the data into blocks there might be a case where the last block is shorter than 239 symbols. This block is noted as a shortened block. A shortened block of length r octets results in the data vector assignment of D_{238} to D_r as zeros and $\mathrm{D}_{\mathrm{r-1}}$ to D_0 as valid data, where $\mathrm{D}_{\mathrm{r-1}}$ is the first octet of the shortened block and D_0 is the last. This full size block is then encoded and the 16 parity symbols are generated. The data is then sent without the zero symbols. At the receiver, the decoder completes the block again into the full block (by adding back the zeros) for decoding.

65.2.3.2.3 Special frame markers

The Ethernet frame consists of a number of blocks plus special frame start and stop markers. In order to decode the FEC code, the receiver must first synchronize on the Ethernet frame. The Ethernet frame markers are not protected by the FEC code and are exposed to higher BER. Therefore, special start and stop marker symbols are added at the beginning and the end of the FEC coded frame that are capable of being correctly detected in a high noise environment. The special symbol noise immunity is made possible by the implementation of a simple correlator. The marker framing sequences used are at least 5 octets long, long enough to be detected with very high probability. The start FEC framing sequence is denoted by /S_FEC/ and the end FEC framing sequence is denoted by /T_FEC/.

In order to determine that an FEC coded frame has started, the input symbol stream is scanned for a match with the /S_FEC/ ordered set with fewer than d/2 errors. In order to determine that an FEC coded frame has ended, the input symbol stream is scanned for a match with the /T_FEC_O/ or /T_FEC_E/ ordered sets with fewer than d/2 errors.

The value chosen for d is 10, the number of bits that are different between these ordered sets and any other regularly occurring five consecutive code-groups when considered in the 10-bit domain.

The sequence can flow through non-FEC PCS transparently (in a False_Carrier_Sense mode).

The start and end symbols are constructed from 8B/10B code-groups:

- /S_FEC/ - start of FEC coded packet - /K28.5/D6.4/K28.5/D6.4/S/
- /T_FEC_E/ - end of FEC coded packet with even alignment. If the starting running disparity is positive, the /T_FEC_E/ has the following pattern: /T/R/K28.5/D10.1/T/R/. If the starting running disparity is negative, the T_FEC_E has the following pattern: /T/R/K28.5/D29.5/T/R/.
- /T_FEC_O/ - end of FEC coded packet with odd alignment - /T/R/R/I/T/R/

/S/, /T/, /R/ and /I/ are described in Table 36–3. The /I/ in both the /T_FEC_E/ and the /T_FEC_O/ ordered sets can be either an /I1/ (a disparity correcting IDLE) or an /I2/ (a disparity preserving IDLE).

Figure 65–7 describes the FEC coded Ethernet frame. Between the FCS and PARITY fields, the T_FEC can be either the /T_FEC_E/ or the /T_FEC_O/ ordered set. After the PARITY field, the T_FEC can only be a /T_FEC_E/ ordered set.

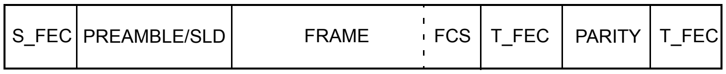


Figure 65–7—FEC coded Ethernet frame

65.2.3.3 FEC sublayer operation

This section describes the functionality and operation of the FEC sublayer.

65.2.3.3.1 Principles of operation

At transmission, the FEC sublayer receives the packets from the PCS, performs the FEC coding, appends the parity octets in place of the stretched IPG and sends the data to the PMA. At reception, the FEC sublayer receives the data from the PMA, performs the octet alignment, detects the Start FEC Framing Sequence, decodes the FEC code, correcting data where necessary and possible, replaces the parity octets with IDLE and sends the data to the PCS.

NOTE—To ensure correct MPCP operation, FEC function must maintain constant and equal delay for all code-groups and all signals transmitted from PMA to PCS. Timing effects of adding FEC function should be indistinguishable from an increased propagation delay.

65.2.3.3.2 Functional block diagram

As depicted in Figure 65–4, the FEC sublayer comprises a transmit side and a receive side. The following sections define the functionality of each block in the sublayer. See 36.3.3 for a complete description of the TBI.

65.2.3.3.3 Transmission

Figure 65–8 describes a block diagram of the FEC sublayer transmit data path. The packet delimiters of the packets from the PCS are detected. The /I/I/S/ is replaced with the /S_FEC/ ordered set. The data in the frame is then 8B/10B decoded so that the FEC coding can take place and the parity octets buffered. The /T/R/I/I/ or /T/R/R/I/I/ is detected and replaced with the /T_FEC_E/ or /T_FEC_O/, respectively. Then the parity octets and another /T_FEC_E/ is appended, replacing the stretched interframe spacing.

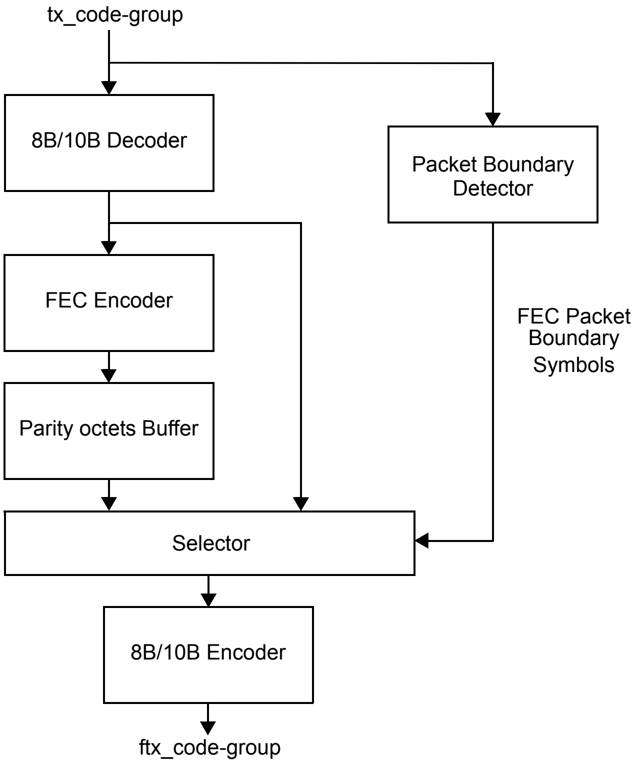


Figure 65–8—Transmit block diagram

The FEC Transmit process continually generates code-groups based upon information provided in the PMA_UNITDATA.request primitive with the tx_code-group<9:0> parameter, sending them immediately to the PMA Service Interface via the same primitive with the ftx_code-group<9:0> parameter.

65.2.3.3.4 Reception

Figure 65–9 describes the receive synchronization block diagram of the FEC sublayer receive data path. The FEC Synchronization process continually accepts code-groups via the PMA_UNITDATA.indication service primitive and conveys received code-groups to the FEC Receive process via the SYNC_UNITDATA.indicate service primitive. The FEC Synchronization process sets the sync_status flag to indicate whether the PMA is functioning dependably (as well as can be determined without exhaustive error-ratio analysis).

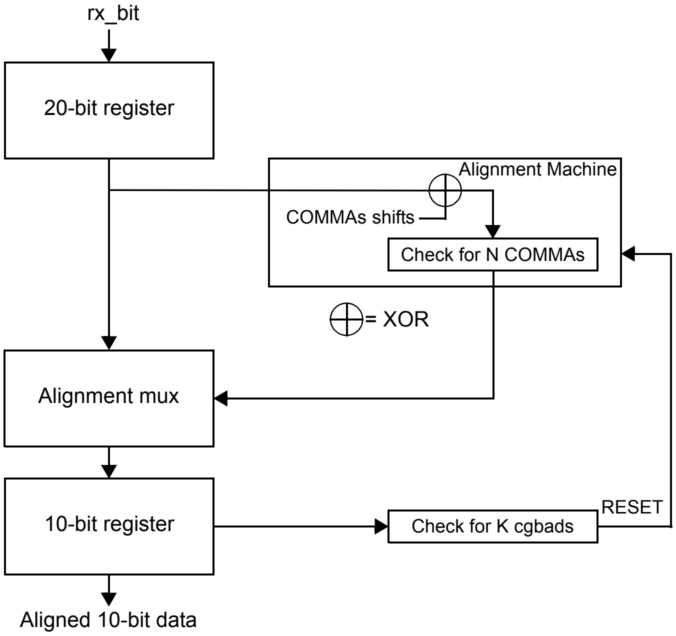


Figure 65–9—Receive synchronization block diagram

Figure 65–10 describes a block diagram of the FEC sublayer receive data path. The FEC Receive process continuously accepts code-groups via the SYNC_UNITDATA.indicate service primitive. It fills a buffer with these code-groups, converting an /S_FEC/ with fewer than d/2 errors to /I/I/S/ and converting all /T_FEC/ with fewer than d/2 errors to a clean /T_FEC/. This buffer exists in order to store all necessary data until the parity octets are available for performing data correction. Data correction is performed within the buffer. While emptying the buffer, the parity octets, along with the latter /T/R/ of the first /T_FEC/ and the entire second /T_FEC/ are converted to /I/.

NOTE—Under specific conditions, the PCS may generate a large number of FALSE_CARRIER events. FEC encryption only protects Ethernet frames. The IDLEs are not FEC-protected. During idle periods, excessive bit errors may results in FALSE_CARRIER events. Additionally, when FEC and non-FEC devices are combined in the same EPON, a non-FEC device will treat FEC parity data as FALSE_CARRIER events.

65.2.3.4 Detailed functions and state diagrams

The body of this clause comprises state diagrams, including the associated definitions of variables, constants, and functions. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation used in the state diagrams in this clause follows the conventions in 21.5. State diagram variables follow the conventions of 21.5.2 except when the variable has a default value. Variables in a state diagram with default values evaluate to the variable default in each state where the variable value is not explicitly set.

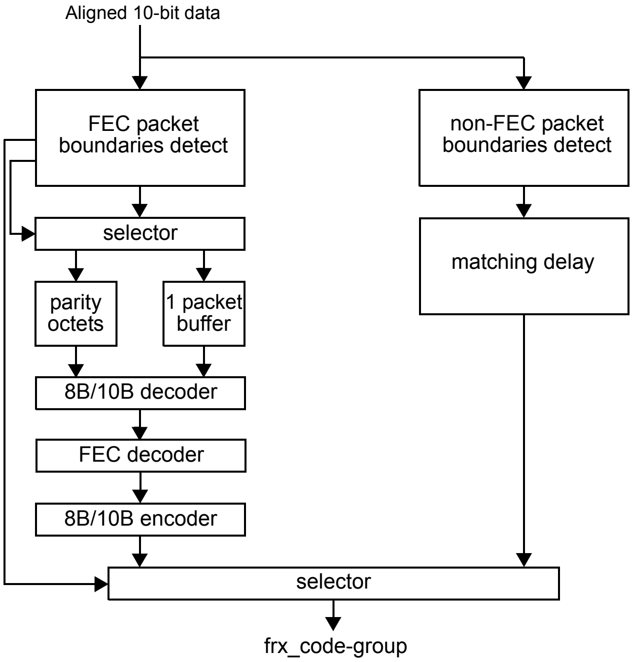


Figure 65–10—Receive data block diagram

65.2.3.4.1 State variables

65.2.3.4.2 Notation conventions

/x/

Denotes the constant code-group specified in 36.2.5.1.2 (valid code-groups must follow the rules of running disparity as per 36.2.4.5 and 36.2.4.6).

[/x/]

Denotes the latched received value of the constant code-group (/x/) specified in 36.2.5.1.2 and conveyed by the SYNC_UNITDATA.indicate message described in 36.2.5.1.6.

65.2.3.4.3 Constants

/COMMA/

The set of special code-groups that include a comma as specified in 36.2.4.9 and listed in Table 36–2.

/D/

The set of 256 code-groups corresponding to valid data, as specified in 36.2.4.11.

/Dx.y/

One of the set of 256 code-groups corresponding to valid data, as specified in 36.2.4.11.

/I/

The IDLE ordered set group, comprising either the /I1/ or /I2/ ordered sets, as specified in 36.2.4.12.

/INVALID/

The set of invalid data or special code-groups, as specified in 36.2.4.6.

/Kx.y/

One of the set of 12 code-groups corresponding to valid special code-groups, as specified in Table 36–2.

/R/

The code-group used as either: End_of_Packet delimiter part 2; End_of_Packet delimiter part 3; Carrier_Extend; and /I/ alignment.

/S/

The code-group corresponding to the Start_of_Packet delimiter (SPD) as specified in 36.2.4.14.

/T/

The code-group used for the End_of_Packet delimiter part 1.

/V/

The Error_Propagation code-group, as specified in 36.2.4.17.

65.2.3.4.4 Variables

buffer

The Receive process buffer of undefined length containing code-groups.

buffer_head

The code-group at the head of the Receive process buffer.

cgbad

Alias for the following terms: ((rx_code-group∈/INVALID/) + (rx_code-group=/COMMA/ *rx_even=TRUE)) * PMA_UNITDATA.indication

cggood

Alias for the following terms: !((rx_code-group∈/INVALID/) + (rx_code-group=/COMMA/ *rx_even=TRUE)) * PMA_UNITDATA.indication

fec_encode

A Boolean set by the FEC Transmit process to indicate the status of the RS_Encode(Data) function.

Values: TRUE; data is acted upon by the RS_Encode(Data) function.
FALSE; data is not being acted upon by the RS_Encode(Data) function.

ftx_bit

A binary parameter used to convey data from the PMA to the PMD via the PMD_UNITDATA.request service primitive as specified in 60.1.5.1.

Values: ZERO; Data bit is a logical zero.
ONE; Data bit is a logical one.

ftx_code-group<9:0>

A vector of bits representing one code-group, as specified in Table 36–1a through Table 36–2, which has been prepared for transmission by the FEC Transmit process. This vector is conveyed to the PMA as the parameter of a PMA_UNITDATA.request(ftx_code-group) service primitive. The element ftx_code-group<0> is the first ftx_bit transmitted; ftx_code-group<9> is the last ftx_bit transmitted.

parity<D7:D0>

An 8-bit array that contains the current parity bits to be encoded in the FEC Transmit Process. The elements within the array are updated with the next 8-bits to be encoded upon each entry into the XMIT_PARITY state.

Values for each element in the array: ZERO; Data bit is a logical zero.
ONE; Data bit is a logical one.

parity_buffer_empty

A Boolean set by the FEC Transmit process to indicate if more parity octets need to be encoded.

Values: TRUE; No more parity octets need to be encoded.
FALSE; More parity octets need to be encoded.

rx_disparity

A Boolean set by the FEC Receive process to indicate the running disparity at the end of code-group reception as a binary value. Running disparity is described in 36.2.4.3.

Values: POSITIVE
NEGATIVE

rx_even

A Boolean set by the FEC Synchronization process to designate received code-groups as either even- or odd-numbered code-groups as specified in 36.2.4.2.

Values: TRUE; Even-numbered code-group being received.
FALSE; Odd-numbered code-group being received.

rx_code-group<9:0>

A 10-bit vector represented by the most recently received code-group from the PMA. The element rx_code-group<0> is the least recently received (oldest) rx_bit; rx_code-group<9> is the most recently received rx_bit (newest). When code-group alignment has been achieved, this vector contains precisely one code-group.

signal_detect

A Boolean set by the PMD continuously via the PMD_SIGNAL.indication(signal_detect) message to indicate the status of the incoming link signal.

Values: FAIL; A signal is not present on the link.
OK; A signal is present on the link.

sync_status

A parameter set by the FEC Synchronization process to reflect the status of the link as viewed by the receiver.

Values: FAIL; The receiver is not synchronized to code-group boundaries.
OK; The receiver is synchronized to code-group boundaries.

tx_bit

A binary parameter used to convey data from the PMA to the PMD via the PMD_UNITDATA.request service primitive as specified in 60.1.5.1.

Values: ZERO; Data bit is a logical zero.
ONE; Data bit is a logical one.

tx_code-group<9:0>

A vector of bits representing one code-group, as specified in Table 36–1a or Table 36–2, which has been prepared for transmission by the PCS Transmit process. This vector is conveyed to the PMA as the parameter of a PMD_UNITDATA.request(tx_bit) service primitive. The element tx_code-group<0> is the first tx_bit transmitted; tx_code-group<9> is the last tx_bit transmitted.

tx_disparity

A Boolean set by the FEC Transmit process to indicate the running disparity at the end of code-group transmission as a binary value. Running disparity is described in 36.2.4.3.

Values: POSITIVE
NEGATIVE

65.2.3.4.5 Functions

check_ahead_tx

Prescient function used by the FEC Transmit process to find the Start_of_Packet in order to replace the Start_of_Packet and its two preceding IDLE ordered sets with /S_FEC/.

check_ahead_rx

Prescient function used by the FEC Receive process to find the /S_FEC/ and /T_FEC/, with fewer than d/2 errors.

DECODE ([/x/])

In the PCS Receive process, this function takes as its argument the latched value of rx_code-group<9:0> ([/x/]) and the current running disparity, and returns the corresponding GMII RXD<7:0>, rx_Config_Reg<D7:D0>, or rx_Config_Reg<D15:D8> octet, per Table 36–1a–e. DECODE also updates the current running disparity per the running disparity rules outlined in 36.2.4.4.

ENCODE(x)

In the PCS Transmit process, this function takes as its argument (x), where x is a GMII TXD<7:0>, tx_Config_Reg<D7:D0>, or tx_Config_Reg<D15:D8> octet, and the current running disparity, and returns the corresponding ten-bit code-group per Table 36–1a. ENCODE also updates the current running disparity per Table 36–1a–e.

POP_BUFFER

Removes the octet at the head of the Receive process buffer, making the next octet available.

RS_Encode(Data)

This function is used to encode the Reed-Solomon (255,239,8) code. The encoder encodes the 239 octets data frame and generates 16 parity octets for each data frame. Before being passed to the Reed-Solomon encoder, this function passes the data through DECODE([/x/]).

RS_Decode(Data)

This function is used to decode the Reed-Solomon (255,239,8) code. The decoder decodes the 255 symbols data frame and generates 239 corrected data octets for each frame and an error signal.

signal_detectCHANGE

In the PCS Synchronization process, this function monitors the signal_detect variable for a state change. The function is set upon state change detection.

Values: TRUE; A signal_detect variable state change has been detected.
FALSE; A signal_detect variable state change has not been detected (default).

65.2.3.4.6 Counters

good_cgs

Count of consecutive valid code-groups received.

loop_count
A 3-bit counter used to keep track of the number of loops in the receive synchronization process.

65.2.3.4.7 Messages

FEC_UNITDATA.indicate(frx_code-group<9:0>)
A signal sent by the FEC Receive process conveying the next code-group received over the medium.

FUDI
Alias for FEC_UNITDATA.indicate(frx_code-group<9:0>).

PMA_UNITDATA.indication(rx_code-group<9:0>)
A signal sent by the PMA Receive process conveying the next code-group received over the medium (see 36.3.1.2).

PMA_UNITDATA.request(tx_code-group<9:0>)
A signal sent to the PMA or FEC Transmit process conveying the next code-group ready for transmission over the medium (see 36.3.1.1).

PUDI
Alias for PMA_UNITDATA.indication(rx_code-group<9:0>).

PUDR
Alias for PMA_UNITDATA.request(tx_code-group<9:0>).

SUDI
Alias for SYNC_UNITDATA.indicate(parameters).

SYNC_UNITDATA.indicate(parameters)
A signal sent by the FEC Synchronization process to the FEC Receive process conveying the following parameters:

Parameters: [/x/]; the latched value of the indicated code-group (/x/);
EVEN/ODD; The latched state of the rx_even variable;

Value: EVEN; Passed when the latched state of rx_even=TRUE.
ODD; Passed when the latched state of rx_even=FALSE.

65.2.3.5 State diagrams

65.2.3.5.1 Transmit state diagram

The FEC shall implement its transmit process as depicted in Figure 65–11, including compliance with the associated state variables as specified in 65.2.3.4.1.

65.2.3.5.2 Receive synchronization state diagram

The FEC shall implement its synchronization process as depicted in Figure 65–12, including compliance with the associated state variables in 65.2.3.4.1.

65.2.3.5.3 Receive state diagram

The FEC shall implement its receive process as depicted in Figure 65–13 and Figure 65–14, including compliance with the associated state variables in 65.2.3.4.1.

It is expected that the FEC decoding is performed while the data is in the buffer.

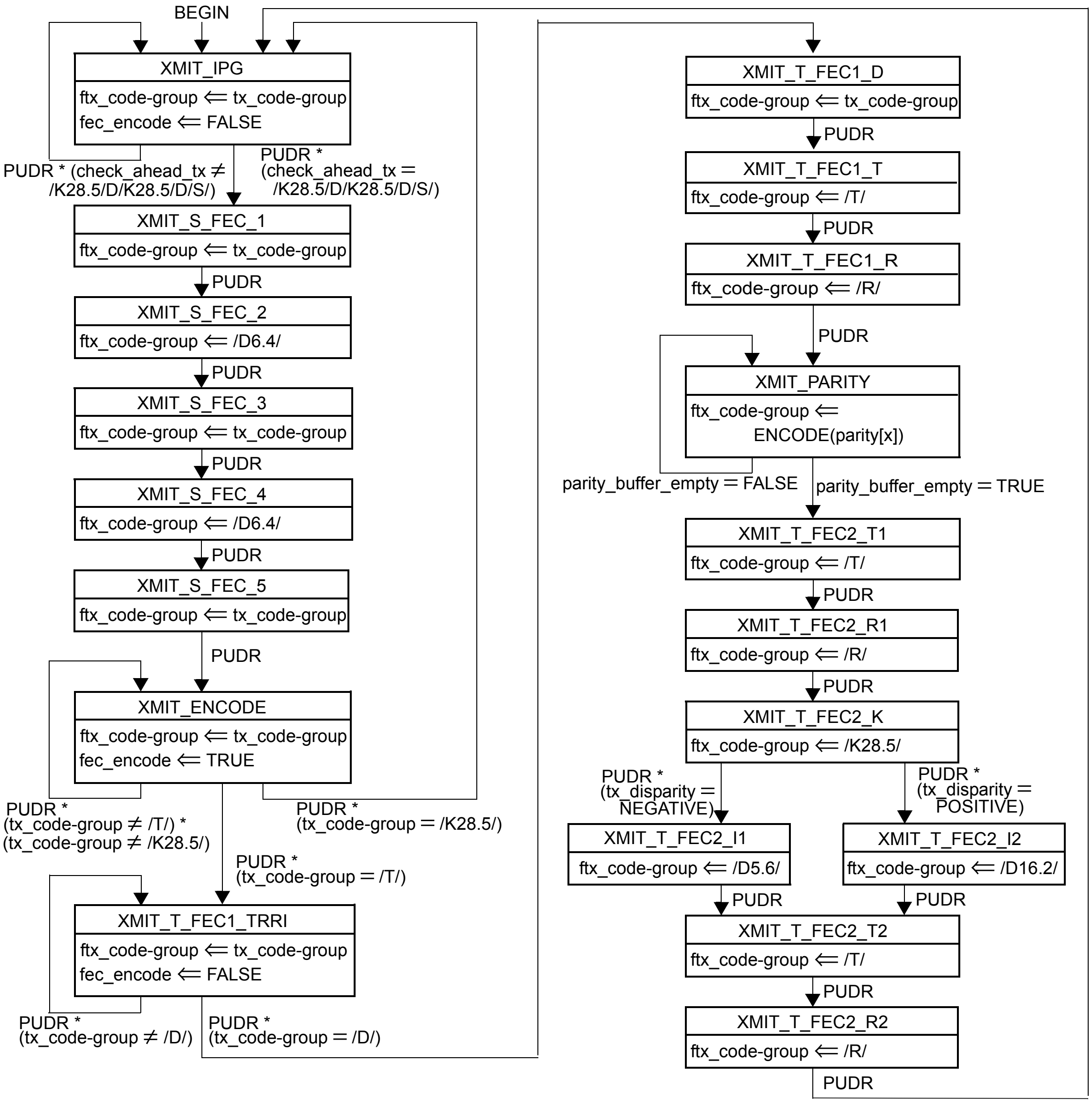


Figure 65–11—Transmit state diagram

65.2.3.6 Error monitoring capability

The following counters apply to FEC sublayer management and error monitoring. If an MDIO interface is provided (see Clause 22), it is accessed via that interface. If not, it is recommended that an equivalent access be provided. These counters are reset to zero upon read or upon reset of the FEC sublayer. When a counter reaches all ones, it stops counting. The counters' purpose is to help monitor the quality of the link.

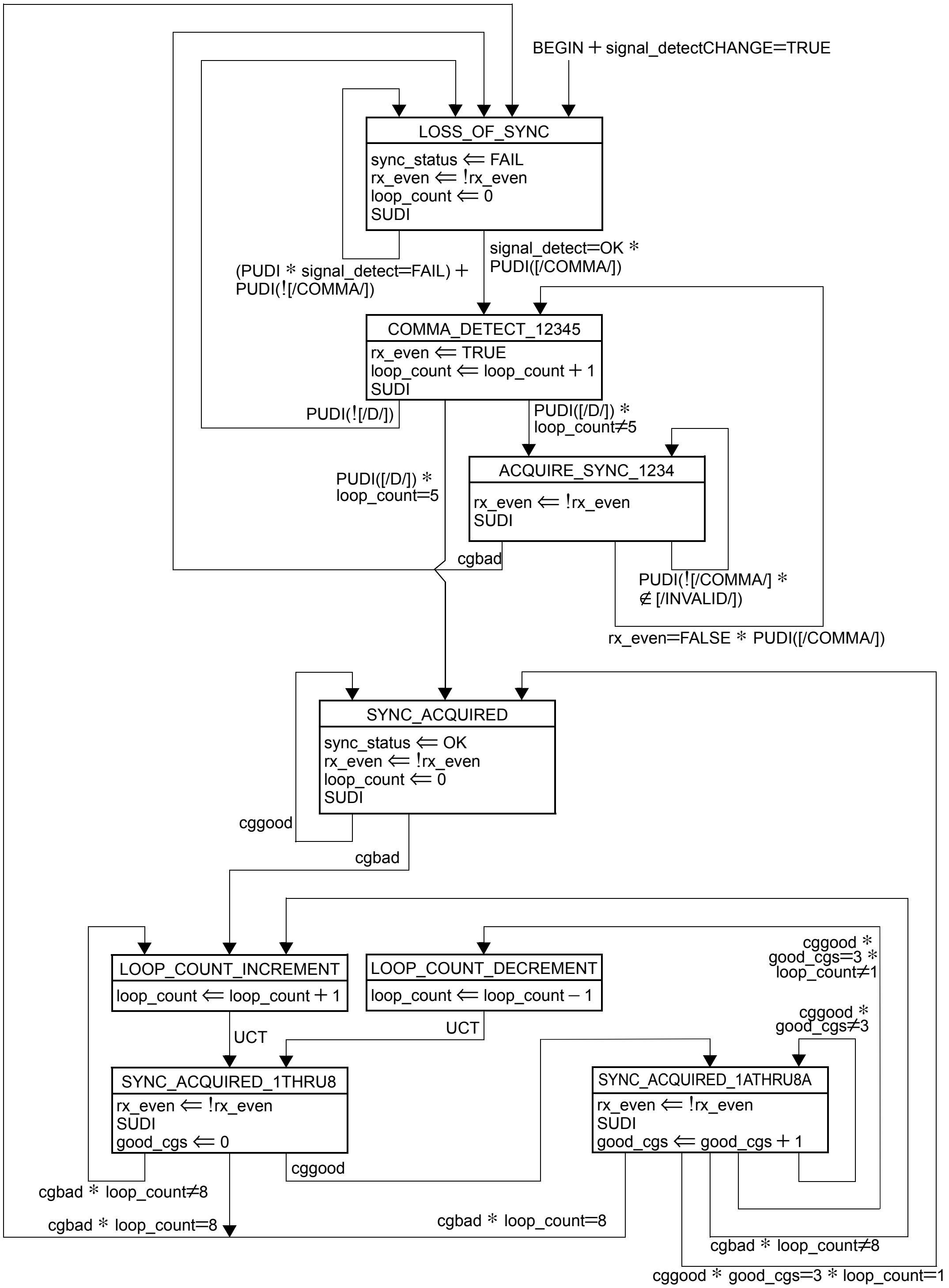


Figure 65–12—Receive synchronization state diagram

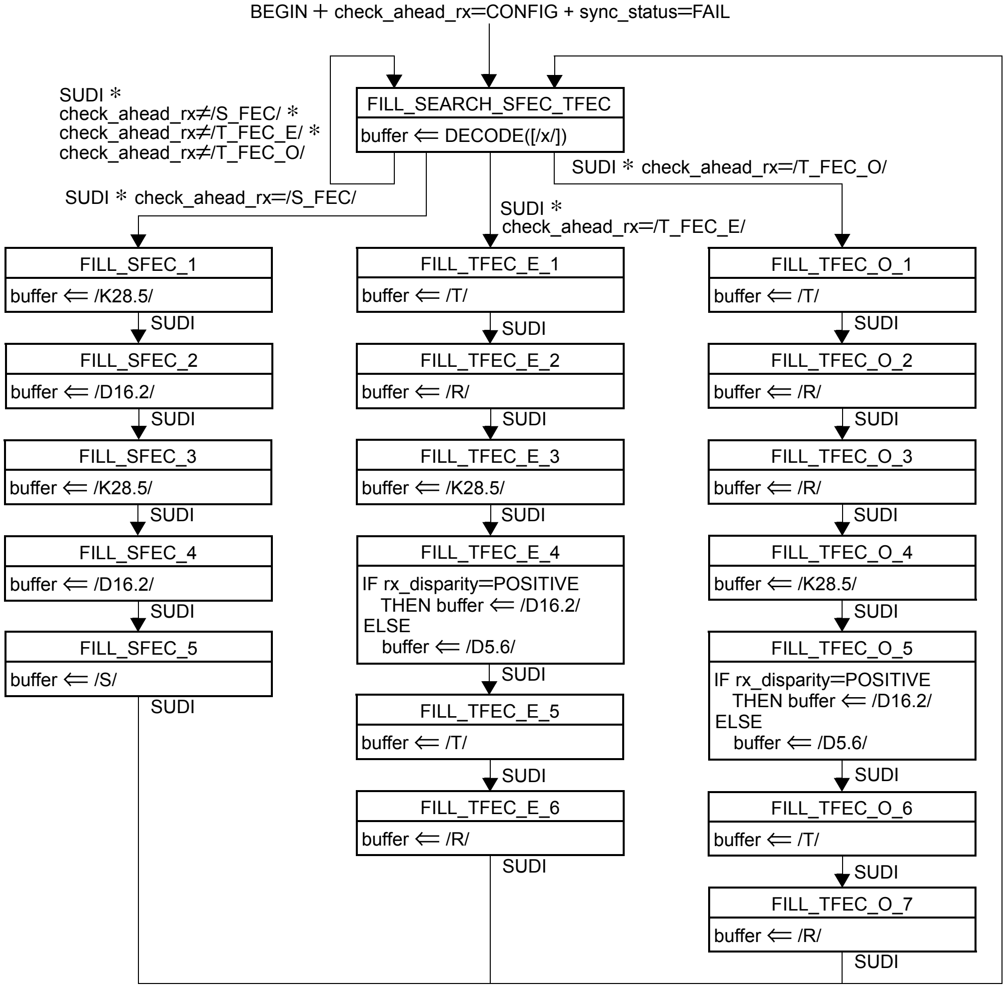


Figure 65–13—Receive buffer-fill state diagram

65.2.3.6.1 buffer_head_coding_violation_counter

32-bit counter. buffer_head_coding_violation_counter counts once for each invalid code-group received directly from the link. This variable is provided by a management interface that may be mapped to the 45.2.8.4 register (29.9.15:0).

65.2.3.6.2 FEC_corrected_blocks_counter

32-bit counter. FEC_corrected_blocks_counter counts once for each corrected FEC blocks in the decoding. This variables is provided by a management interface that may be mapped to the 45.2.8.5 register (29.10.15:0).

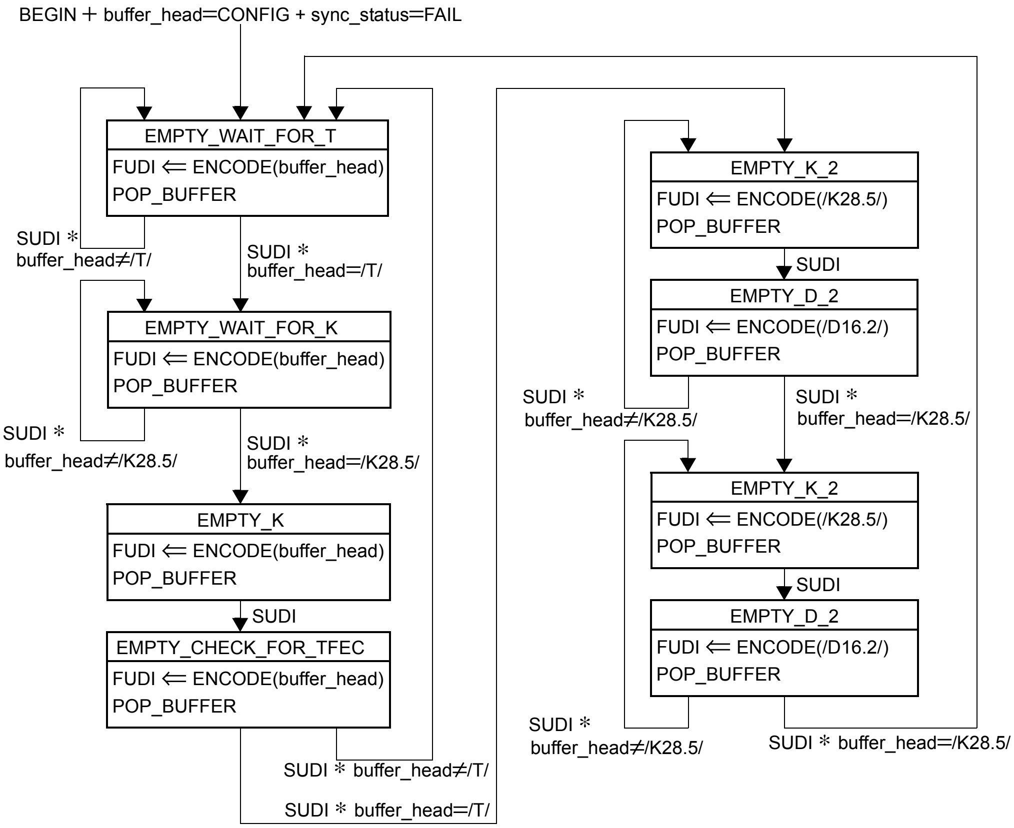


Figure 65–14—Receive buffer-empty state diagram

65.2.3.6.3 FEC_uncorrected_Blocks_counter

32-bit counter. FEC_uncorrected_blocks_counter counts once for each uncorrected FEC blocks in the decoding. This variables is provided by a management interface that may be mapped to the 45.2.8.6 register (29.11.15:0).

65.3 Extensions to PMA for 1000BASE-PX

In addition to the requirements defined in Clause 36, P2MP operation imposes the following requirement on the PMA sublayer of the OLT and ONU.

65.3.1 Extensions for 1000BASE-PX-U

65.3.1.1 Physical Medium Attachment (PMA) sublayer interfaces

In addition to the primitives of Clause 36, the following primitive is defined:

PMD_SIGNAL.request(tx_enable)

This primitive controls PMD emission of light. It is generated by the PCS's data detector (see 65.2.2.2.3) and the effect of its receipt is defined in 60.1.5.3. This primitive is received from the PCS and passed in timely fashion and without modification to the PMD. It takes the following parameter:

tx_enable	The tx_enable parameter can take one of two values, ON or OFF.

65.3.1.2 Loop-timing specifications for ONUs

ONUs shall operate at the same time basis as the OLT, i.e., the ONU TX clock tracks the ONU RX clock. Jitter transfer masks are defined in 60.8.

65.3.2 Extensions for 1000BASE-PX-D

65.3.2.1 CDR lock timing measurement

A PMA instantiated in an OLT becomes synchronized at the bit level within 400 ns (T_{CDR}) and code-group level within an additional 32 ns ($T_{code\_group\_alignment}$) of the appearance of a valid 1000BASE-X IDLE pattern at TP4 when the PMA_TX_CLK frequency is equal to twice the PMA_RX_CLK frequency.

65.3.2.1.1 Definitions

CDR Lock Time (denoted T_{CDR}) is defined as a time interval required by the receiver to acquire phase and frequency lock on the incoming data stream. T_{CDR} is measured as the time elapsed from the moment when electrical signal after the PMD at TP4 reaches the conditions specified in 60.9.13.2.1 for receiver settling time to the moment when the phase and frequency are recovered and jitter is maintained for a network with BER of no more than 10^{-12} for non-FEC systems, or no more than 10^{-4} for FEC enabled systems.

The combined value of measured T_{CDR} and $T_{code\_group\_alignment}$ shall not exceed 432 ns.

65.3.2.1.2 Test specification

Figure 60–2 illustrates the tests setup for the OLT PMA receiver (upstream) T_{CDR} time. The test assumes that there is an optical PMD transmitter at the ONU with well known parameters, having a fixed known T_{on} time as defined in 60.9.13.1, and an optical PMD receiver at the OLT with well-known parameters, having a fixed known $T_{receiver\_settling}$ time as defined in 60.9.13.2. After T_{on} + $T_{receiver\_settling}$ time the parameters at TP4 reach within 15% of their steady state values.

Measure T_{CDR} as the time from the TX_ENABLE assertion, minus the known T_{on} + $T_{receiver\_settling}$ time, to the time the electrical signal at the output of the PMA reaches up to phase difference from the input signal of the transmitting PMA, assuring BER of 10^{-12} for non-FEC systems, or BER of 10^{-4} for FEC enabled systems, and maintaining its jitter specifications. The signal throughout this test, is the 1000BASE-X IDLE pattern.

A non-rigorous way to describe this test setup would be (using a transmitter PMD at the ONU, with a known T_{on} time and a receiver PMD at the OLT, with a known $T_{receiver\_settling}$ time):

For a tested PMA receiver with a declared T_{CDR} time, measure the phase and jitter of the recovered PMA receiver signal after T_{CDR} time from the TX_ENABLE trigger minus the reference T_{on} + $T_{receiver\_settling}$ time, reassuring synchronization to the ONU PMA input signal and conformance to the specified steady state phase, frequency, and jitter values for BER of 10^{-12} for non-FEC systems, or BER of 10^{-4} for FEC enabled systems.

65.3.3 Delay variation requirements

The MPCP relies on strict timing based on the distribution of timestamps. The actual delay is implementation dependent but an implementation shall maintain a combined delay variation through RS, PCS, and PMA sublayers of no more than 16 bit times so as to comply with this mechanism.

65.4 Protocol implementation conformance statement (PICS) proforma for Clause 65, Extensions of the Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS) / Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction[21]

65.4.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 65, Extensions of the Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS) / Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

65.4.2 Identification

65.4.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

65.4.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 65, Extensions of the Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS) / Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[21] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

65.4.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*OLT	OLT functionality	65.1.1	Device supports functionality required for OLT	O.1	Yes [ ] No [ ]
*ONU	ONU functionality	65.1.1	Device supports functionailty required for ONU	O.1	Yes [ ] No [ ]
*FEC	Forward error correction for multipoint optical links	65.2.3	Device supports FEC for multipoint optical links	O	Yes [ ] No [ ]

65.4.4 PICS proforma tables for Extensions of Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS) / Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction

65.4.4.1 Operating modes of OLT MACs

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Unidirectional mode	65.1.2	Device operates in unidirectional transmission mode	OLT:M	Yes [ ]

65.4.4.2 ONU and OLT variables

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	enable variable	65.1.3.1	True for ONU MAC, TRUE for OLT MAC if enabled, FALSE for OLT MAC if not enabled	M	Yes [ ]
FS2	mode variable	65.1.3.1	0 for ONU MAC, 0 or 1 for enabled OLT MAC	M	Yes [ ]
FS3	logical_link_id variable	65.1.3.1	Set to 0x7FFF until ONU MAC is registered Set to any value for enabled OLT MAC. Set to any value other then 0x7FFF for registered ONU MAC	M	Yes [ ]
FS4	multicast LLID support	65.1.3.1	Supports multicast LLID, multicast_link_id variable	O	Yes [ ] No [ ]

65.4.4.3 Preamble mapping and replacement

Item	Feature	Subclause	Value/Comment	Status	Support
PM1	CRC-8 generation	65.1.3.2.3	CRC calculation produces same result as serial implementation	M	Yes [ ] No [ ]
PM2	CRC-8 initial value	65.1.3.2.3	CRC shift register initialized to 0x00 before each new calculations	M	Yes [ ] No [ ]
PM3	SLD parsing	65.1.3.3.1	If SLD is not found then discard packet	M	Yes [ ] No[ ]
PM4	SLD replacement	65.1.3.3.1	Replace SLD with preamble	M	Yes [ ] No [ ]
PM5	LLID matching	65.1.3.3.2	If LLID does not match then discard packet	M	Yes [ ] No [ ]
PM6	multicast LLID matching	65.1.3.3.2	If multicast LLID matches accept the packet	*FS4:M	Yes [ ] No [ ]
PM7	LLID Replacement	65.1.3.3.2	Replace LLID with preamble	M	Yes [ ] No [ ]
PM8	CRC-8 checking	65.1.3.3.3	If CRC does not match then discard packet	M	Yes [ ] No [ ]
PM9	CRC-8 replacement	65.1.3.3.3	Replace CRC with preamble	M	Yes [ ] No [ ]

65.4.4.4 Data detection

Item	Feature	Subclause	Value/Comment	Status	Support
DD1	Buffer depth	65.2.2.1	Depth sufficient to turn on laser and settle receiver	ONU:M	Yes [ ] No [ ]
DD2	OLT laser control	65.2.2.2.3	Always takes the value ON	OLT:M	Yes [ ] No [ ]
DD3	State diagrams	65.2.2.3	Meets the requirements of Figure 65–6	ONU:M	Yes [ ] No[ ]

65.4.4.5 FEC requirements

Item	Feature	Subclause	Value/Comment	Status	Support
FE1	FEC Coding Choice	65.2.3	If FEC is used, it is this one	FEC:M	Yes [ ] No [ ]
FE2	Uncorrectable block replacement	65.2.3.1	Replace all code-groups in an uncorrectable block with /V/	FEC:M	Yes [ ] No [ ]

65.4.4.6 FEC State diagrams

Item	Feature	Subclause	Value/Comment	Status	Support
SM1	Transmit	65.2.3.5.1	Meets the requirements of Figure 65–11	FEC:M	Yes [ ]
SM2	Receive synchronization	65.2.3.5.2	Meets the requirements of Figure 65–12	FEC:M	Yes [ ]
SM3	Receive	65.2.3.5.3	Meets the requirements of Figure 65–13 for buffer fill and Figure 65–14 for buffer empty	FEC:M	Yes [ ]

65.4.4.7 PMA

Item	Feature	Subclause	Value/Comment	Status	Support
BMC1	Loop Timing	65.3.1.2	ONU RX clock tracks OLT TX clock	ONU:M	Yes [ ] No [ ]

65.4.4.8 OLT Receiver

Item	Feature	Subclause	Value/Comment	Status	Support
OR1	Code-group synchronization delay	65.3.2.1.1	$T_{CDR} + T_{code\_group\_alignment} \leq 432$ ns	M	Yes [ ] No [ ]

65.4.4.9 Delay variation

Item	Feature	Subclause	Value/Comment	Status	Support
DV1	Delay variation	65.3.3	Combined delay variation through RS, PCS, and PMA sublayers is limited to 16 bit times	M	Yes [ ] No [ ]

66. Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport

In the absence of unidirectional operation, the sublayers in this clause are precisely the same as their equivalents in Clause 24, Clause 36, and Clause 46. Otherwise, this clause describes additions and modifications to the 100BASE-X, 1000BASE-X, 10GBASE-R, 10GBASE-W, and 10GBASE-X Physical Layers, making them capable of unidirectional operation, which is required to initialize a 1000BASE-PX network, and allows the transmission of Operations, Administration and Management (OAM) frames regardless of whether the PHY has determined that a valid link has been established.

However, unidirectional operation may only be enabled under very limited circumstances. Before enabling this mode, the MAC shall be operating in full-duplex mode and Auto-Negotiation, if applicable, shall be disabled. In addition, the OAM sublayer above the MAC (see Clause 57) shall be present and enabled or (for 1000BASE-X), the PCS shall be part of a 1000BASE-PX-D PHY (see Clause 60 and Clause 64). Unidirectional operation shall not be invoked for a PCS that is part of a 1000BASE-PX-U PHY (except for out-of-service test purposes or where the PON contains just one ONU). Failure to follow these restrictions results in an incompatibility with the assumptions of IEEE 802.1 protocols, a PON that cannot initialize, or collisions, which are unacceptable in the P2MP protocol.

66.1 Modifications to the physical coding sublayer (PCS) and physical medium attachment (PMA) sublayer, type 100BASE-X

66.1.1 Overview

This subclause specifies the 100BASE-X PCS and PMA for support of subscriber access networks.

66.1.2 Functional specifications

The 100BASE-X PCS and PMA for subscriber access networks shall conform to the requirements of the 100BASE-X PCS specified in 24.2 and the 100BASE-X PMA specified in 24.3 with the following exception: The 100BASE-X PCS for subscriber access networks may have the ability to transmit data regardless of whether the PHY has determined that a valid link has been established. The following are the detailed changes to Clause 24 in order to support this additional ability.

66.1.2.1 Variables

Insert a new variable among those already described in 24.2.3.2:

mr_unidirectional_enable

A control variable that enables the unidirectional mode of operation. This variables is provided by a management interface that may be mapped to the Clause 22 Control register Unidirectional enable bit (0.5).

Values: FALSE; Unidirectional capability is not enabled
TRUE; Unidirectional capability is enabled

66.1.2.2 Transmit state diagram

The description of the transmit state diagram is changed to include the contribution of the new mr_unidirectional_enable variable. The third paragraph of 24.2.4.2 is changed to read (~~strikethroughs~~ show deleted text and underscores show inserted text):

> The indication of link_status ≠ OK by the ~~PMA at any time~~ PMA, when mr_unidirectional_enable = FALSE, causes an immediate transition to the IDLE state and supersedes any other Transmit process operations. When mr_unidirectional_enable = TRUE, the Transmit process ignores the value of link_status. This enables the ability to transmit data from the MII when link_status ≠ OK.

Additionally, the functionality of Figure 24–13 shall be changed as represented by Figure 66–1.

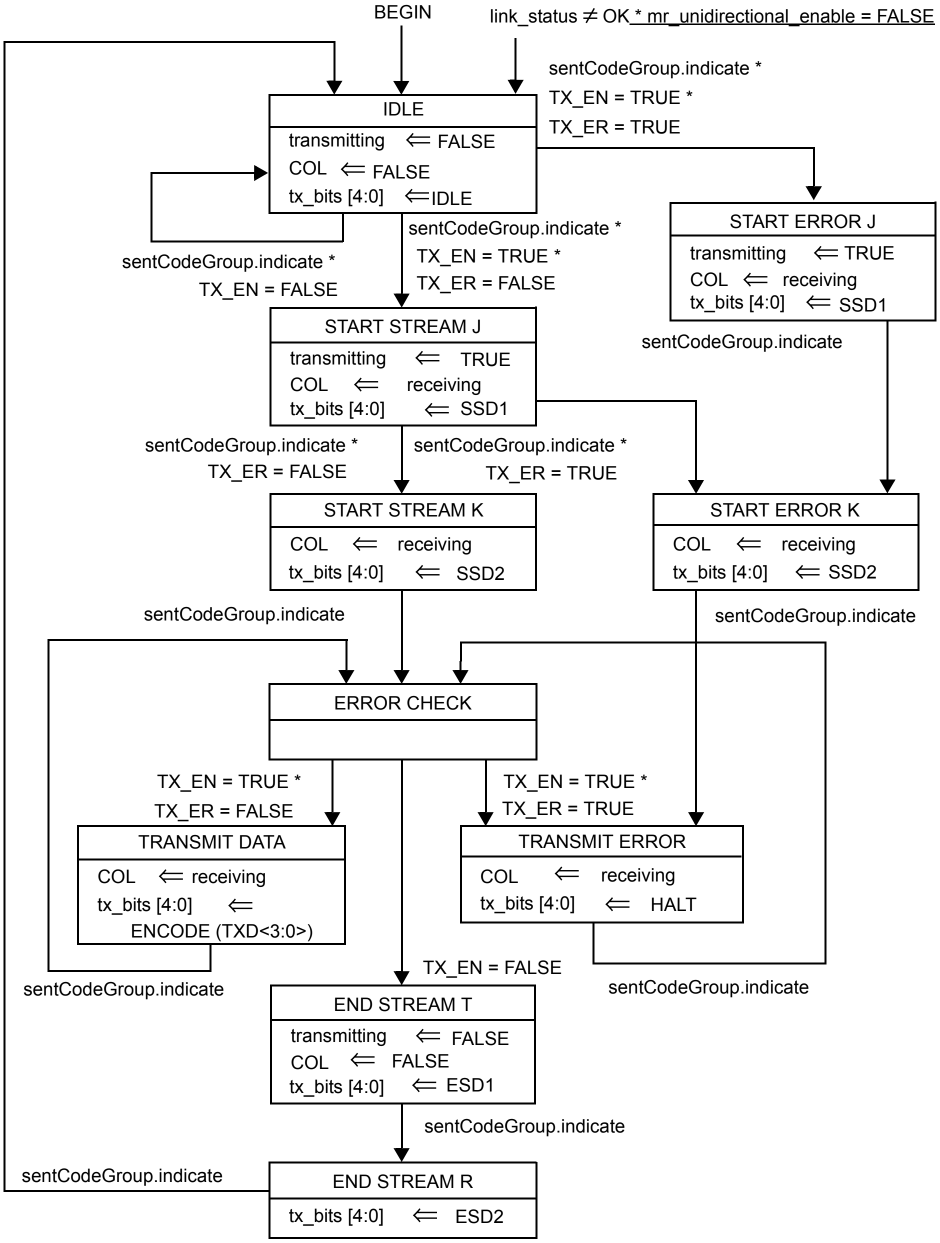

Figure 66–1—Transmit state diagram

66.1.2.3 Far-end fault generate

The description of the far-end fault generate state diagram is also changed to include the contribution of the new mr_unidirectional_enable variable. The first paragraph of 24.3.4.5 is changed to read (~~strikethroughs~~ show deleted text and <u>underscores</u> show inserted text):

> Far-End Fault Generate simply passes tx_code-bits to the TX process when signal_status=ON <u>or when mr_unidirectional_enable=TRUE</u>. When signal_status=OFF <u>and mr_unidirectional_enable=FALSE</u>, it repetitively generates each cycle of the Far-End Fault Indication until signal_status is reasserted <u>or mr_unidirectional_enable is set to TRUE</u>.

Additionally, the functionality of Figure 24–16 shall be changed as represented by Figure 66–2.

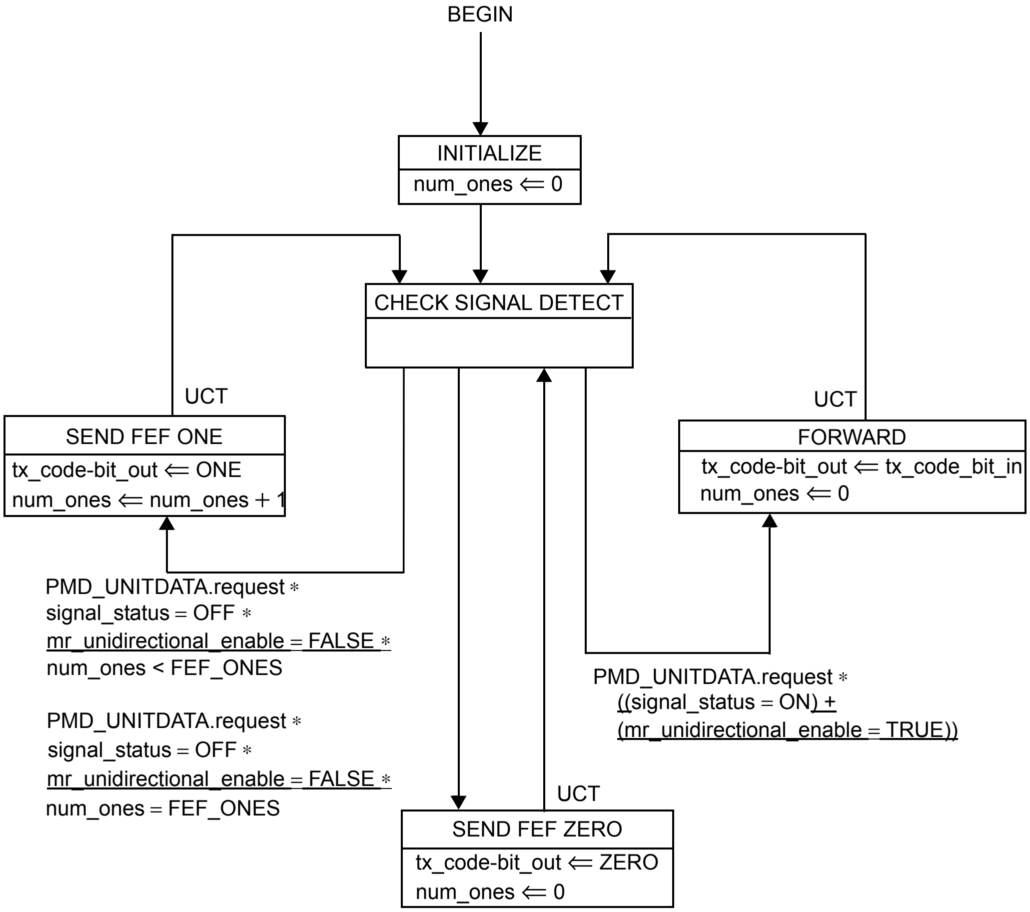

Figure 66–2—Far-End Fault Generate state diagram

66.2 Modifications to the physical coding sublayer (PCS) and physical medium attachment (PMA) sublayer, type 1000BASE-X

66.2.1 Overview

This subclause specifies the 1000BASE-X PCS and PMA for support of subscriber access networks.

66.2.2 Functional specifications

The 1000BASE-X PCS for subscriber access networks shall conform to the requirements of the 1000BASE-X PCS specified in 36.2 with the following exception: The 1000BASE-X PCS for subscriber access networks may have the ability to transmit data regardless of whether the PHY has determined that a valid link has been established. The 1000BASE-X PMA for subscriber access networks shall conform to the requirements of the 1000BASE-X PMA specified in 36.3 with no changes. The following are the detailed changes to Clause 36 in order to support this additional ability.

66.2.2.1 Variables

Insert a new variable among those already described in 36.2.5.1.3:

mr_unidirectional_enable

A control variable that enables the unidirectional mode of operation. This variable is provided by a management interface that may be mapped to the Clause 22 Control register Unidirectional enable bit (0.5).

Values: FALSE; Unidirectional capability is not enabled
TRUE; Unidirectional capability is enabled

Additionally, modify the existing xmit variable from 36.2.5.1.3 as follows (~~strikethroughs~~ show deleted text and underscores show inserted text):

xmit

When mr_unidirectional_enable=FALSE, xmit is d~~D~~efined in 37.3.1.1. When mr_unidirectional_enable=TRUE, xmit always takes the value DATA.

66.2.2.2 Transmit

The description of the transmit state diagram is changed to include the contribution of the new mr_unidirectional_enable variable. The second paragraph of 36.2.5.2.1 is changed to read (~~strikethroughs~~ show deleted text and underscores show inserted text):

> The Transmit ordered set process continuously sources ordered sets to the Transmit code-group process. When mr_unidirectional_enable = TRUE, the Auto-Negotiation process xmit flag always takes the value DATA and the Auto-Negotiation process is never invoked. Otherwise, when initially invoked, and when the Auto-Negotiation process xmit flag indicates CONFIGURATION, the Auto-Negotiation process is invoked. When the Auto-Negotiation process xmit flag indicates IDLE, and between packets (as delimited by the GMII), /I/ is sourced. Upon the assertion of TX_EN by the GMII when the Auto-Negotiation process xmit flag indicates DATA, the SPD ordered set is sourced. Following the SPD, /D/ code-groups are sourced until TX_EN is deasserted. Following the de-assertion of TX_EN, EPD ordered sets are sourced. If TX_ER is asserted when TX_EN is deasserted and carrier extend error is not indicated by TXD, /R/ ordered sets are sourced for as many GTX_CLK periods as TX_ER is asserted with a delay of two GTX_CLK periods to first source the /T/ and /R/ ordered sets. If carrier extend error is indicated by TXD during carrier extend, /V/ ordered sets are sourced. If TX_EN and TX_ER are both de-asserted, the /R/ ordered set may be sourced, after which the sourcing of /I/ is resumed. If, while TX_EN is asserted, the TX_ER signal is asserted, the /V/ ordered set is sourced except when the SPD ordered set is selected for sourcing.

66.2.2.3 Transmit state diagram

The 1000BASE-X PCS for subscriber access networks shall implement the transmit process as depicted in Figure 36–5 and Figure 36–6, including compliance with the associated state variables as specified in 36.2.5.1 and as modified in 66.2.2.1.

66.3 Modifications to the reconciliation sublayer (RS) for P2P 10 Gb/s operation

66.3.1 Overview

This subclause specifies the 10 Gb/s RS for support of P2P subscriber access networks.

66.3.2 Functional specifications

The 10 Gb/s RS for subscriber access networks shall conform to the requirements of the 10 Gb/s RS specified in Clause 46 with the following exception: The 10 Gb/s RS for subscriber access networks may have the ability to transmit data regardless of whether the PHY has determined that a valid link has been established. The following are the detailed changes to Clause 46 in order to support this additional ability.

66.3.2.1 Link fault signaling

The description of the link fault signaling functional specification is changed to include the contribution of the new mr_unidirectional_enable variable. The second paragraph of 46.3.4 is changed to read (~~strikethroughs~~ show deleted text and underscores show inserted text):

> Sublayers within the PHY are capable of detecting faults that render a link unreliable for communication. Upon recognition of a fault condition a PHY sublayer indicates Local Fault status on the data path. When this Local Fault status reaches an RS, the RS tests the unidirectional_enable variable. If this variable is FALSE, the RS stops sending MAC data, and continuously generates a Remote Fault status on the transmit data path (possibly truncating a MAC frame being transmitted). If this variable is TRUE, the RS continues to allow the transmission of MAC data but replaces IPG with a Remote Fault status. When Remote Fault status is received by an RS, the RS tests the unidirectional_enable variable. If this variable is FALSE, the RS stops sending MAC data, and continuously generates Idle control characters. If this variable is TRUE, the RS continues to allow the transmission of MAC data. When the RS no longer receives fault status messages, it returns to normal operation, sending MAC data.

66.3.2.2 Variables

Insert a new variable among those already described in 46.3.4.2:

unidirectional_enable

A control variable that enables the unidirectional mode of operation.

Values: FALSE; Unidirectional capability is not enabled
TRUE; Unidirectional capability is enabled

66.3.2.3 State diagram

The description of what the RS outputs onto TXC<3:0> and TXD<31:0> is changed to include the contribution of the new mr_unidirectional_enable variable. The lettered list of 46.3.4.3 is changed to read (~~strikethroughs~~ show deleted text and underscores show inserted text):

a) link_fault = OK
The RS shall send MAC frames as requested through the PLS service interface. In the absence of MAC frames, the RS shall generate Idle control characters.

b) link_fault = Local Fault
If unidirectional_enable=FALSE, t~~T~~he RS shall continuously generate Remote Fault Sequence ordered sets.
If unidirectional_enable=TRUE, the RS shall send MAC frames as requested through the PLS service interface. After a MAC frame and before transition to generation of Remote Fault Sequence

the RS shall ensure a column of idles has been sent. In the absence of MAC frames, the RS shall generate Remote Fault Sequence ordered sets.

c) link_fault = Remote Fault
If unidirectional_enable=FALSE, t~~T~~he RS shall continuously generate Idle control characters.
If unidirectional_enable=TRUE, the RS shall send MAC frames as requested through the PLS service interface. In the absence of MAC frames, the RS shall generate Idle control characters.

66.4 Modifications to the RS for P2MP 10 Gb/s operation

66.4.1 Overview

This subclause specifies the 10 Gb/s RS for support of P2MP subscriber access networks.

66.4.2 Functional specifications

The 10 Gb/s RS for P2MP subscriber access networks shall conform to the requirements of the 10 Gb/s RS specified in Clause 46 with the following exception: The 10 Gb/s RS for P2MP subscriber access networks may have the ability to transmit data regardless of whether the PHY has determined that a valid link has been established. The following are the detailed changes to Clause 46 in order to support this additional ability.

66.4.2.1 Link fault signaling

The description of the link fault signaling functional specification is changed to include the contribution of the new unidirectional_enable variable. The second paragraph of 46.3.4 is changed to read (~~strikethroughs~~ show deleted text and underscores show inserted text):

Sublayers within the PHY are capable of detecting faults that render a link unreliable for communication. The nature of the P2MP link allows for some of these fault conditions to be ignored. Upon recognition of a fault condition a PHY sublayer indicates Local Fault status on the data path. When this Local Fault status reaches an RS, the RS tests the unidirectional_enable variable. If this variable is FALSE, the RS stops sending MAC data, and continuously generates ~~a Remote Fault status~~ Idle control characters on the transmit data path (possibly truncating a MAC frame being transmitted). If this variable is TRUE, the RS continues to allow the transmissions of MAC data. When Remote Fault status is received by an RS, the RS tests the unidirectional_enable variable. If this variable is FALSE, the RS stops sending MAC data, and continuously generates Idle control characters. If this variable is TRUE, the RS continues to allow the transmission of MAC data. When the RS no longer receives fault status messages, it returns to normal operation, sending MAC data.

66.4.2.2 Variables

Insert a new variable among those already described in 46.3.4.2:
unidirectional_enable
A control variable that enables the unidirectional mode of operation.
Values:FALSE; Unidirectional capability is not enabled
TRUE; Unidirectional capability is enabled

66.4.2.3 State diagram

The description of what the RS outputs onto TXC<3:0> and TXD<31:0> is changed to include the contribution of the new unidirectional_enable variable. The lettered list of 46.3.4.3 is changed to read (~~strikethroughs~~ show deleted text and underscores show inserted text):

a) link_fault = OK
The RS shall send MAC frames as requested through the PLS service interface. In the absence of MAC frames, the RS shall generate Idle control characters.

b) link_fault = Local Fault
If unidirectional_enable = FALSE, t~~T~~he RS shall continuously generate Idle control characters~~Remote Fault Sequence ordered sets~~.
If unidirectional_enable = TRUE, the RS shall send MAC frames as requested through the PLS service interface. In the absence of MAC frames, the RS shall generate Idle control characters.

c) link_fault = Remote Fault
If unidirectional_enable = FALSE, t~~T~~he RS shall continuously generate Idle control characters.
If unidirectional_enable = TRUE, the RS shall send MAC frames as requested through the PLS service interface. In the absence of MAC frames, the RS shall generate Idle control characters.

66.5 Protocol implementation conformance statement (PICS) proforma for Clause 66, Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport[22]

66.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 66, Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

66.5.2 Identification

66.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

66.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 66, Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[22] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

66.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*PUNI	Unidirectional operation	66	Device supports unidirectional operation	O	Yes [ ] No [ ]
*HUN	100BASE-X functionality	66.1	Device supports functionality required for 100BASE-X PHY for subscriber access networks	O	Yes [ ] No [ ]
*GIG	1000BASE-X functionality	66.2	Device supports functionality required for 1000BASE-X PCS for subscriber access networks	O	Yes [ ] No [ ]
*XG	10 Gb/s functionality	66.3	Device supports functionality required for 10 Gb/s RS for subscriber access networks	O	Yes [ ] No [ ]
*XP2MP	10 Gb/s P2MP operation	66.4	Device supports 10 Gb/s P2MP operation	O	Yes [ ] No [ ]

66.5.4 PICS proforma tables for Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport

66.5.4.1 Maintaining compatibility with IEEE 802.1 protocols

Item	Feature	Subclause	Value/Comment	Status	Support
MC1	Unidirectional mode enabled	66	Full duplex and disable AutoNeg and [(OAM present and enabled) or 1000BASE-PX-D] and not 1000BASE-PX-U	M	Yes [ ] No [ ]

66.5.4.2 Extensions of the 100BASE-X PHY

Item	Feature	Subclause	Value/Comment	Status	Support
H1	Integrates 100BASE-X PCS and PMA	66.1.2	See Clause 24	HUN:M	Yes [ ]
H2	Transmit state diagram	66.1.2.2	Replaces Figure 24–8	PUNI* HUN:M	Yes [ ]
H3	Far-End Fault Generate state diagram	66.1.2.3	Replaces Figure 24–16	PUNI* HUN:M	Yes [ ]

66.5.4.3 Extensions of the 1000BASE-X PHY

Item	Feature	Subclause	Value/Comment	Status	Support
G1	Integrates 1000BASE-X PCS and PMA	66.2.2	See Clause 36	GIG:M	Yes [ ]
G2	Transmit state diagram	66.2.2.3	As modified by the new variables	PUNI* GIG:M	Yes [ ]

66.5.4.4 Extensions of the 10 Gb/s P2P RS

Item	Feature	Subclause	Value/Comment	Status	Support
LF1	Integrates 10 Gb/s RS	66.3.2	See Clause 46	XG:M	Yes [ ]
LF2	link_fault = OK and MAC frames	66.3.2.3	RS services MAC frame transmission requests	PUNI* XG:M	Yes [ ] No [ ]
LF3	link_fault = OK and no MAC frames	66.3.2.3	In absence of MAC frames, RS transmits Idle control characters	PUNI* XG:M	Yes [ ] No [ ]
LF4	link_fault = Local Fault and unidirectional_enable = FALSE	66.3.2.3	RS transmits continuous Remote Fault Sequence ordered sets	PUNI* XG:M	Yes [ ] No[ ]
LF5	link_fault = Local Fault and unidirectional_enable = TRUE and MAC frames	66.3.2.3	RS services MAC frame transmission requests	PUNI* XG:M	Yes [ ] No[ ]
LF6	link_fault = Local Fault and unidirectional_enable = TRUE and MAC frame ends	66.3.2.3	RS transmits one full column of IDLE after frame	PUNI* XG:M	Yes [ ] No[ ]
LF7	link_fault = Local Fault and unidirectional_enable = TRUE and no MAC frames	66.3.2.3	RS transmits continuous Remote Fault Sequence ordered sets	PUNI* XG:M	Yes [ ] No[ ]
LF8	link_fault = Remote Fault and unidirectional_enable = FALSE	66.3.2.3	RS transmits continuous Idle control characters	PUNI* XG:M	Yes [ ] No [ ]
LF9	link_fault = Remote Fault and unidirectional_enable = TRUE and MAC frames	66.3.2.3	RS services MAC frame transmission requests	PUNI* XG:M	Yes [ ] No [ ]
LF10	link_fault = Remote Fault and unidirectional_enable = TRUE and no MAC frames	66.3.2.3	RS transmits continuous Idle control characters	PUNI* XG:M	Yes [ ] No[ ]

66.5.4.5 Extensions of the 10 Gb/s P2MP RS

Item	Feature	Subclause	Value/Comment	Status	Support
PF1	Integrates 10 Gb/s P2MP RS	66.4.2	See Clause 76	PUNI * XP2MP:M	Yes [ ]
PF2	link_fault = OK and MAC frames	66.4.2.3	RS services MAC frame transmission requests	PUNI * XP2MP:M	Yes [ ] No [ ]
PF3	link_fault = OK and no MAC frames	66.4.2.3	In absence of MAC frames, RS transmits Idle control characters	PUNI * XP2MP:M	Yes [ ] No [ ]
PF4	link_fault = Local Fault and unidirectional_enable = FALSE	66.4.2.3	RS transmits continuous Idle control characters	PUNI * XP2MP:M	Yes [ ] No [ ]
PF5	link_fault = Local Fault and unidirectional_enable = TRUE and MAC frames	66.4.2.3	RS services MAC frame transmission requests	PUNI * XP2MP:M	Yes [ ] No [ ]
PF6	link_fault = Local Fault and unidirectional_enable = TRUE and no MAC frames	66.4.2.3	In absence of MAC frames, RS transmits Idle control characters	PUNI * XP2MP:M	Yes [ ] No [ ]
PF7	link_fault = Remote Fault and unidirectional_enable = FALSE	66.4.2.3	RS transmits continuous Idle control characters	PUNI * XP2MP:M	Yes [ ] No [ ]
PF8	link_fault = Remote Fault and unidirectional_enable = TRUE and no MAC frames	66.4.2.3	RS services MAC frame transmission requests	PUNI * XP2MP:M	Yes [ ] No [ ]
PF9	link_fault = Remote Fault and unidirectional_enable = TRUE and no MAC frames	66.4.2.3	In absence of MAC frames, RS transmits Idle control characters	PUNI * XP2MP:M	Yes [ ] No [ ]

67. System considerations for Ethernet subscriber access networks

67.1 Overview

This clause provides information on building Ethernet subscriber access networks, also referred to as “Ethernet in the First Mile” or EFM networks.

EFM encompasses a family of technologies that vary in media type and signaling speed. EFM is designed to be deployed in networks of one or multiple EFM media type(s) as well as interact with mixed 10/100/1000/10000 Mb/s Ethernet networks. Any network topology defined in IEEE Std 802.3 can be used within the subscriber premises and then connected to an Ethernet subscriber access network via an IEEE Std 802.1D compliant bridge, or a router.

Further, within a given EFM domain, the specific EFM technologies allow for a variety of topologies affording the subscriber access network maximum flexibility. For example, a 1000BASE-PX10 P2MP system with 16 ONUs can be built with a 1:16 splitter or as a tree-and-branch network utilizing more than one splitter.

The design of multiple-domain networks is governed by the rules defining each of the transmission systems incorporated into the design. The physical size of a network is limited by the characteristics of individual network components. These characteristics include the media lengths and type.

Table 67–1 summarizes the various EFM media characteristics.

67.2 Discussion and examples of EFM P2MP topologies

This subclause discusses EFM P2MP topologies. It details flexibility of trading off split ratio for link span. This subclause also shows some examples of different P2MP topologies.

67.2.1 Trade off between link span and split ratio

While the P2MP PMDs are nominally described in terms of a link span of either 10 km or 20 km with a 1:16 split ratio, other link spans and split ratios can be implemented provided that the requirements of Table 60–1 are met.

Table 67–1—Characteristics of the various EFM network media segments

Media type	Rate (Mb/s)	Number of PHYs per segment	Nominal reach (km)
Optical 100 Mb/s fiber segment (100BASE-LX10, 100BASE-BX10)	100	2	10
Optical 1000 Mb/s fiber segment (1000BASE-LX10, 1000BASE-BX10)	1000	2	10
Optical 1000 Mb/s P2MP segment (1000BASE-PX10)	1000[a]	17[b,c]	10
Optical 1000 Mb/s P2MP segment (1000BASE-PX20)		17[b,c]	20
Optical 1000 Mb/s P2MP segment (1000BASE-PX30)		33[b,c]	20
Optical 1000 Mb/s P2MP segment (1000BASE-PX40)		65[b,c]	20
Optical 10/1 Gb/s P2MP segment (10/1GBASE-PRX10)	10 000 / 1000[d]	17[b,c]	10
Optical 10/1 Gb/s P2MP segment (10/1GBASE-PRX20)		17[b,c]	20
Optical 10/1 Gb/s P2MP segment (10/1GBASE-PRX30)		33[b,c]	20
Optical 10/1 Gb/s P2MP segment (10/1GBASE-PRX40)		65[b,c]	20
Optical 10 Gb/s P2MP segment (10GBASE-PR10)	10 000[e]	17[b,c]	10
Optical 10 Gb/s P2MP segment (10GBASE-PR20)		17[b,c]	20
Optical 10 Gb/s P2MP segment (10/1GBASE-PR30)		33[b,c]	20
Optical 10 Gb/s P2MP segment (10GBASE-PR40)		65[b,c]	20
Copper high-speed segment (10PASS-TS)	10[f]	2	0.75
Copper long reach segment (2BASE-TL)	2[c]	2	2.7

[a] 1000 Mb/s in downstream direction, 1000 Mb/s in upstream direction.

[b] P2MP segments may be implemented with a trade off between link span and split ratio listed. Refer to 67.2.1.

[c] The number of PHYs in the P2MP segment includes the OLT PHY.

[d] 10 000 Mb/s in downstream direction, 1000 Mb/s in upstream direction (asymmetric data rate in 10/1G-EPON).

[e] 10 000 Mb/s in downstream direction, 10 000 Mb/s in upstream direction (symmetric data rate in 10/10G-EPON).

[f] Nominal rate stated at the nominal reach in this table. Rate and reach can vary depending on the plant. For 2BASE-TL please refer to Annex 63B for more information. For 10PASS-TS, please refer to Annex 62A for more information.

67.2.2 Single splitter topology

A P2MP topology implemented with a single optical splitter is shown in Figure 67–1.

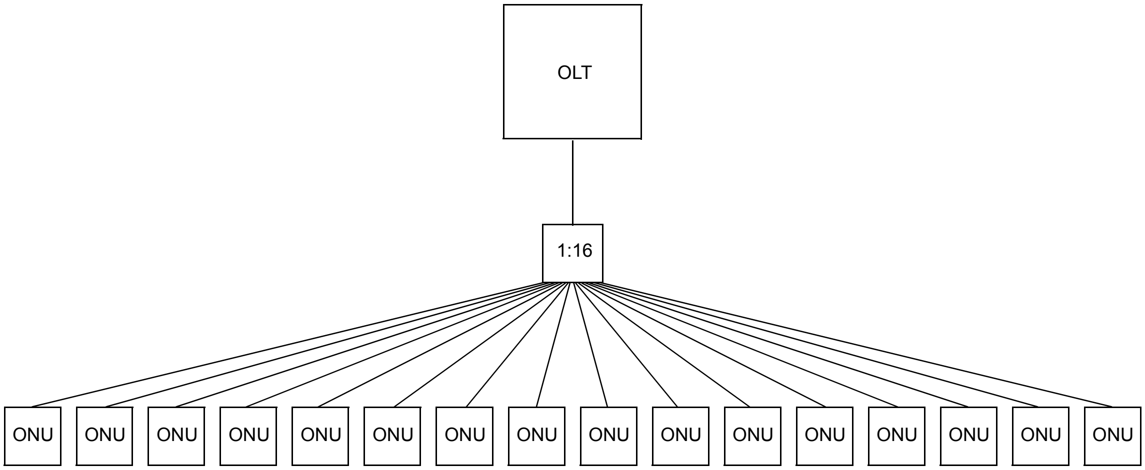


Figure 67–1—Single splitter topology

67.2.3 Tree-and-branch topology

A P2MP topology implemented with a tree-and-branches of optical splitters is shown in Figure 67–2.

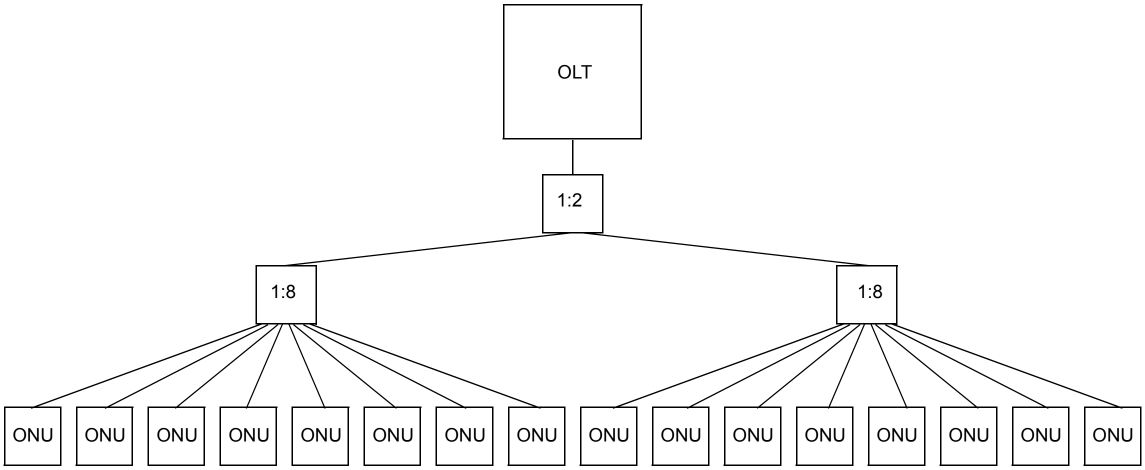


Figure 67–2—Tree-and-branch topology

67.2.4 Interoperability between certain 1000BASE-PX10 and 1000BASE-PX20

1000BASE-PX20-D PMD is interoperable with a 1000BASE-PX10-U PMD, this allows certain upgrade possibilities from 10 km to 20 km P2MP networks.

67.3 Hybrid media topologies

Hybrid media topologies, such as those shown in Figure 67–3, can be implemented using a combination of P2P or P2MP optical links and copper links.

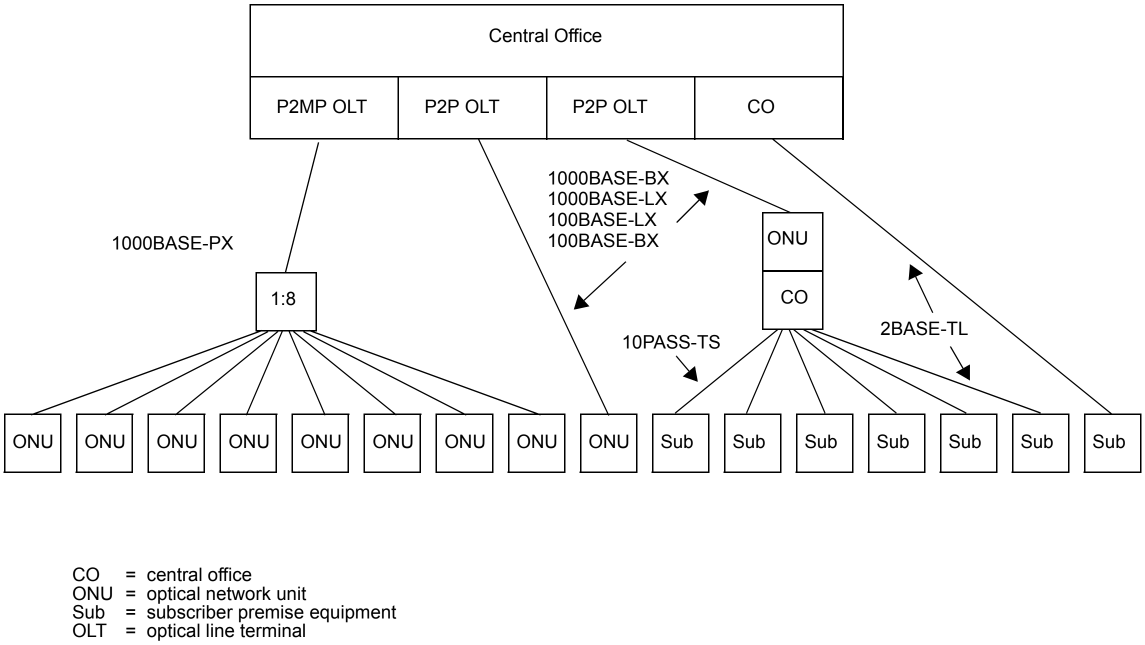


Figure 67–3—Hybrid media topologies

67.4 Topology limitations

The physical size of EFM networks is not limited by the round-trip collision propagation delay. Instead, the maximum link length between DTEs is limited by the signal transmission characteristics of the specific link.

67.5 Deployment restrictions for subscriber access copper

10PASS-TS and 2BASE-TL PHYs have been specified to allow deployment on public access networks. Non-loaded cable is a requirement of the signaling methods employed. The 10PASS-TS do not preclude coexistence with POTS. However, it is important that systems are designed and configured to comply with all appropriate regulatory, governmental and regional requirements. Refer to Annex 62A (10PASS-TS) and Annex 63A (2PASS-TL) for further information regarding configuration profiles.

67.6 Operations, Administration, and Maintenance

All P2P and emulated P2P links, including all of the EFM network media segments, support the optional OAM sublayer as defined in Clause 57. 2BASE-TL and 10PASS-TS PHYs do not support unidirectional links as defined in 57.2.6 (see 61.1).

67.6.1 Unidirectional links

Some Physical Layer devices have the optional ability to encode and transmit data while one direction of the link is non-operational.

This ability should be used only when the OAM sublayer is present and enabled or for a 1000BASE-PX-D, 10/1GBASE-PRX, or 10GBASE-PR PHY. Otherwise, MAC Client frames will be sent across a unidirectional link potentially causing havoc with bridge and other higher layer protocols. The feature should not be enabled for 1000BASE-PX-U, 10/1GBASE-PRX-U, or 10GBASE-PR-U PHYs in service, to avoid simultaneous transmission by more than one ONU.

67.6.2 Active and Passive modes

A device may be configured to be in either Active or Passive OAM mode. At least one end of a given link is required to be in Active mode.

In an access network, customer premises devices will commonly be configured as Passive devices. All other devices in an access network will commonly be configured as Active devices. For a detailed description of Active and Passive mode, refer to 57.2.6.

67.6.3 Link status signaling in P2MP networks

In P2MP networks the local_link_status parameter should reflect the status of a logical link associated with the underlying instance of Multipoint MAC Control. This is achieved by mapping the local_link_status parameter to variable 'registered' defined in 64.3.3.2 for 1 Gb/s P2MP links and in 77.3.3.2 for 10 Gb/s links as follows:

local_link_status = OK if registered = true

local_link_status = FAIL if registered = false

68. Physical medium dependent (PMD) sublayer type 10GBASE-LRM

68.1 Overview

This clause specifies the 10GBASE-LRM PMD and the associated multimode fiber media. In order to form a complete Physical Layer, the PMD is combined with the sublayers appropriate for 10GBASE-R, as specified in Table 52–2, and optionally with the management functions that may be accessible through the management interface defined in Clause 45.

Figure 68–1 depicts the relationships of the PMD (shown hatched) with other sublayers and the ISO/IEC Open System Interconnection (OSI) reference model. Clause 44 contains an introduction to 10 Gigabit Ethernet and the relationship of the 10GBASE-LRM PMD to other sublayers. Further relevant information may be found in Clause 1 (i.e., terminology and conventions, references, definitions and abbreviations) and Annex A (i.e., bibliography, entries referenced here in the format [B*n*]).

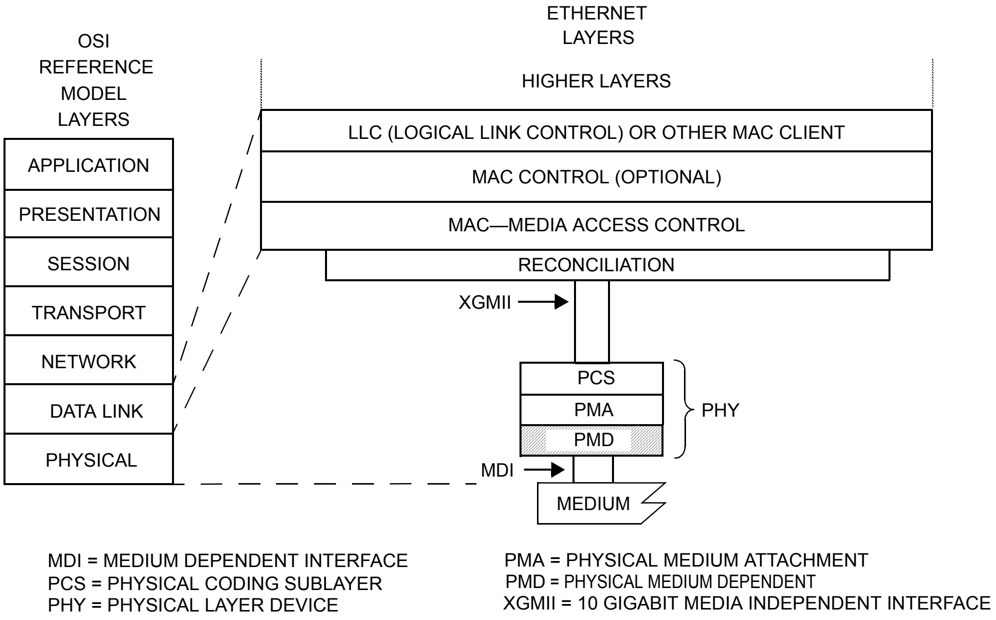


Figure 68–1—10GBASE-LRM PMD relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

68.1.1 Physical Medium Dependent (PMD) sublayer service interface

The PMD service interface is the 10GBASE-R PMD service interface as described in 52.1.1.

68.2 Delay constraints

An upper bound to the delay through the PMA and PMD is required for predictable operation of the MAC Control PAUSE operation. The PMA and PMD shall incur a round-trip delay (transmit and receive) of not more than 9216 bit times, or 18 pause_quanta, while including two meters of fiber. A description of overall system delay constraints and the definitions for bit times and pause_quanta can be found in 44.3.

68.3 PMD MDIO function mapping

If present, the 10GBASE-LRM PMD MDIO function mapping shall be as specified in 52.3.

68.4 PMD functional specifications

The 10GBASE-LRM PMD performs the transmit and receive functions that convey data between the PMD service interface and the MDI.

68.4.1 PMD block diagram

For the purposes of system conformance, the PMD sublayer is standardized at test points TP2 and TP3, as shown in Figure 68–2. The optical transmit signal is defined at the output end of a patch cord (TP2), of between 2 m and 5 m in length. The optical launch condition at TP2 is either the preferred launch or the alternative launch (at the user's choice), as specified in 68.5.1. A compliant PMD shall support both options. The launch is selected by using either a single-mode fiber offset-launch mode-conditioning patch cord or a regular multimode fiber patch cord inserted between the MDI and TP2, consistent with the media type. Unless specified otherwise, all transmitter measurements and tests defined in 68.6 are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3) that is the input to the MDI of the optical receiver. Unless specified otherwise, for all receiver measurements and tests defined in 68.6, the test stimulus is applied at TP3.

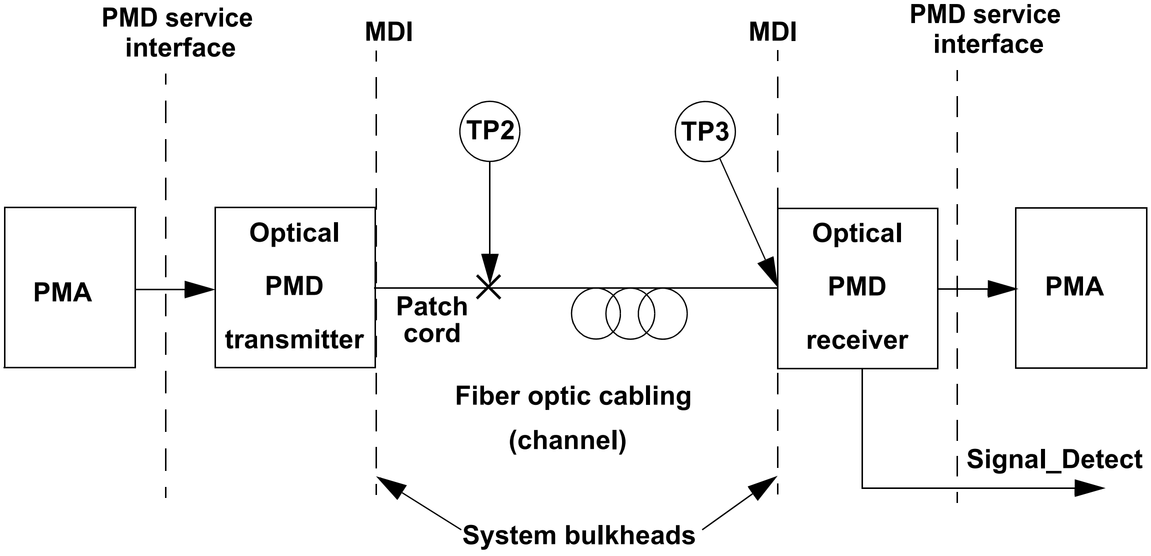


Figure 68–2—Block diagram

68.4.2 PMD transmit function

The PMD transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the optical specifications in this clause. The higher optical power level shall correspond to tx_bit = ONE.

68.4.3 PMD receive function

The PMD receive function shall convey the bits received from the MDI according to the optical specifications in this clause to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). The higher optical power level shall correspond to rx_bit = ONE.

68.4.4 PMD signal detect function

The PMD signal detect function shall report to the PMD service interface using the message PMD_SIGNAL.indication(SIGNAL_DETECT), which is signaled continuously. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence. If the MDIO interface is implemented, then PMD_global_signal_detect (1.10.0) shall be continuously set to the value of SIGNAL_DETECT as described in 45.2.1.9.7.

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 68–1. The PMD receiver is not required to verify whether a compliant 10GBASE-R signal is being received. This standard imposes no response time requirements on the generation of the SIGNAL_DETECT parameter.

Table 68–1—SIGNAL_DETECT value definition

Receive conditions	SIGNAL_DETECT value
Input average power < –30 dBm	FAIL
Compliant 10GBASE-R input signal with optical power in OMA > stressed sensitivity in OMA in Table 68–5	OK
All other conditions	Unspecified

As an unavoidable consequence of the requirements for the setting of the SIGNAL_DETECT parameter, implementations must provide adequate margin between the optical power level at which the SIGNAL_DETECT parameter is set to OK, and the inherent noise level of the PMD due to crosstalk, power supply noise, etc.

Various implementations of the signal detect function are permitted, including implementations that generate the SIGNAL_DETECT parameter values in response to the amplitude of the modulation of the received optical signal and implementations that respond to the average power of the received optical signal.

68.4.5 PMD_reset function

If the MDIO interface is implemented, and if PMD_reset is asserted, the PMD shall be reset as specified in 45.2.1.1.1.

68.4.6 PMD_fault function

If the MDIO is implemented, PMD_fault is the logical OR of PMD_receive_fault, PMD_transmit_fault, and any other implementation-specific fault.

68.4.7 PMD_global_transmit_disable function

The PMD_global_transmit_disable function is optional. When asserted, this function shall turn off the optical transmitter so that it meets the requirements of the average launch power of OFF transmitter in Table 68–3.

If a PMD_transmit_fault (optional) is detected, then the PMD_global_transmit_disable function should also be asserted.

If the MDIO interface is implemented, then this function shall map to the PMD_global_transmit_disable bit as specified in 45.2.1.8.7.

68.4.8 PMD_transmit_fault function

The PMD_transmit_fault function is optional. The faults detected by this function are implementation specific, but should not include the assertion of the PMD_global_transmit_disable function.

If a PMD_transmit_fault (optional) is detected, then the PMD_global_transmit_disable function should also be asserted.

If the MDIO interface is implemented, then this function shall be mapped to the PMD_transmit_fault bit as specified in 45.2.1.7.4.

68.4.9 PMD_receive_fault function

The PMD_receive_fault function is optional. PMD_receive_fault is the logical OR of NOT SIGNAL_DETECT and any implementation-specific fault.

If the MDIO interface is implemented, then this function shall contribute to the PMA/PMD receive fault bit as specified in 45.2.1.7.5.

68.5 PMD to MDI optical specifications

The operating ranges for 10GBASE-LRM are given in Table 68–2. A PMD that exceeds the operational range requirements given in this clause, while meeting all other specifications, is considered compliant.

Table 68–2—10GBASE-LRM fiber types and operating ranges

Multimode fiber type[a]	ISO/IEC 11801:2002 fiber type	Operating range (m)	Maximum channel insertion loss (dB)[b]
62.5 µm 160/500[c]		0.5 to 220	1.9
62.5 µm 200/500	OM1	0.5 to 220	1.9
50 µm 500/500	OM2	0.5 to 220	1.9
50 µm 400/400		0.5 to 100	1.7
50 µm 1500/500[d]	OM3	0.5 to 220	1.9

[a] Each fiber type is identified by its core diameter followed by a pair of OFL bandwidth values separated by "/". The OFL bandwidths are in MHz · km and are for 850 nm and 1300 nm respectively.
[b] Channel insertion loss includes cabled optical fiber attenuation and an allocation of 1.5 dB for connectors.
[c] 160/500, 62.5 µm fiber is commonly referred to as "FDDI-grade" fiber.
[d] The OM3 fiber specification includes the 850 nm laser launch bandwidth in addition to the OFL bandwidths.

68.5.1 Transmitter optical specifications

The 10GBASE-LRM transmitter shall meet the specifications given in Table 68–3 and Figure 68–3, per definitions in 68.6.

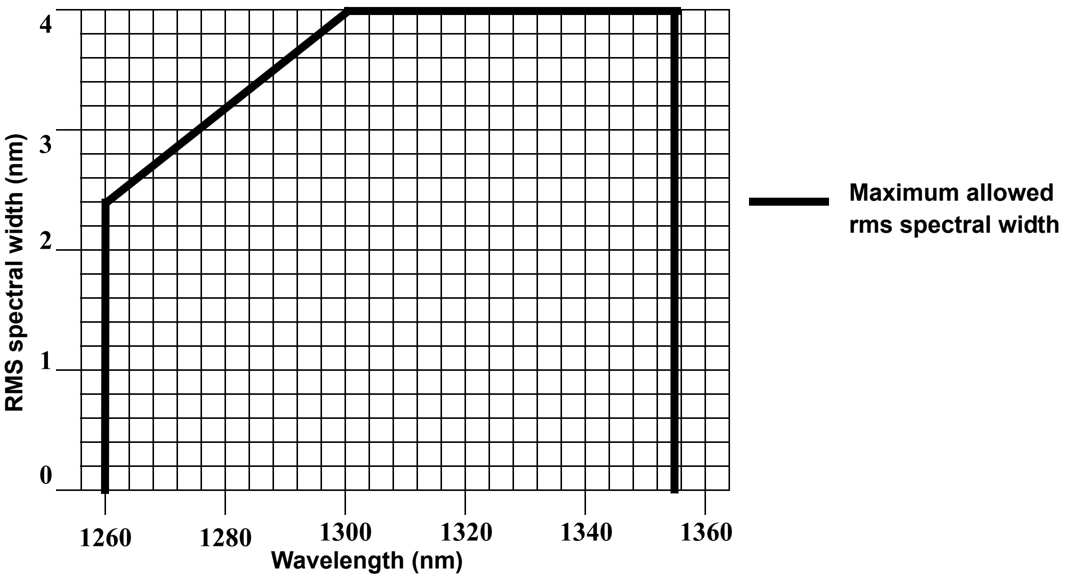


Figure 68–3—10GBASE-LRM Transmitter spectral limits

68.5.2 Characteristics of signal within, and at the receiving end of, a compliant 10GBASE-LRM channel (informative)

Table 68–4 gives the characteristics of a signal within, and at the receiving end of, a compliant 10GBASE-LRM channel. A signal with power in OMA and average power not within the ranges given cannot be compliant. However, a signal with power values within the ranges is not necessarily compliant.

68.5.3 Receiver optical specifications

The 10GBASE-LRM receiver shall meet the specifications given in Table 68–5, per definitions in 68.6.

68.5.3.1 Dynamic response

Channel responses are expected to vary with time at rates of up to 10 Hz. It is highly recommended that receivers tolerate such time varying channel responses.

68.6 Definitions of optical parameters and measurement methods

The following definitions and measurement methods apply to the transmitter and receiver optical parameters given in Table 68–3 and Table 68–5.

68.6.1 Test patterns and related subclauses for optical parameters

Compliance is to be achieved in normal operation. Table 68–6 gives the test patterns to be used in each measurement, unless otherwise specified, and also lists references to the subclauses in which each parameter is defined. The test patterns include pattern 1, pattern 2, pattern 3, and square waves, defined in 52.9.1.1 and 52.9.1.2, as well as the PRBS9 pattern.

NOTE—The longer test patterns are designed to emulate system operation; however, they do not form valid 10GBASE-R frames.

Table 68–3—10GBASE-LRM transmit characteristics

Description	Type	Value	Unit
Signaling speed	nom	10.3125	GBd
Signaling speed variation from nominal	max	± 100	ppm
Center wavelength	range	1260 to 1355	nm
RMS spectral width[a] at 1260 nm RMS spectral width between 1260 nm and 1300 nm RMS spectral width between 1300 nm and 1355 nm	max max max	2.4 Figure 68–3 4	nm nm nm
Launch power in OMA[b]	max	1.5	dBm
Launch power in OMA[b]	min	–4.5	dBm
Average launch power[b]	max	0.5	dBm
Average launch power[b]	min	–6.5	dBm
Average launch power[b] of OFF transmitter	max	–30	dBm
Extinction ratio	min	3.5	dB
Peak launch power[b][c]	max	3	dBm
$RIN_{20}OMA$	max	–128	dB/Hz
Eye mask parameters {X1, X2, X3, Y1, Y2, Y3}		{0.25, 0.40, 0.45, 0.25, 0.28, 0.80}	
Transmitter waveform and dispersion penalty (TWDP)	max	4.7	dB
Uncorrelated jitter (rms)	max	0.033	UI
Optical launch for OM1 and 160/500, 62.5 µm fiber Preferred[d] Encircled flux[e] for alternative launch	 — min min	 62.5 µm mode-conditioning patch cord, as specified in 68.9.3 30% within 5 µm radius 81% within 11 µm radius	
Optical launch for OM2, and 400/400, 50 µm fiber Preferred[d] Encircled flux[e] for alternative launch	 — min min	 50 µm mode-conditioning patch cord, as specified in 68.9.3 30% within 5 µm radius 81% within 11 µm radius	
Optical launch for OM3, 50 µm, fiber Encircled flux[e]	 min min	 30% within 5 µm radius 81% within 11 µm radius	
Optical return loss tolerance	min	20	dB

[a] RMS spectral width is the standard deviation of the spectrum.

[b] The OMA, average launch power and peak launch power specifications apply at TP2. This is after each type of patch cord. For information: Patch cord losses, between MDI and TP2, differ. The range of losses must be accounted for to ensure compliance to TP2.

[c] Peak optical power can be determined as the maximum value from the waveform capture for the TWDP test, or equivalent method.

[d] The PMD must support both the preferred and alternative launch types by the use of a single-mode fiber offset-launch mode-conditioning patch cord, or a regular multimode fiber patch cord, between the MDI and TP2.

[e] This encircled flux specification, measured per IEC 61280-1-4, defines the near field light distribution at TP2 when the MDI is coupled directly into a 50 µm patch cord and when the MDI is coupled directly into a 62.5 µm patch cord.

Table 68–4—Characteristics of signal within, and at the receiving end of, a compliant 10GBASE-LRM channel (informative)

Description	Type	Value	Unit
Highest power in OMA	max	1.5	dBm
Lowest power in OMA	min	–6.4	dBm
Highest average power	max	0.5	dBm
Lowest average power	min	–8.4	dBm
Peak power	max	3	dBm

68.6.2 Optical modulation amplitude (OMA)

For the purposes of Clause 68, OMA is defined by the measurement method given in 52.9.5, and as illustrated in Figure 68–4. The mean logic ONE and mean logic ZERO values are measured over the center 20% of the two time intervals of the square wave. The OMA is the difference between these two means.

NOTE—An estimate of the OMA value is provided by the variable Measured OMA in 68.6.6.2.

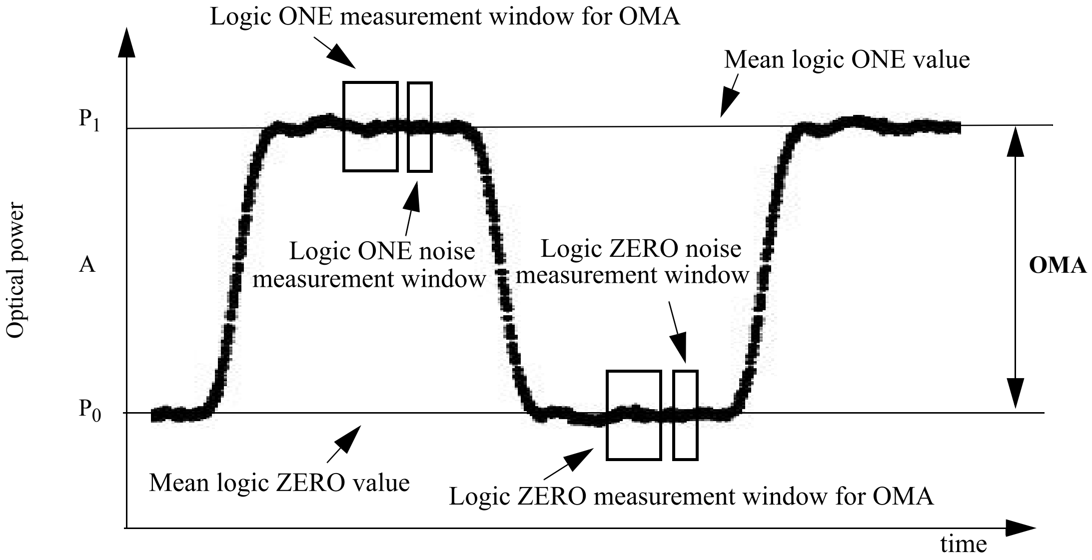


Figure 68–4—Positions of logic ZERO and logic ONE measurement windows for OMA and transmitter noise measurements

68.6.3 Extinction ratio measurement

The extinction ratio shall meet specifications according to 52.9.4.

NOTE—Extinction ratio and OMA are defined with different test patterns (see Table 68–6).

Table 68–5—10GBASE-LRM receive characteristics

Description	Type	Value	Unit
Signaling speed	nom	10.3125	GBd
Signaling speed variation from nominal	max	±100	ppm
Center wavelength	range	1260 to 1355	nm
Stressed sensitivity in OMA	—	–6.5	dBm
Stressed sensitivity in OMA for symmetrical test	—	–6	dBm
Overload in OMA	—	1.5	dBm
Conditions of comprehensive stressed receiver tests:			
Bandwidth of Gaussian white noise source[a]	min	10	GHz
Test transmitter signal to noise ratio, Q_{sq}[b]	—	26.3	
Tap spacing, Δt, of ISI generator	—	0.75	UI
Pre-cursor tap weights {A1, A2, A3, A4}	—	{0.158, 0.176, 0.499, 0.167}	
Symmetrical tap weights {A1, A2, A3, A4}	—	{0.00, 0.513, 0.00, 0.487}	
Post-cursor tap weights {A1, A2, A3, A4}	—	{0.254, 0.453, 0.155, 0.138}	
Conditions of simple stressed receiver test:			
Signal rise and fall times (20% to 80%)	—	115	ps
Conditions of receiver jitter tolerance test:			
Jitter frequency and peak to peak amplitude	—	(75, 5)	(kHz, UI)
Jitter frequency and peak to peak amplitude	—	(375, 1)	(kHz, UI)
Received average power for damage[c]	—	1.5	dBm
Receiver reflectance	max	–12	dB

[a] Bandwidth of Gaussian white noise source refers to the –3 dB (electrical) frequency of the noise spectrum before any subsequent filtering.

[b] Transmitter signal to noise ratio, Q_{sq}, is defined in 68.6.7 and its use here is qualified by 68.6.9.3.

[c] The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average received power level.

Table 68–6—Test-pattern definitions and related subclauses

Test	Pattern	Related subclause
Transmitter OMA (modulated optical power)	Square	68.6.2
Calibration of OMA for receiver tests	Square, eight ONEs and eight ZEROs	68.6.9 and 68.6.10

Table 68–6—Test-pattern definitions and related subclauses *(continued)*

Test	Pattern	Related subclause
Calibration of noise for receiver tests	Square, eight ONEs and eight ZEROs	68.6.9
Transmitter noise	Square	68.6.7
Transmitter uncorrelated jitter	1, 2, or PRBS9[a]	68.6.8
Extinction ratio	1 or 3	68.6.3
Average optical power	1 or 3	52.9.3
Transmitted waveform (eye mask)	1 or 3	68.6.5
Transmitter waveform and dispersion penalty (TWDP) Pattern 1 subsequence Pattern 1 subsequence key	1 or PRBS9[a] 348 bits, beginning at bit 3258 101010111011011, beginning immediately before the subsequence at bit 3243	68.6.6
Encircled flux	Not specified here	See IEC 61280-1-4
Wavelength, spectral width	1 or 3	52.9.2
Receiver jitter tolerance	1 or 3	68.6.11
Comprehensive stressed receiver sensitivity	2 or 3	68.6.9
Comprehensive stressed receiver overload	1 or 3	68.6.9
Simple stressed receiver sensitivity	1 or 3	68.6.10
Simple stressed receiver overload	1 or 3	68.6.10

[a] The PRBS9 pattern is optional. If used, it is generated by the polynomial $x^9 + x^5 + 1$ as specified in ITU-T O.153. The binary (0,1) data sequence $d(n)$ is given by $d(n) = d(n - 9) + d(n - 5)$, modulo 2. The pattern has a run of nine ones in its length of 511 bits.

68.6.4 Relationship between OMA, extinction ratio and average power (informative)

The relationship between OMA, extinction ratio and average power is described in 58.7.6. Note that the difference between Clause 68 and Clause 58 measurement methods for OMA causes the equations in 58.7.6 to become approximations for transmitter signals with undershoot, overshoot, or intersymbol interference. It is recommended that these equations not be used for signals at TP3. Figure 68–5 illustrates the approximate region of transmitter compliance and also the approximate relationships between OMA, extinction ratio, and average power.

68.6.5 Transmitter optical waveform—transmitter eye mask

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 68–6. Compliance is to be assured with pattern 1 or 3 defined in 52.9.1. Measurements during system operation or with other patterns, such as a $2^{23} - 1$ PRBS or a valid 10GBASE-R signal, are likely to give very similar results. The transmitter optical waveform of a port transmitting the test pattern specified in Table 68–6 shall meet specifications according to the methods specified below.

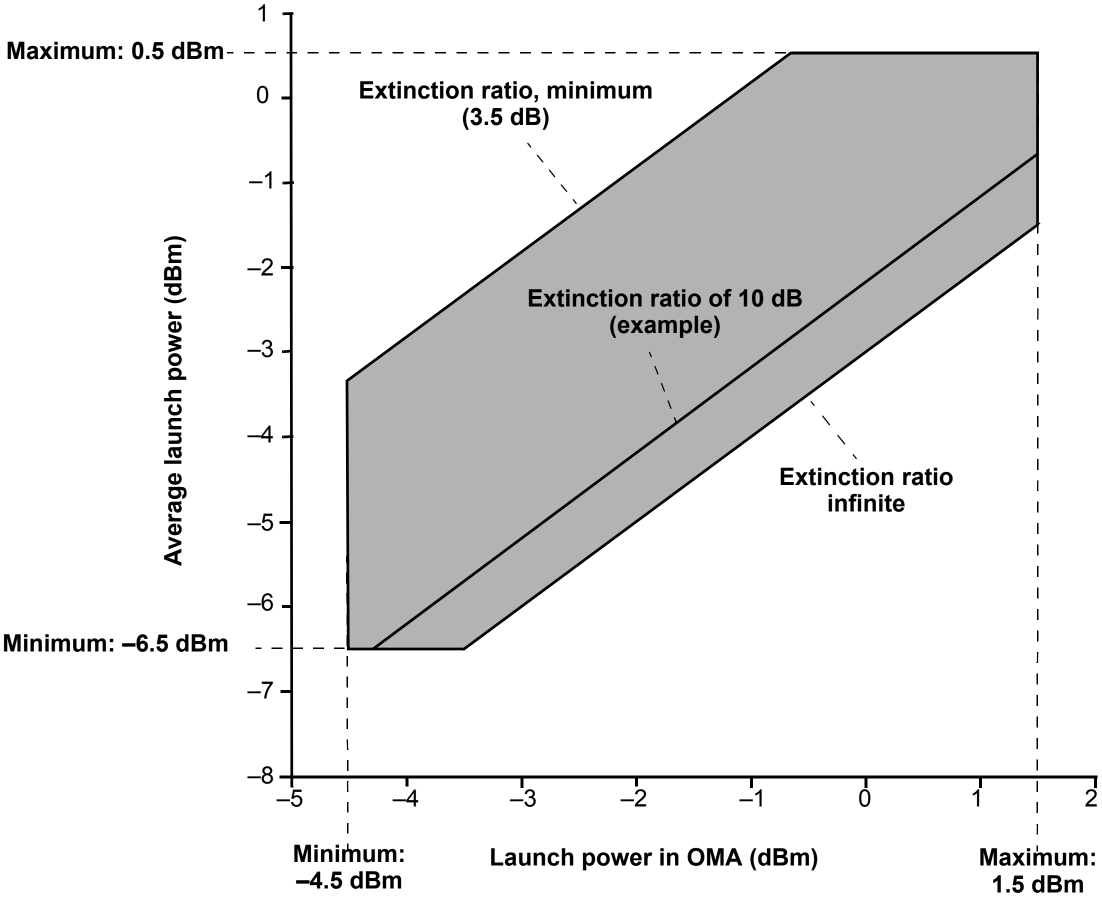


Figure 68–5—Graphical representation of approximate region of transmitter compliance (shown shaded) (informative)

Normalized amplitudes of 0 and 1 represent the amplitudes of logic ZERO and ONE respectively. These are defined by the means of the lower and upper halves of the central 0.2 UI of the eye. Normalized times of 0 and 1 on the unit interval scale are determined by the eye crossing means measured at the average value of the optical eye pattern. A clock recovery unit (CRU) should be used to trigger the oscilloscope for mask measurements, as shown in Figure 52–9. It should have a high-frequency corner bandwidth of 4 MHz and a slope of –20 dB/decade. The CRU tracks acceptable levels of low-frequency jitter and wander.

The eye is measured with respect to the mask using a receiver with the fourth-order Bessel-Thomson response with nominal f_r of 7.5 GHz as specified for STM-64 in ITU-T G.691, with the tolerances there specified. The Bessel-Thomson receiver is not intended to represent the noise filter used within a compliant optical receiver, but is intended to provide uniform measurement conditions at the transmitter. The nominal transfer function is given in Equation (52–2) and Equation (52–3).

The transmitter shall achieve a hit ratio lower than 5×10^{-5} hits per sample, where "hits" are the number of samples within the grey areas of Figure 68–6, and the sample count is the total number of samples from 0 UI to 1 UI. Some illustrative examples are provided in 68.6.5.1.

Further information on optical eye pattern measurement procedures may be found in IEC 61280-2-2.

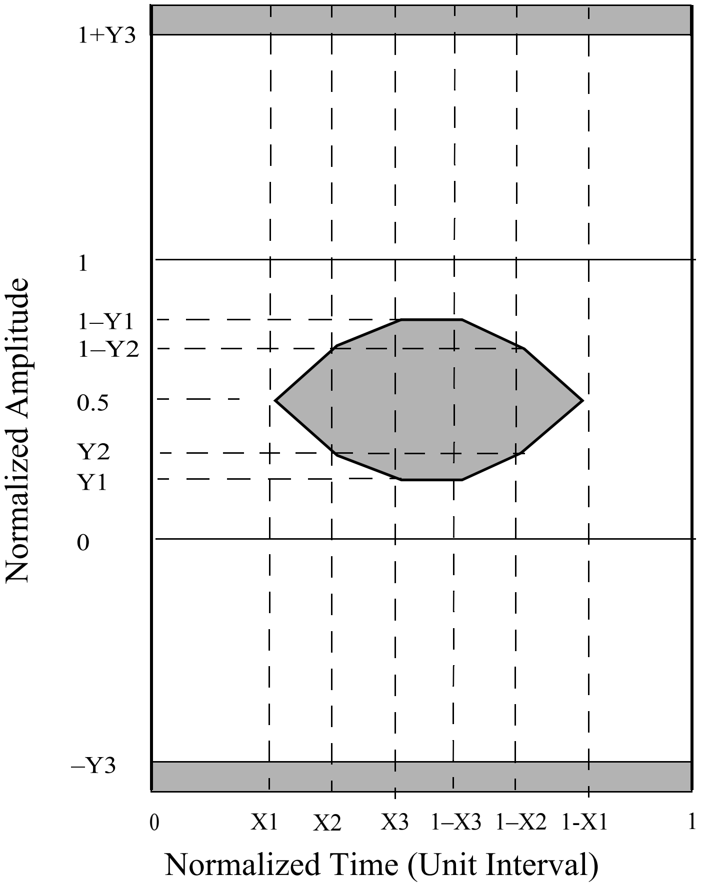


Figure 68–6—Transmitter eye mask definition

68.6.5.1 Transmitter eye mask acceptable hit count examples (informative)

If an oscilloscope records 1350 samples/screen, and the time-base is set to 0.2 UI per division with 10 divisions across the screen, and the measurement is continued for 200 waveforms, then a transmitter with an expectation of less than 6.75 hits is compliant. i.e.,

$$\frac{5 \times 10^{-5} \times 200 \times 1350}{0.2 \times 10} = 6.75 \qquad (68–1)$$

Likewise, if a measurement is continued for 1000 waveforms, then an expectation of less than 33.75 hits is compliant. An extended measurement is expected to give a more accurate result, and a single reading of 6 hits in 200 waveforms would not give a statistically significant pass or fail. Measurements to “zero hits,” which involve finding the position of the worst single sample in the measurement, have degraded reproducibility because random processes cause the position of such a single low-probability event to vary.

The hit ratio limit has been chosen to avoid misleading results due to transmitter and oscilloscope noise.

68.6.6 Transmitter waveform and dispersion penalty (TWDP)

The transmitter waveform shall meet the transmitter waveform and dispersion penalty (TWDP) specification given in Table 68–3.

TWDP is a measure of the deterministic dispersion penalty due to a particular transmitter with reference emulated multimode fibers and receiver. Figure 68–7 shows the TWDP measurement configuration. A waveform from TP2 of the system under test is captured for analysis using an oscilloscope having a fourth-order, 7.5 GHz Bessel-Thomson response.

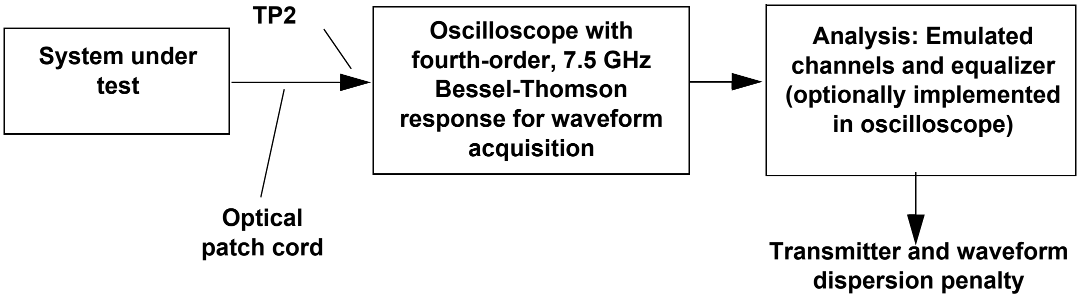


Figure 68–7—Transmitter waveform and dispersion penalty measurement configuration

68.6.6.1 TWDP measurement procedure

The system under test repetitively transmits a test pattern, as specified in Table 68–6. The waveform is captured using averaging to avoid a pessimistic estimate of TWDP. An effective sample rate of at least seven samples per unit interval is required. If test pattern 1 is transmitted, then the specified sub-pattern is to be captured. If PRBS9 is used, then the entire pattern is to be captured.

NOTE—The algorithm assumes 16 samples per unit interval. Interpolation is required for a waveform not captured with 16 samples per unit interval. Use of the $\sin(x)/x$ method or the cubic spline method is recommended. Linear interpolation is not recommended.

The captured waveform is analyzed using the algorithm given below, or equivalent. This algorithm analyses the waveform in combination with each of three emulated channels, equivalent to those given in Table 68–5 for the comprehensive stressed receiver specifications, and with an emulated reference receiver equalizer. A penalty is computed for each of the three emulated channels and the TWDP value is the largest of the three penalty results.

The reference equalizer is a decision feedback equalizer with defined tap number and spacing, as specified in 68.6.6.2. This is not intended to represent the equalizer used within an optical receiver, but is intended to provide uniform measurement conditions at the transmitter.

See Swenson, et al. [B58] for a detailed explanation of the TWDP algorithm.

68.6.6.2 TWDP signal processing algorithm[23], [24]

```
%%%%%%% MATLAB (R) script to compute TWDP %%%%%%%%%%%%%%%%%%%%%

%% TP2 test inputs
%% The values given below for TxDataFile and MeasuredWaveformFile are examples and should be
%% replaced by actual path\filenames for each waveform tested.
%% Transmit data file: The transmit data sequence is one of the TWDP test patterns defined in
%% Table 68–6. The file format is ASCII with a single column of chronological ones and zeros
%% with no headers or footers.
TxDataFile = 'prbs9_950.txt';
%% Measured waveform: The waveform consists of exactly N samples per unit interval T, where N is the
%% oversampling rate. The waveform must be circularly shifted to align with the data sequence. The file
%% format for the measured waveform is ASCII with a single column of chronological numerical samples,
%% in optical power, with no headers or footers.
MeasuredWaveformFile = 'preproc-1207-01.txt';
OverSampleRate = 16; % Oversampling rate, must be even
%% Simulated fiber responses, modeled as a set of ideal delta functions with specified amplitudes in optical
%% power and delays in nanoseconds, in rows. The three cases specified in Table 68–5 for the
%% comprehensive stressed receiver tests are used. The vector 'PCoefs' contains the amplitudes, and the
%% vector 'Delays' contains the delays.
FiberResp = [...
   0.000000 0.072727 0.145455 0.218182
   0.158 0.176 0.499 0.167
   0.000 0.513 0.000 0.487
   0.254 0.453 0.155 0.138];
Delays = FiberResp(1,:)';

%% Program constants %%
SymbolPeriod = 1/10.3125; % Symbol period (ns)
EqNf = 14; EqNb = 5; % 14 T/2-spaced feedforward equalizer taps; 5 T-spaced feedback equalizer taps
%% Set search range for equalizer delay, specified in symbol periods. Lower end of range is minimum
%% channel delay. Upper end of range is the sum of the lengths of the FFE and channel. Round up and add
%% 5 to account for the antialiasing filter.
EqDelMin = floor(min(Delays)/SymbolPeriod);
EqDelMax = ceil(EqNf/2 + max(Delays)/SymbolPeriod)+5;
EqDelVec = [EqDelMin:EqDelMax];
PAlloc = 6.5; % Total allocated dispersion penalty (dBo)
Q0 = 7.03; % BER = 10^(-12)
N0 = SymbolPeriod/2 / (Q0 * 10^(PAlloc/10))^2;

%% Load input waveform and data sequence, generate filter and other matrices
yout0 = load(MeasuredWaveformFile);
XmitData = load(TxDataFile);
PtrnLength = length(XmitData);
TotLen = PtrnLength*OverSampleRate;
Fgrid = [-TotLen/2:TotLen/2-1].'/(PtrnLength*SymbolPeriod);
%% Compute frequency response of 7.5 GHz 4th order Butterworth antialiasing filter
a = [1 123.1407 7581.811 273453.7 4931335]; % Denominator polynomial for frequency response
b = 4931335; % Numerator for frequency response
ExpArg = -j*2*pi*Fgrid;
H_r = b./polyval(a,-ExpArg); % Frequency response of Butterworth antialiasing filter
```

---

[23] *Copyright release for MATLAB code:* Users of this standard may freely copy or reproduce the MATLAB code in this subclause so it can be used for its intended purpose. Users should be aware, however, that this copyright release does not cover any patent rights that a third party may have in the MATLAB code.

[24] The script and associated files are available at http://standards.ieee.org/downloads/802.3/.

```
ONE=ones(PtrnLength,1);

%% Normalize the received OMA to 1. Estimate the OMA of the captured waveform by using a linear fit to
%% estimate a pulse response, synthesize a square wave, and calculate the OMA of the synthesized square
%% wave per 52.9.5
ant=4; mem=40; % Anticipation and memory parameters for linear fit
X=zeros(ant+mem+1,PtrnLength); % Size data matrix for linear fit
Y=zeros(OverSampleRate,PtrnLength); % Size observation matrix for linear fit
for ind=1:ant+mem+1
   X(ind,:)=circshift(XmitData,ind-ant-1)'; % Wrap appropriately for lin fit
end
X=[X;ones(1,PtrnLength)]; % The all-ones row is included to compute the bias
for ind=1:OverSampleRate
   Y(ind,:)=yout0([0:PtrnLength-1]*OverSampleRate+ind)'; % Each column is one bit period
end
Qmat=Y*X'*(X*X')^(-1); % Coefficient matrix resulting from linear fit. Each column (except
%% the last) is one bit period of the pulse response. The last column is the bias.
SqWvPer=16; % Even number; sets the period of the square wave used to compute the OMA
SqWv=[zeros(SqWvPer/2,1);ones(SqWvPer/2,1)]; % One period of square wave (column)
X=zeros(ant+mem+1,SqWvPer); % Size data matrix for synthesis
for ind=1:ant+mem+1
   X(ind,:)=circshift(SqWv,ind-ant-1)'; % Wrap appropriately for synthesis
end
X=[X;ones(1,SqWvPer)]; % Include the bias
Y=Qmat*X;Y=Y(:); % Synthesize the modulated square wave, put into one column
avgpos=[0.4*SqWvPer/2*OverSampleRate:0.6*SqWvPer/2*OverSampleRate]; % samples to average over
ZeroLevel=mean(Y(round(avgpos),:)); % Average over middle 20% of "zero" run
% Average over middle 20% of "one" run, compute OMA
MeasuredOMA=mean(Y(round(SqWvPer/2*OverSampleRate+avgpos),:))-ZeroLevel;
%% Subtract zero level and normalize OMA
yout0 = (yout0-ZeroLevel)/MeasuredOMA;

%% Compute the noise autocorrelation sequence at the output of the front-end antialiasing filter and
%% rate-2/T sampler.
Snn = N0/2 * fftshift(abs(H_r).^2) * 1/SymbolPeriod * OverSampleRate;
Rnn = real(ifft(Snn));
Corr = Rnn(1:OverSampleRate/2:end);
C = toeplitz(Corr(1:EqNf));

%% Compute the minimum slicer MSE and corresponding TWDP for the three stressor fibers
X = toeplitz(XmitData, [XmitData(1); XmitData(end:-1:2)]); % Used in MSE calculation
Rxx = X'*X; % Used in MSE calculation
TrialTWDP = [];
for ii=1:3 % index for stressor fiber
   %% Propagate the waveform through fiber ii.
   %% The DC response of each fiber is normalized to 1.
   PCoefs = FiberResp(ii+1,:)';
   Hsys = exp(ExpArg * Delays') * PCoefs; Hx = fftshift(Hsys/sum(PCoefs));
   yout = real(ifft(fft(yout0).*Hx));
   %% Process signal through front-end antialiasing filter %%%%%%%%%%%%%%%%%%
   yout = real(ifft(fft(yout) .* fftshift(H_r)));
   %% Compute MMSE-DFE %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   %% The MMSE-DFE filter coefficients computed below minimize mean-squared error at the slicer input.
   %% The derivation follows from the fact that the slicer input over the period of the data sequence can be
   %% expressed as Z = (R+N)*W - X*[0 B]', where R and N are Toeplitz matrices constructed from the
   %% signal and noise components, respectively, at the sampled output of the antialiasing filter, W is the
   %% feedforward filter, X is a Toeplitz matrix constructed from the input data sequence, and B is the
   %% feedback filter. The computed W and B minimize the mean square error between the input to the
   %% slicer and the transmitted sequence due to residual ISI and Gaussian noise. Minimize MSE over 2/T
```

```
  %% sampling phase and FFE delay and determine BER
  MseOpt = Inf;
  for jj= [0:OverSampleRate-1]-OverSampleRate/2 % sampling phase
    %% Sample at rate 2/T with new phase (wrap around as required)
    yout_2overT = yout(mod([1:OverSampleRate/2:TotLen]+jj-1,TotLen)+1);
    Rout = toeplitz(yout_2overT, [yout_2overT(1); yout_2overT(end:-1:end-EqNf+2)]);
    R = Rout(1:2:end, :);
    RINV = inv([R'*R+PtrnLength*C R'*ONE;ONE'*R PtrnLength]);
    R=[R ONE]; % Add all-ones column to compute optimal offset
    Rxr = X'*R; Px_r = Rxx - Rxr*RINV*Rxr';
    %% Minimize MSE over equalizer delay
    for kk = 1:length(EqDelVec)
      EqDel = EqDelVec(kk);
      SubRange = [EqDel+1:EqDel+EqNb+1];
      SubRange = mod(SubRange-1,PtrnLength)+1;
      P = Px_r(SubRange,SubRange);
      P00 = P(1,1); P01 = P(1,2:end); P11 = P(2:end,2:end);
      Mse = P00 - P01*inv(P11)*P01';
      if (Mse<MseOpt)
        MseOpt = Mse;
        B = -inv(P11)*P01'; % Feedback filter
        XSel = X(:,SubRange);
        W = RINV*R'*XSel*[1;B]; % Feedforward filter
        Z = R*W - XSel*[0;B]; % Input to slicer
        %% STEP 6 - Compute BER using semi-analytic method %%%%%%%%%%%%%%%%%%
        MseGaussian = W(1:end-1)'*C*W(1:end-1);
        Ber = mean(0.5*erfc((abs(Z-0.5)/sqrt(MseGaussian))/sqrt(2)));
      end
    end
  end

  %% Compute equivalent SNR %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  %% This function computes the inverse of the Gaussian error probability function. The
  %% built-in function erfcinv() is not sensitive enough for low probability of error cases.
  if Ber>10^(-12) Q = sqrt(2)*erfinv(1-2*Ber);
  elseif Ber>10^(-323) Q = 2.1143*(-1.0658-log10(Ber)).^0.5024;
  else Q = inf;
  end

  %% Compute penalty %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  RefSNR = 10 * log10(Q0) + PAlloc;
  TrialTWDP(ii) = RefSNR-10*log10(Q);
end

%% Pick highest value due to the multiple fiber responses from TrialTWDP.
TWDP = max(TrialTWDP)
%% End of program
```

68.6.7 Transmitter signal to noise ratio

The system under test shall meet the $RIN_{x}OMA$ specification, given in Table 68–3 as $RIN_{20}OMA$, when measured using the procedure given in 58.7.7. A different measurement procedure for the same quantity, giving approximately the same results, uses the setup shown in Figure 68–8 and proceeds as follows:

a) Measure OMA, using a square wave and following the method of 68.6.2
b) Using the same square wave, measure the rms noise over flat regions of the logic ONE and logic ZERO portions of the square wave, as indicated in Figure 68–4, compensating for noise in the

measurement system. The optical path and detector combination are configured for a single dominant reflection with the reflector adjusted to produce an optical return loss, as seen by the system under test, equal to the optical return loss tolerance (min) specified in Table 68–3. The length of the single-mode fiber is not critical, but should be in excess of 2 m. The polarization rotator is capable of transforming an arbitrary orientation elliptically polarized wave into a fixed orientation linearly polarized wave, and should be adjusted to maximize the noise. The receiver of the system under test should be receiving a signal that is asynchronous to that being transmitted. If possible, means should be used to prevent noise of frequency less than 1 MHz from affecting the result. Q_{sq} is given by Equation 68–2:

$$Q_{\mathrm{sq}} = \frac{\mathrm{OMA}}{\text{logic ONE noise (rms)} + \text{logic ZERO noise (rms)}} \tag{68–2}$$

where OMA and rms noise are measured in the same linear units of optical power, for example mW.

c) RIN_xOMA is then computed using the relationship shown in Equation 68–3:

$$RIN_xOMA = -20 \times \log_{10}(Q_{\mathrm{sq}}) - 10 \times \log_{10}(BW) \qquad \text{dB/Hz} \tag{68–3}$$

where BW is the low-pass bandwidth of oscilloscope minus high-pass bandwidth of the measurement system. For the specified measurement setup, BW is approximately 7.5×10^9 Hz.

Q_{sq} may be computed from the RIN_xOMA using the relationship shown in Equation 68–4:

$$Q_{\mathrm{sq}} = 10^{-RINxOMA/20} / \sqrt{BW} \tag{68–4}$$

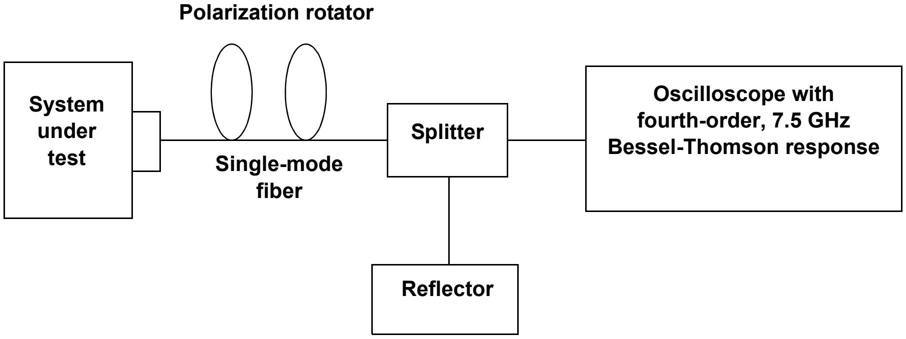


Figure 68–8—Transmitter signal to noise measurement setup

68.6.8 Transmitter uncorrelated jitter

Uncorrelated jitter refers to the component of jitter in the transmitted optical signal that is not correlated to the transmitter data.

The uncorrelated jitter specification of Table 68–3 shall be met when measured using an oscilloscope with a fourth-order, 7.5 GHz Bessel-Thomson response. The test pattern specified in Table 68–6 is used. A clock recovery unit (CRU) should be used to trigger the oscilloscope as shown in Figure 52–9. It should have a high frequency corner bandwidth of 4 MHz and a slope of –20 dB/decade. The CRU tracks acceptable levels of low-frequency jitter and wander. The oscilloscope is to be synchronized to the data pattern. The receiver of the system under test should be receiving a signal that is asynchronous to that being transmitted.

Figure 68–9 illustrates two measurement window positions, one on a rising edge, the other on a falling edge and both placed at the average power level of the pattern. The uncorrelated jitter (rms) is given by the RMS value of the standard deviations of the two distributions, as shown in Equation 68–5:

$$\text{Uncorrelated jitter (rms)} = \sqrt{(\sigma_r^2 + \sigma_f^2)/2} \tag{68–5}$$

where

σ_r is the standard deviation of the jitter on the rising edge

σ_f is the standard deviation of the jitter on the falling edge

Compensation for measurement system jitter is encouraged.

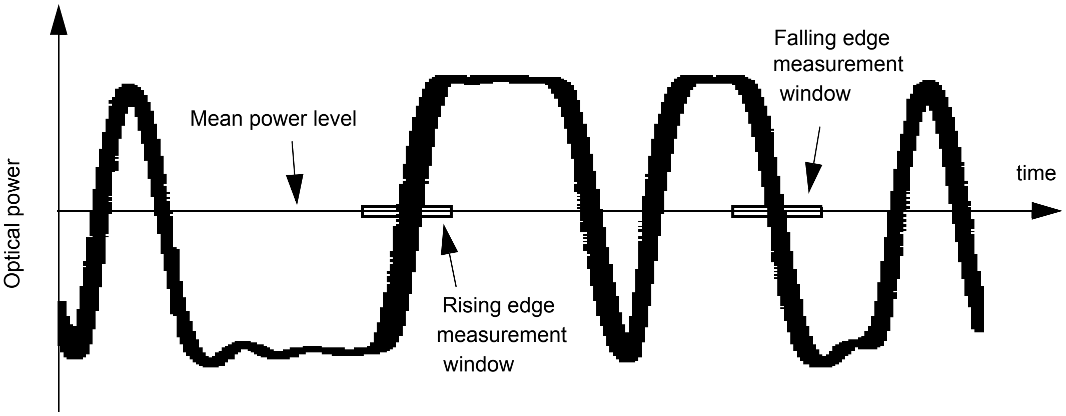


Figure 68–9—Measurement windows for transmitter uncorrelated jitter

68.6.9 Comprehensive stressed receiver sensitivity and overload

The PMD's receiver shall satisfy the comprehensive stressed receiver sensitivity and comprehensive stressed receiver overload specifications given in Table 68–5. These parameters are defined by reference to the procedures of 68.6.9.1 to 68.6.9.4. A BER of better than 10^{-12} shall be achieved with asynchronous transmission from the system under test. The received and transmitted patterns are the same, and as specified in Table 68–6 for the comprehensive stressed receiver sensitivity and the comprehensive stressed receiver overload.

68.6.9.1 Comprehensive stressed receiver sensitivity and overload test block diagram

Figure 68–10 shows the reference block diagram for the comprehensive stressed receiver test. As shown in the figure, an electrical signal is created using a pattern generator with pattern according to Table 68–6, and impaired by the following:

Gaussian low-pass filter

a) Gaussian white noise source
b) Intersymbol interference (ISI)

NOTE—Gaussian noise that extends, positively and negatively, to at least seven times its rms value is adequate.

The resulting electrical signal is converted to an optical signal using a linear electrical/optical converter, and the optical waveform is connected to an optical attenuator, and to the receiver under test via a mode-conditioning patch cord of the type defined in 38.11.4 or 59.9.5 for use with 62.5/125 µm fiber.

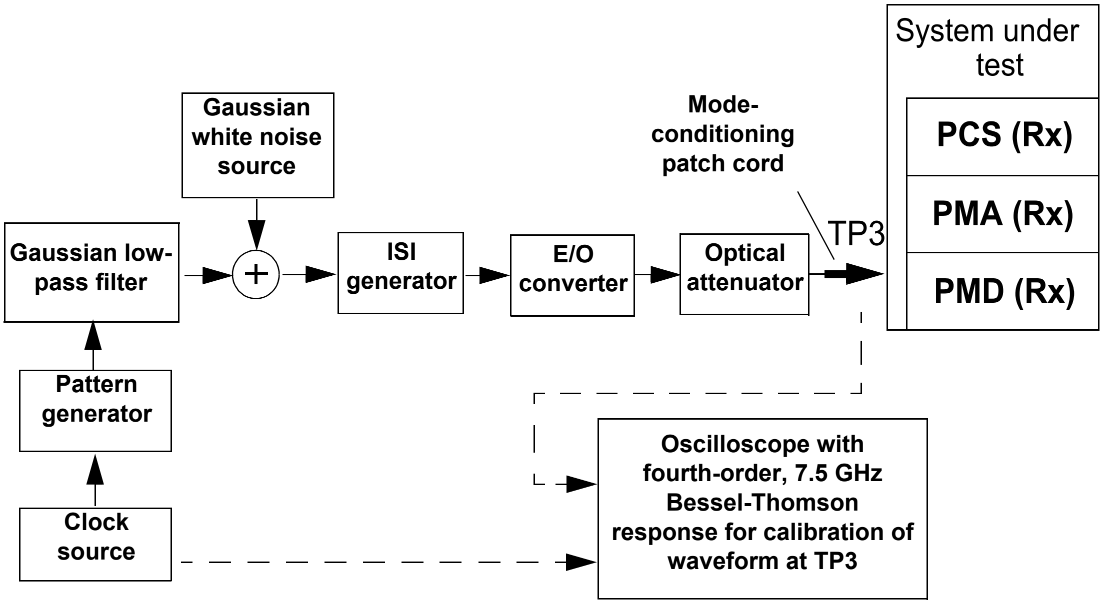


Figure 68–10—Reference measurement configuration for comprehensive stressed receiver sensitivity and overload test

The characteristics of the stressed test signal are defined in 68.6.9.2 and are based upon the parameters in Table 68–5. These parameters and the definition in 68.6.9.2 describe an ISI generator as a tapped delay line with four weighted taps, having equally spaced delays and with impulse response as illustrated in Figure 68–11.

Any implementation of the measurement configuration may be used, provided that the resulting signal and noise in the optical domain match those defined here. This consideration includes the shaping of the noise by the ISI generator.

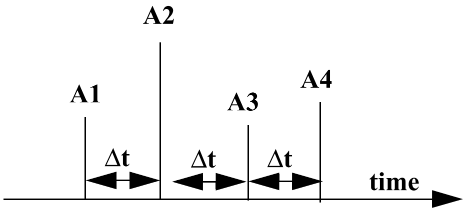


Figure 68–11—Illustration of parameters defining ISI generator impulse responses

68.6.9.2 Comprehensive stressed receiver test signal characteristics

The comprehensive stressed receiver test signal impairments are specified in Table 68–5 as the conditions of the comprehensive stressed receiver tests. These conditions include three sets of ISI parameters that are applied in turn. The ISI impaired test signal is defined by Equation 68–6:

$$S_{\mathrm{ISI}}(t) = S(t) * G_{47}(t) * \left[\sum_{i=1}^{4} A_i \times \delta(t - i \times \Delta t) \right] \quad (68\text{–}6)$$

where

$S(t)$ is an ideal NRZ test pattern signal specified in Table 68–6
$G_{47}(t)$ is a Gaussian low-pass filter with a 20% to 80% step response of 47 ps
A_i are the amplitudes of the four impulses
Δt is their spacing
δ is the Dirac delta function
* denotes convolution

The impulse spacing, and the amplitudes of the impulses for the three different test cases, are specified in Table 68–5.

The test signal is also impaired by broadband white Gaussian noise with a minimum bandwidth specified in Table 68–5 and with the amplitude adjusted such that Q_{sq} of the test signal, without ISI impairment, is as specified in Table 68–5.

Two different optical signal powers, in OMA, are used for the comprehensive stressed receiver sensitivity test. For the test with pre-cursor ISI tap weights, and the test with the post-cursor ISI tap weights, the OMA is set to the stressed sensitivity in OMA, given in Table 68–5. For the test with the symmetrical ISI tap weights, the OMA is set to the stressed sensitivity in OMA for symmetrical test, given in Table 68–5. For all three tests, the minimum extinction ratio specified in Table 68–3 is used.

For the comprehensive stressed receiver overload test, the OMA is set to the overload in OMA, given in Table 68–5, and with the maximum average power specified in Table 68–3.

68.6.9.3 Comprehensive stressed receiver test signal calibration

The test signal is calibrated as follows, using an optical reference receiver with a multimode compatible input and a 7.5 GHz fourth-order ideal Bessel-Thomson response.

The extinction ratio of the optical output is calibrated with the Gaussian low-pass filter but without the ISI generator.

Without ISI impairment due to the ISI generator, the level of the Gaussian noise is adjusted such that Q_{sq} is as specified in Table 68–5. See 68.6.7 for the definition of signal to noise ratio Q_{sq}.

The ISI generator is configured and calibrated for each of the three ISI cases specified in Table 68–5. The calibration of the ISI may be done with any portion of a repeating test signal. One convenient example is an isolated ONE bit with at least ten ZERO bits before and after. The ISI generator is adjusted such that the signal, S_{meas}, recorded on the reference receiver is given by Equation 68–7:

$$S_{\mathrm{meas}}(t) = S_{\mathrm{cal}}(t) * G_{47}(t) * \left[\sum_{i=1}^{4} A_i \times \delta(t - i \times \Delta t)\right] * BT4_{7.5GHz}(t) \tag{68–7}$$

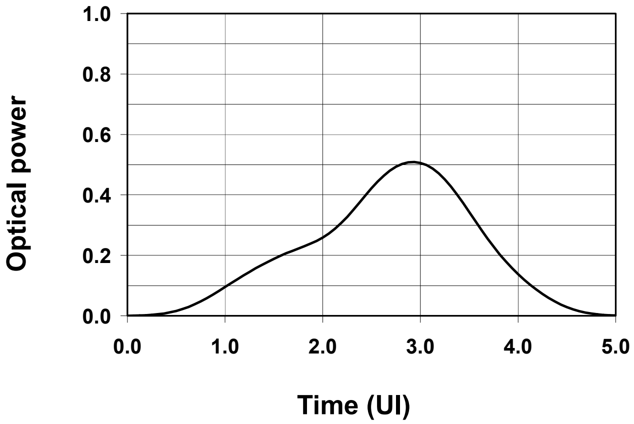
where

S_{cal} is an ideal NRZ calibration test signal
G_{47}, A_i , Δt, and * are defined as in 68.6.9.2
$BT4_{7.5GHz}(t)$ is the impulse response of an ideal 7.5 GHz fourth-order Bessel-Thomson filter representing the optical reference receiver response

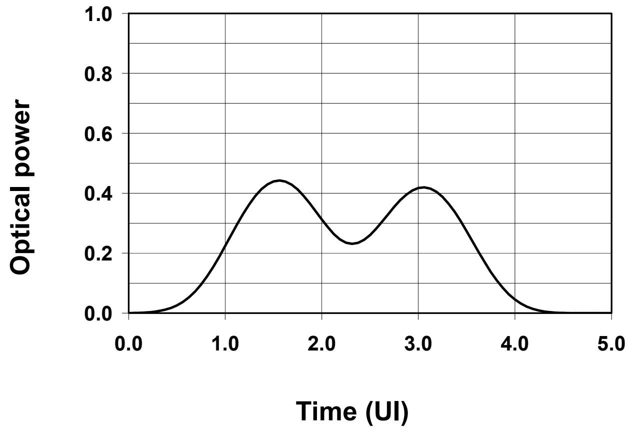
In practice, the bandwidth of, or need for, the Gaussian low-pass filter shown in block diagram of Figure 68–10 is determined by the characteristics of the signal source, ISI generator and E/O converter such that the final measured signal has the overall pulse response given by Equation 68–7.

Figure 68–12 illustrates the required measured test signals for the three cases specified in Table 68–5, where the test signal, S_{cal}, is a single ONE bit (rectangular pulse with 1 UI width) surrounded by ZEROs. Table 68–7 gives the tabulated amplitude vs. time for these curves.

Pre-cursor pulse signal:



Symmetric pulse signal:



Post-cursor pulse signal:

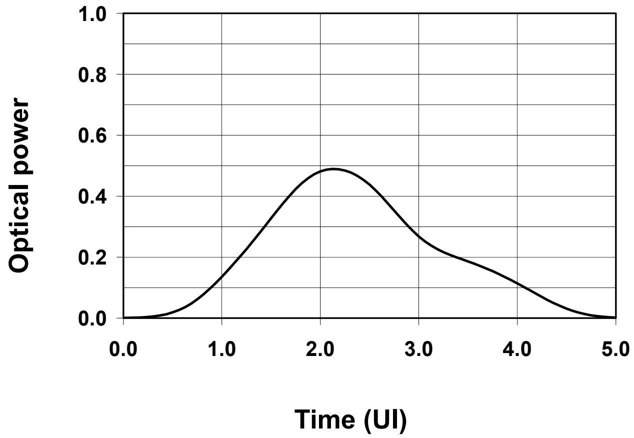


Figure 68–12—Comprehensive stressed receiver test pulse signals (i.e., signals corresponding to an isolated ONE bit)

NOTE—The optical powers have been normalized to correspond to waveforms with OMA of one.

NOTE—The TWDP values without simulated channels, which are measured using the same method as TWDP except that the simulated fiber stressors are set to (0,1,0,0), are 4.1 dB, 3.9 dB, and 4.2 dB for the pre-cursor, symmetrical and post-cursor tests, respectively. Significant differences from these values indicate problems with the test equipment (possibly nonlinearities) and that the test will not provide valid results. For small differences, the ISI generator should be adjusted to obtain the expected values. Also, one should ensure that the test system has adequate low-frequency response to avoid baseline wander problems with the longer test patterns used for the test.

Table 68–7—Tabulated amplitude vs. time values for test signals of Figure 68–13

Time (UI)	Pre-cursor	Symmetrical	Post-cursor
0.000	0.000	0.000	0.000
0.125	0.001	0.001	0.001
0.250	0.003	0.004	0.003
0.375	0.008	0.011	0.009
0.500	0.016	0.026	0.019
0.625	0.029	0.053	0.036
0.750	0.048	0.095	0.061
0.875	0.071	0.154	0.095
1.000	0.096	0.224	0.136
1.125	0.121	0.298	0.180
1.250	0.146	0.364	0.227
1.375	0.168	0.413	0.276
1.500	0.189	0.439	0.327
1.625	0.207	0.439	0.378
1.750	0.223	0.413	0.423
1.875	0.239	0.367	0.459
2.000	0.259	0.312	0.481
2.125	0.288	0.264	0.489
2.250	0.327	0.235	0.484
2.375	0.374	0.234	0.467
2.500	0.422	0.261	0.437
2.625	0.464	0.305	0.398
2.750	0.494	0.355	0.352
2.875	0.508	0.395	0.307
3.000	0.506	0.417	0.268
3.125	0.487	0.415	0.238
3.250	0.451	0.388	0.216
3.375	0.402	0.338	0.200
3.500	0.344	0.273	0.186
3.625	0.284	0.203	0.171
3.750	0.228	0.137	0.154
3.875	0.180	0.084	0.135
4.000	0.138	0.046	0.114
4.125	0.103	0.022	0.091
4.250	0.072	0.009	0.069
4.375	0.048	0.003	0.048
4.500	0.029	0.001	0.031
4.625	0.016	0.000	0.018
4.750	0.007	0.000	0.009
4.875	0.003	0.000	0.004
5.000	0.001	0.000	0.001

With the ISI generator present, the Q_{sq} values are as follows for the three different ISI impairments—pre-cursor: 45.6; symmetrical: 37.2; post-cursor: 47.0. Significant differences from these values indicate problems with the test equipment (possibly noise sources within the ISI generator), and the test will not provide valid results. For small differences, the amplitude of the added Gaussian white noise should be adjusted to obtain the expected values.

The attenuator setting is determined by measuring the OMA of the impaired test signal according to 68.6.2.

68.6.9.4 Comprehensive stressed receiver test procedure

The three ISI impairments defined in Table 68–5 and 68.6.9.2, together with the appropriate OMA values, also as specified in Table 68–5, define six discrete signal conditions.

With the test system setup as described in 68.6.9.2 and 68.6.9.3, for each case, select the required ISI impairment and set the attenuator and Gaussian white noise source to obtain either the stressed sensitivity in OMA, stressed sensitivity in OMA for symmetrical test or overload in OMA, with the appropriate noise, as specified in Table 68–5. Set the pattern generator to one of the patterns specified in Table 68–6 for these measurements. Connect the test signal to the system receiver TP3 and a BER of better than 10^{-12} shall be achieved for each case.

68.6.10 Simple stressed receiver sensitivity and overload (informative)

The simple stressed receiver sensitivity and simple stressed receiver overload are informative and compliance is not required. If measured, the receiver under test will be expected to satisfy the simple stressed receiver sensitivity and simple stressed receiver overload specifications in Table 68–5.

Figure 68–13 gives the block diagram for the simple stressed receiver test. A pattern generator output is impaired by a low-pass filter and the resulting electrical signal is converted to an optical signal using a linear electrical/optical converter. Other signal impairments, such as jitter and RIN, should be negligible. The optical waveform is connected to an optical attenuator, and to the receiver under test via a mode-conditioning patch cord of the type defined in 38.11.4 or 59.9.5 for use with 62.5/125 µm fiber.

The filter should be chosen so as to produce an optical output with the rise and fall times given in Table 68–5, and dominated by a fourth-order Bessel-Thomson response. The rise and fall times of the test signal are defined as measured with a 7.5 GHz Bessel-Thomson reference receiver and with the square wave pattern used for calibrating OMA for the comprehensive stressed receiver test of 68.6.9.

Other implementations may be used provided that the resulting signal in the optical domain matches that created using the implementation described.

NOTE—The TWDP without simulated channels, which is measured using the same method as TWDP except that the simulated fiber stressors are set to (0, 1, 0, 0), for this test signal is 4 dB.

For the two OMA values (i.e., the stressed sensitivity in OMA, and the overload in OMA, both specified in Table 68–5), a BER of better than 10^{-12} should be achieved. For the simple stressed receiver sensitivity test, the minimum extinction ratio specified in Table 68–3 is used. For the simple stressed receiver overload test, the maximum average power specified in Table 68–3 is used.

68.6.11 Receiver jitter tolerance

The receiver jitter tolerance specification given in Table 68–5 shall be met when measured as described here. This specification addresses the need for the receiver to track low-frequency jitter without the occurrence of errors.

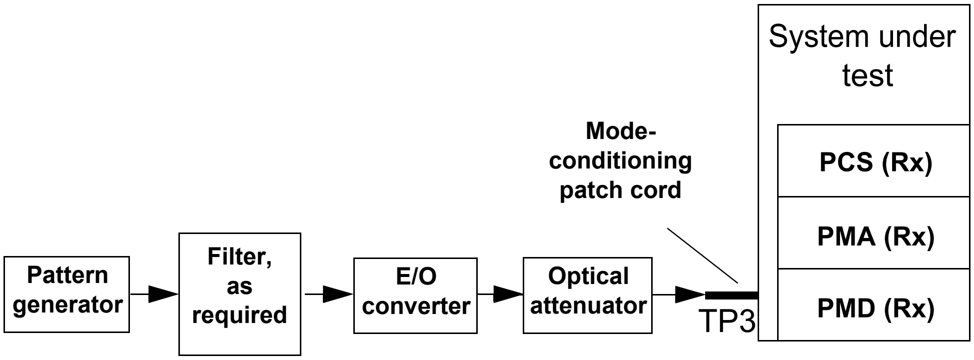


Figure 68–13—Measurement configuration for simple stressed receiver sensitivity test (informative)

Figure 68–14 gives the measurement configuration for the receiver jitter tolerance test. An optical pattern generator output is impaired by frequency modulation of the generating clock. The optical waveform is connected to the receiver under test via an optical attenuator and mode-conditioning patch cord suitable for 62.5/125 µm fiber.

Two jitter frequency and amplitude combinations are specified in Table 68–5. These are applied as the conditions of two separate receiver jitter tolerance tests. For each, the power in OMA at the receiver is adjusted, using the optical attenuator, to be equal to the stressed sensitivity in OMA, also given in Table 68–5, and a BER of better than 10^{-12} shall be achieved.

Various implementations may be used, provided that the resulting jitter in the optical domain matches that specified. Phase or frequency modulation may be applied to induce the sinusoidal jitter, and the modulation may be applied to the clock source or to the data stream itself.

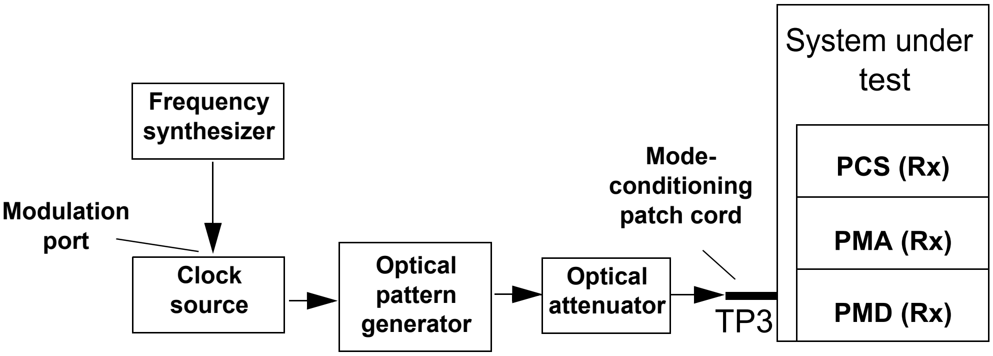


Figure 68–14—Measurement configuration for receiver jitter tolerance test

68.7 Safety, installation, environment, and labeling

68.7.1 Safety

The 10GBASE-LRM environmental specifications are as defined in 52.10.1 for general safety, and as defined in 52.10.2 for laser safety.

68.7.2 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulation, be followed in every instance in which such practices are applicable.

NOTE—The preferred launch (as specified in Table 68–3) is expected to provide more stable operation. It is recommended that link stability be confirmed by physical manipulation of the transmitter patch cord.

68.7.3 Environment

The 10GBASE-LRM operating environment specifications are as defined in 52.11, as defined in 52.11.1 for electromagnetic emission, and as defined in 52.11.2 for temperature, humidity, and handling.

68.7.4 PMD labeling

The 10GBASE-LRM labeling recommendations and requirements are as defined in 52.12.

68.8 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 38–7.

A channel may contain additional connectors or other optical elements as long as the optical characteristics of the channel such as attenuation, dispersion, reflections, modal bandwidth and total connector loss meet the specifications. Insertion loss measurements of installed multimode fiber cables are made in accordance with IEC 61280-4-1/Method 2. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards.

68.9 Characteristics of the fiber optic cabling (channel)

The channel consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together. The fiber optic cabling shall meet the requirements of Table 68–8.

Table 68–8—Fiber optic cabling (channel)

Description	Type	Value	Unit
Cabled optical fiber insertion loss at 1300 nm	max	0.4	dB
Losses of all connectors and splices	max	1.5	dB

68.9.1 Optical fiber and cable

The optical fiber shall meet the requirements of IEC 60793-2-10 and the requirements given in Table 68–9, where they differ. Multimode cables chosen from IEC 60794-2-11 or IEC 60794-3-12 may be suitable.

68.9.2 Optical fiber connections

An optical fiber connection, as shown in Figure 38–7, consists of a mated pair of optical connectors.

Table 68–9—Optical fiber and cable

Description	Type	Value	Unit
Cabled optical fiber attenuation at 1300 nm	max	1.5	dB/km
Modal bandwidth at 1300 nm	min	Value used as 1300 nm modal bandwidth portion of fiber identifier in Table 68–2	MHz · km
Zero dispersion wavelength (λ_0) for 62.5 µm MMF	range	$1320 \leq \lambda_0 \leq 1365$	nm
Chromatic dispersion slope for 62.5 µm MMF	max	0.11 for $1320 \leq \lambda_0 \leq 1348$ and $0.001(1458 - \lambda_0)$ for $1348 \leq \lambda_0 \leq 1365$	$\mathrm{ps/nm^2 \cdot km}$
Zero dispersion wavelength (λ_0) for 50 µm MMF	range	$1295 \leq \lambda_0 \leq 1320$	nm
Chromatic dispersion slope for 50 µm MMF	max	0.11 for $1300 \leq \lambda_0 \leq 1320$ and $0.001(\lambda_0 - 1190)$ for $1295 \leq \lambda_0 \leq 1300$	$\mathrm{ps/nm^2 \cdot km}$

68.9.2.1 Connection insertion loss

The insertion loss is specified for a connection, which consists of a mated pair of optical connectors.

The maximum link distances for multimode fiber are calculated based on an allocation of 1.5 dB total connector and splice loss. For example, this allocation supports three connections with an insertion loss equal to 0.5 dB (or less) per connection, or two connections (as shown in Figure 38–7) with an insertion loss equal to 0.75 dB per connection. Connections with different loss characteristics may be used provided the requirements of Table 68–8 are met.

68.9.2.2 Maximum discrete reflectance

The maximum discrete reflectance shall be less than –20 dB.

68.9.3 Single-mode fiber offset-launch mode-conditioning patch cord

Single-mode fiber offset-launch mode-conditioning patch cords shall satisfy the requirements of 38.11.4 or 59.9.5. Any discrete reflectance within the patch cord shall be less than –20 dB.

68.10 Protocol implementation conformance statement (PICS) proforma for Clause 68, Physical medium dependent (PMD) sublayer type 10GBASE-LRM[25]

68.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3, Physical medium dependent (PMD) sublayer type 10GBASE-LRM, shall complete the following protocol implementation conformance statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

68.10.2 Identification

68.10.2.1 Implementation identification

Supplier[1]	
Contact point for inquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1,3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

68.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 68, Physical medium dependent (PMD) sublayer type 10GBASE-LRM
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[25] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that if can be used for its intended purpose and may further publish the completed PICS.

68.10.2.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*MD	MDIO capability	68.3	Registers and interface supported	O	Yes [ ] No [ ]
*INS	Installation / Cable	68.9	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer	O	Yes [ ] No [ ]
DLY	Delay constraints	68.2	Device conforms to delay constraints	M	Yes [ ]

68.10.3 PICS proforma tables for physical medium dependent (PMD) sublayer type 10GBASE-LRM

68.10.3.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	Optical launch	68.4.1, 68.5.1	PMD supports both preferred and alternative launches	M	Yes [ ]
FS2	Transmit function	68.4.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FS3	Transmitter optical signal	68.4.2	Higher optical power transmitted is a logic 1	M	Yes [ ]
FS4	Receive function	68.4.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FS5	Receiver optical signal	68.4.3	Higher optical power received is a logic 1	M	Yes [ ]
FS6	Signal detect function	68.4.4	Mapping to PMD service interface	M	Yes [ ]
FS7	Signal detect parameter	68.4.4	Generated according to Table 68–1	M	Yes [ ]

68.10.3.2 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
MD1	Management register set	68.3	Mapped as per Table 52–3 and Table 52–4	MD:M	Yes [ ] N/A [ ]
MD2	PMD_reset bit	68.4.5, 45.2.1.1.1		MD:M	Yes [ ] N/A[ ]
MD3	PMD_global_transmit_disable bit	68.4.7, 45.2.1.8.7		MD:O	Yes [ ] No [ ] N/A [ ]
MD4	PMD_transmit_fault bit	68.4.8, 45.2.1.7.4		MD:O	Yes [ ] No [ ] N/A [ ]
MD5	PMD receive fault bit	68.4.9, 45.2.1.7.5		MD:O	Yes [ ] No [ ] N/A [ ]
MD6	PMD fault bit	68.4.6		MD:O	Yes [ ] No [ ] N/A [ ]
MD7	PMD_signal_detect bit	68.4.4, 45.2.1.9.7		MD:M	Yes [ ] N/A [ ]

68.10.3.3 PMD to MDI optical specifications

Item	Feature	Subclause	Value/Comment	Status	Support
LRM1	10GBASE-LRM transmitter	68.5.1	Meets specifications in Table 68–3	M	Yes [ ]
LRM2	10GBASE-LRM receiver	68.5.3	Meets specifications in Table 68–5	M	Yes [ ]

68.10.3.4 Definitions of optical parameters and measurement methods

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Optical modulation amplitude	68.6.2		M	Yes [ ]
OM2	Extinction ratio	68.6.3		M	Yes [ ]
OM3	Transmitter optical waveform— transmitter eye mask	68.6.5		M	Yes [ ]
OM4	Transmitter optical waveform— transmitter waveform and dispersion penalty (TWDP)	68.6.6		M	Yes [ ]
OM5	Transmitter signal to noise ratio	68.6.7		M	Yes [ ]
OM6	Transmitter uncorrelated jitter	68.6.8		M	Yes [ ]
OM7	Comprehensive stressed receiver sensitivity	68.6.9		M	Yes [ ]
OM8	Comprehensive stressed receiver overload	68.6.9		M	Yes [ ]
OM9	Simple stressed receiver sensitivity	68.6.10		O	Yes [ ] No [ ]
OM10	Simple stressed receiver overload	68.6.10		O	Yes [ ] No [ ]
OM11	Receiver jitter tolerance	68.6.11		M	Yes [ ]

68.10.3.5 Safety, installation, environment, and labeling

Item	Feature	Subclause	Value/Comment	Status	Support
SE1	General safety	68.7.1	As 52.10.1. Conforms to IEC-60950-1	M	Yes [ ]
SE2	Laser safety — IEC Hazard Level 1	68.7.1	As 52.10.2. Conform to Hazard Level 1 laser requirements defined in IEC 60825-1 and IEC 60825-2.	M	Yes [ ]
SE3	Electromagnetic interference	68.7.3	As 52.11.1. Comply with applicable local and national codes for the limitation of electromagnetic interference	M	Yes [ ]
SE4	PMD labeling	68.7.4	As 52.12.	M	Yes [ ]

68.10.3.6 Characteristics of the fiber optic cabling (channel)

Item	Feature	Subclause	Value/Comment	Status	Support
FO1	Characteristics of fiber optic cabling (channel)	68.9	Meet the requirements of	INS:M	Yes [ ] N/A [ ]
FO2	Optical fiber characteristics	68.9.1	Meet the requirements given, including those of Table 68–9	INS:M	Yes [ ] N/A [ ]
FO3	Optical fiber connections	68.9.2	Insertion loss within specification of 68.9.2.1	INS:M	Yes [ ] N/A [ ]
FO4	Patch cords	68.9.3		INS:M	Yes [ ] N/A [ ]

69. Introduction to Ethernet operation over electrical backplanes

69.1 Overview

69.1.1 Scope

Ethernet operation over electrical backplanes, also referred to as “Backplane Ethernet,” combines the IEEE 802.3 Media Access Control (MAC) and MAC Control sublayers with a family of Physical Layers defined to support operation over a modular chassis backplane.

Backplane Ethernet supports the IEEE 802.3 full duplex MAC operating at 1000 Mb/s, 10 Gb/s, 40 Gb/s, or 100 Gb/s providing a bit error ratio (BER) better than or equal to 10^{-12} at the MAC/PLS service interface. The following Physical Layers are supported:

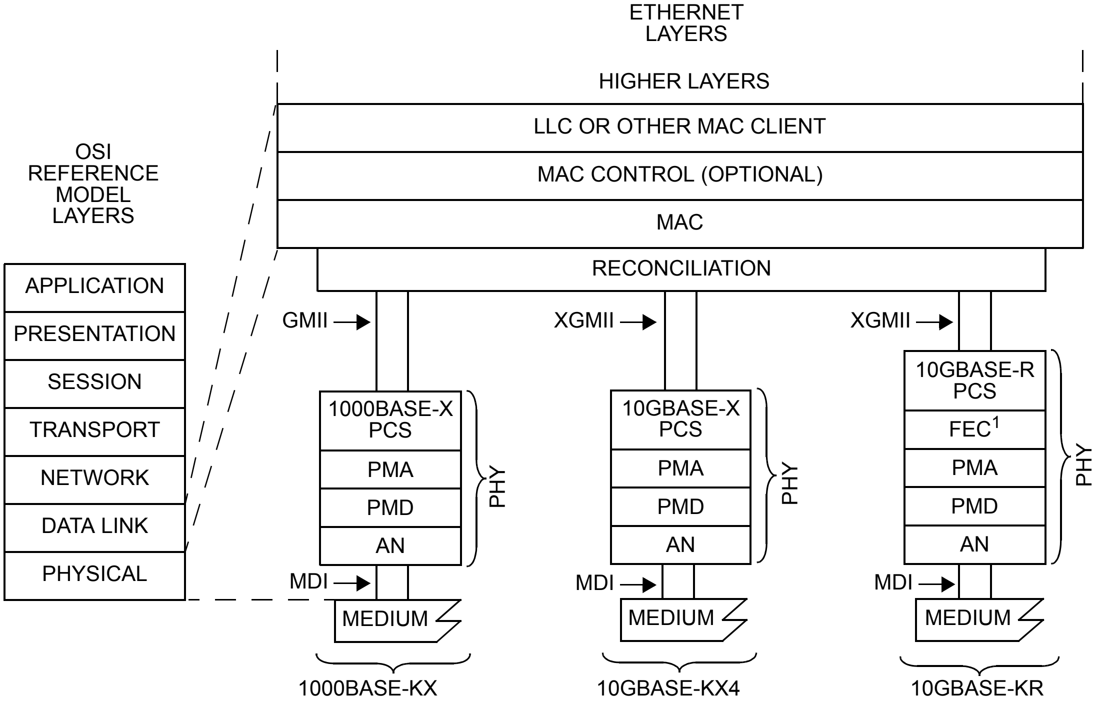
- 1000BASE-KX for 1 Gb/s operation over a single lane
- 10GBASE-KX4 for 10 Gb/s operation over four lanes
- 10GBASE-KR for 10 Gb/s operation over a single lane
- 40GBASE-KR4 for 40 Gb/s operation over four lanes
- 100GBASE-KR4 and 100GBASE-KP4 for 100 Gb/s operation over four lanes

Auto-Negotiation enables PHY selection amongst Backplane Ethernet Physical Layer signaling systems.

Energy Efficient Ethernet (EEE) is optionally supported for all Backplane Ethernet PHYs.

69.1.2 Relationship of Backplane Ethernet to the ISO OSI reference model

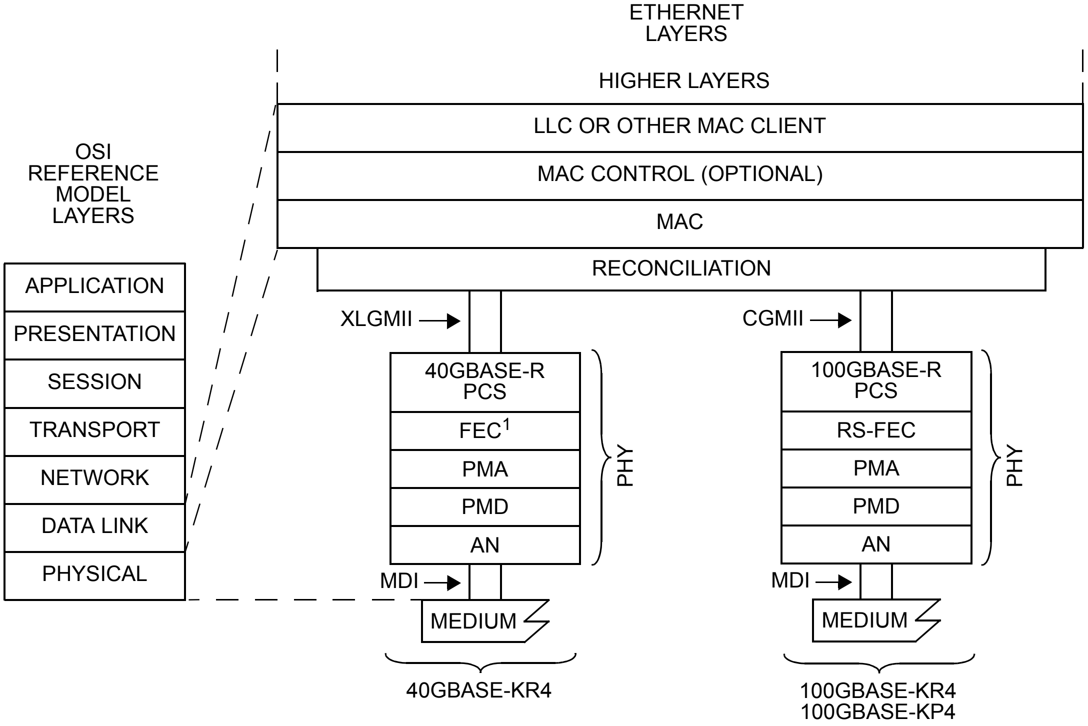
Backplane Ethernet couples the IEEE 802.3 MAC to a family of Physical Layers defined for operation over electrical backplanes. The relationships among Backplane Ethernet, the IEEE 802.3 MAC, and the ISO Open System Interconnection (OSI) reference model are shown in Figure 69–1 and Figure 69–2.



AN = AUTO-NEGOTIATION
FEC = FORWARD ERROR CORRECTION
GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
LLC = LOGICAL LINK CONTROL
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
XGMII = 10 GIGABIT MEDIA INDEPENDENT INTERFACE

NOTE 1—OPTIONAL

Figure 69–1—Architectural positioning of 1 Gb/s and 10 Gb/s Backplane Ethernet



AN = AUTO-NEGOTIATION
CGMII = 100 Gb/s MEDIA INDEPENDENT INTERFACE
FEC = FORWARD ERROR CORRECTION
LLC = LOGICAL LINK CONTROL
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER

PHY = PHYSICAL LAYER DEVICE

PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
RS-FEC = REED-SOLOMON FEC
XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE

NOTE 1—OPTIONAL

Figure 69–2—Architectural positioning of 40 Gb/s and 100 Gb/s Backplane Ethernet

It is important to note that, while this specification defines interfaces in terms of bits, octets, and frames, implementers may choose other data-path widths for implementation convenience. The only exceptions are as follows:

a) The GMII, which, when implemented at an observable interconnection point, uses an octet-wide data path as specified in Clause 35.
b) The XGMII, which, when implemented at an observable interconnection point, uses a 4-octet-wide data path as specified in Clause 46.
c) The management interface, when implemented as the MDIO/MDC (Management Data Input/Output, Management Data Clock) at an observable interconnection point, uses a bit-wide data path as specified in Clause 45.
d) The 1000BASE-X PMA service interface, when implemented at an observable interconnection point (TBI), uses the 10-bit-wide data path as specified in Clause 36.
e) The PMA service interface for 10Gb/s serial, when implemented at an observable interconnection point (XSBI), uses the 16-bit-wide data path as specified in Clause 51.
f) The PMA service interface, which, when physically implemented as XLAUI (40 Gb/s Attachment Unit Interface) or as CAUI-4 (100 Gb/s four-lane Attachment Unit Interface) at an observable interconnection port, uses a four-lane data path as specified in Annex 83A or Annex 83D, respectively.

g) The PMA service interface, which, when physically implemented as CAUI-10 (100 Gb/s ten-lane Attachment Unit Interface) at an observable interconnection port, uses a ten-lane data path as specified in Annex 83A.
h) The MDIs for 1000BASE-KX and 10GBASE-KR use a serial data path while the MDIs for 10GBASE-KX4, 40GBASE-KR4, 100GBASE-KR4, and 100GBASE-KP4 use a four-lane data path.

69.2 Summary of Backplane Ethernet Sublayers

69.2.1 Reconciliation sublayer and media independent interfaces

The Clause 35 RS and GMII, the Clause 46 RS and XGMII, and the Clause 81 RS, XLGMII, and CGMII are employed for the same purpose in Backplane Ethernet, that being the interconnection between the MAC sublayer and the PHY.

69.2.2 Management interface

The MDIO/MDC management interface (Clause 45) is intended to provide an interconnection between MDIO Manageable Devices (MMD) and Station Management (STA) entities.

69.2.3 Physical Layer signaling systems

Backplane Ethernet extends the family of 1000BASE-X Physical Layer signaling systems to include 1000BASE-KX. This embodiment specifies operation at 1 Gb/s over two differential, controlled impedance pairs of traces (one pair for transmit, one pair for receive). This system employs the 1000BASE-X PCS and PMA as defined in Clause 36. The 1000BASE-KX PMD is defined in Clause 70.

Backplane Ethernet also extends the family of 10GBASE-X Physical Layer signaling systems to include 10GBASE-KX4. This embodiment is based on XAUI with 10GBASE-CX4 extensions and specifies 10 Gb/s operation over four differential paths in each direction for a total of eight pairs. This system employs the 10GBASE-X PCS and PMA as defined in Clause 48. The 10GBASE-KX4 PMD is defined in Clause 71.

Backplane Ethernet also extends the family of 10GBASE-R Physical Layer signaling systems to include the 10GBASE-KR. This embodiment specifies 10 Gb/s operation over two differential, controlled impedance pairs of traces (one pair for transmit, one pair for receive). This system employs the 10GBASE-R PCS as defined in Clause 49 and the serial PMA as defined in Clause 51. The 10GBASE-KR PMD is defined in Clause 72. The 10GBASE-KR PHY may optionally include 10GBASE-R Forward Error Correction (FEC), as defined in Clause 74.

Backplane Ethernet also specifies 40GBASE-KR4. This embodiment employs the PCS defined in Clause 82, the PMA defined in Clause 83, and the PMD defined in Clause 84 and specifies 40 Gb/s operation over four differential paths in each direction for a total of eight pairs.

Backplane Ethernet also specifies 100GBASE-KR4 for 100 Gb/s operation using 2-level pulse amplitude modulation (PAM) over four differential signal pairs in each direction for a total of eight pairs where the insertion loss of each pair does not exceed 35 dB at 12.9 GHz. The embodiment of 100GBASE-KR4 employs the PCS defined in Clause 82, the RS-FEC defined in Clause 91, the PMA defined in Clause 83, and the PMD defined in Clause 93.

Backplane Ethernet also specifies 100GBASE-KP4 for 100 Gb/s operation using 4-level PAM over four differential signal pairs in each direction for a total of eight pairs where the insertion loss of each pair does not exceed 33 dB at 7 GHz. The embodiment of 100GBASE-KP4 employs the PCS defined in Clause 82, the RS-FEC defined in Clause 91, and the PMA and PMD defined in Clause 94.

Table 69–1 and Table 69–2 specify the correlation between nomenclature and clauses. A complete implementation conforming to one or more nomenclatures meets the requirements of the corresponding clauses.

Table 69–1—Nomenclature and clause correlation for 1 Gb/s and 10 Gb/s Backplane Ethernet Physical Layers

Nomenclature	Clause													
	35		36	46		48	49	51	70	71	72	73	74	78
	RS	GMII	1000BASE-X PCS/PMA	RS	XGMII	10GBASE-X PCS/PMA	10GBASE-R PCS	Serial PMA	1000BASE-KX PMD	10GBASE-KX4 PMD	10GBASE-KR PMD	Auto-Negotiation	BASE-R FEC	Energy-Efficient Ethernet (EEE)
1000BASE-KX	M[a]	O[a]	M						M			M		O
10GBASE-KX4				M	O	M				M		M		O
10GBASE-KR				M	O		M	M			M	M	O	O

[a] O = Optional, M = Mandatory

Table 69–2—Nomenclature and clause correlation for 40 Gb/s and 100 Gb/s Backplane Ethernet Physical Layers

Nomenclature	Clause																
	73	74	78	81			82		83		83A		83D	84	91	93	94
	Auto-Negotiation	BASE-R FEC	Energy-Efficient Ethernet (EEE)	RS	XLGMII	CGMII	40GBASE-R PCS	100GBASE-R PCS	40GBASE-R PMA	100GBASE-R PMA	XLAUI	CAUI-10	CAUI-4	40GBASE-KR4 PMD	RS-FEC	100GBASE-KR4 PMD	100GBASE-KP4 PMA/PMD
40GBASE-KR4	M[a]	O[a]	O	M	O		M		M		O			M			
100GBASE-KR4	M		O	M		O		M		M		O	O		M	M	
100GBASE-KP4	M		O	M		O		M				O	O		M		M

[a] O = Optional, M = Mandatory

69.2.4 Auto-Negotiation

Auto-Negotiation provides a linked device with the capability to detect the abilities (modes of operation) supported by the device at the other end of the link, determine common abilities, and configure for joint operation.

Auto-Negotiation for Backplane Ethernet is based on the Clause 28 definition of Auto-Negotiation for twisted-pair link segments. Auto-Negotiation for Backplane Ethernet utilizes an extended Base Page and Next Page format and modifies the timers to allow rapid convergence. Furthermore, Auto-Negotiation does not utilize Fast Link Pulses (FLPs) for link codeword signaling and instead uses a signaling more suitable for electrical backplanes.

Auto-Negotiation for Backplane Ethernet is defined in Clause 73.

69.2.5 Management

Managed objects, attributes, and actions are defined for all Backplane Ethernet components. These items are defined in Clause 30.

69.2.6 Low-Power Idle

With the optional EEE feature, described in Clause 78, Backplane Ethernet PHYs can achieve lower power consumption during periods of low link utilization. The EEE capabilities are advertised during Auto-Negotiation for Backplane Ethernet. The Backplane Ethernet LPI allows each link direction to enter sleep, refresh, or wake states asymmetric from the other direction.

69.3 Delay constraints

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers must conform to certain delay maxima, and that network planners and administrators conform to constraints regarding the cable topology and concatenation of devices.

Table 69–3 contains the values of maximum sublayer round-trip (sum of transmit and receive) delay for the 1000BASE-KX port types in bit time as specified in 1.4.

Table 69–3—Round-trip delay constraints for 1000BASE-KX

Sublayer	Maximum (bit time)	Notes
MAC Control, MAC, and RS	696	
1000BASE-X PCS, PMA, and PMD	328	See 36.5.1
Medium	16	See 70.4
Total delay	1040[a]	

[a] Per 31B.3.7, a station incorporating the 1000BASE-KX PHY will not begin to transmit a new frame more than two pause_quanta after the reception of a valid PAUSE frame that contains a non-zero value of pause_time, as measured at the MDI.

Table 69–4 contains the values of maximum sublayer round-trip (sum of transmit and receive) delay for the 10GBASE-KX4 and 10GBASE-KR port types in bit time as specified in 1.4 and pause_quanta as specified in 31B.2.

For 40GBASE-KR4, normative delay specifications may be found in 81.1.4, 82.5, 83.5.4, and 84.4 and also referenced in 80.4

For 100GBASE-KR4, normative delay specifications may be found in 81.1.4, 82.5, 83.5.4, 91.4, and 93.4 and also referenced in 80.4.

For 100GBASE-KP4, normative delay specifications may be found in 81.1.4, 82.5, 91.4, and 94.3.3 and also referenced in 80.4.

.

Table 69–4—Round-trip delay constraints for 10GBASE-KX4 and 10GBASE-KR

Sublayer	Maximum (bit time)	Maximum (pause_quanta)	Notes
MAC Control, MAC, and RS	8192	16	See 46.1.4
XGXS and XAUI	4096	8	Round-trip of 2 XGXS and trace for both directions, see 47.2.2
10GBASE-X PCS and PMA	2048	4	See 48.5
10GBASE-R PCS	3584	7	See 49.2.15
10GBASE-R FEC	6144	12	See 74.6
10GBASE-KX4 PMD[a]	512	1	See 71.3
10GBASE-KR PMA and PMD[a]	1024	2	See 72.4

[a] The 10GBASE-KX4 PMD and 10GBASE-KR PMA and PMD delays include the delay associated with the backplane medium.

69.4 State diagrams

In the case of any ambiguity between the text and the state diagrams, the state diagrams take precedence.

The conventions of 1.2 are adopted, along with the extensions listed in 21.5.

69.5 Protocol implementation conformance statement (PICS) proforma

The supplier of a protocol implementation that is claimed to conform to any part of IEEE Std 802.3, Clause 70 through Clause 74, Clause 84, Clause 91, Clause 93, Clause 94, and related annexes demonstrates compliance by completing a protocol implementation conformance statement (PICS) proforma.

A completed PICS proforma is the PICS for the implementation in question. The PICS is a statement of which capabilities and options of the protocol have been implemented. A PICS is included at the end of each clause as appropriate. Each of the Backplane Ethernet PICS uses the notation and conventions specified in 21.6.

70. Physical Medium Dependent sublayer and baseband medium, type 1000BASE-KX

70.1 Overview

This clause specifies the 1000BASE-KX PMD and baseband medium. When forming a complete PHY, a PMD shall be combined with the appropriate sublayers (see Table 70–1), and with the management functions that are optionally accessible through the management interface defined in Clause 45.

Table 70–1—Physical Layer clauses associated with the 1000BASE-KX PMD

Associated clause	1000BASE-KX
35—GMII[a]	Optional
36—1000BASE-X PCS/PMA	Required
73—Auto-Negotiation for Backplane Ethernet	Required
78—Energy-Efficient Ethernet	Optional

[a] The GMII is an optional interface. However, if the GMII is not implemented, a conforming implementation must behave functionally as though the RS and GMII were present.

The Clause 36 PCS/PMA when used with 1000BASE-KX PMD shall support full duplex operation only.

A 1000BASE-KX PHY with the optional Energy-Efficient Ethernet (EEE) capability may optionally enter the Low Power Idle (LPI) mode to conserve energy during periods of low link utilization. The "Assert LPI" request at the GMII is encoded in the transmitted symbols. Detection of LPI signaling in the received symbols is indicated as "Assert LPI" at the GMII. Upon the detection of "Assert LPI" at the GMII, an energy-efficient 1000BASE-KX PHY continues transmitting for a predefined period, then ceases transmission and deactivates transmit functions to conserve energy. The PHY periodically transmits during this quiet period to allow the remote PHY to refresh its receiver state (e.g., timing recovery, adaptive filter coefficients) and thereby track long-term variations in the timing of the link or the underlying channel characteristics. If, during the quiet or refresh periods, normal interframes resume at the GMII, the PHY reactivates transmit functions and initiates transmission. This transmission will be detected by the remote PHY, causing it to also exit the LPI mode.

70.2 Physical Medium Dependent (PMD) service interface

The 1000BASE-KX PMD performs the following three functions in support of the matching service interface primitives of 38.1.1: Transmit, Receive, and Signal Detect.

The PMD provides the following service interface signals if EEE is supported:

PMD_RXQUIET.request(rx_quiet)
PMD_TXQUIET.request(tx_quiet)

These messages signals are defined for the PCS in 36.2.5.1.6.

70.2.1 PMD_RXQUIET.request

This primitive is generated by the PCS Receive Process when EEE is supported to indicate that the input signal is quiet and the PMA and PMD receiver may go into low power mode. See 36.2.4.13. When EEE is not supported, the primitive is never invoked and the PMD behaves as if rx_quiet = FALSE.

70.2.1.1 Semantics of the service primitive

PMD_RXQUIET.request (rx_quiet)

The rx_quiet parameter takes on one of two values: TRUE or FALSE.

70.2.1.2 When generated

The PCS generates this primitive to request the appropriate PMD receive LPI state.

70.2.1.3 Effect of receipt

This variable is from the receive process of the PCS to control the power-saving function of the local PMD receiver. The 1000BASE-KX PHY receiver should put unused functional blocks into a low power state to save energy.

70.2.2 PMD_TXQUIET.request

This primitive is generated by the PCS Transmit Process when EEE is supported to indicate that the PMA and PMD transmit functions may go into a low power mode and to disable the PMD transmitter. See 70.6.5. When EEE is not supported, the primitive is never invoked and the PMD behaves as if tx_quiet = FALSE.

70.2.2.1 Semantics of the service primitive

PMD_TXQUIET.request (tx_quiet)

The tx_quiet parameter takes on one of two values: TRUE or FALSE.

70.2.2.2 When generated

The PCS generates this primitive to request the appropriate PMD transmit LPI state.

70.2.2.3 Effect of receipt

This primitive affects operation of the PMD Transmit disable function as described in 70.6.5. The 1000BASE-KX PHY transmitter should put unused functional blocks into a lower power state to save energy.

70.3 PCS requirements for Auto-Negotiation (AN) service interface

The PCS associated with this PMD shall support the AN service interface primitive AN_LINK.indication as defined in 73.9. (See 36.2.5.2.7.)

70.4 Delay constraints

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers must consider the delay maxima, and that network planners and administrators consider the delay constraints regarding the physical topology and concatenation of devices. A description of overall system delay constraints and the definitions for bit-times and pause_quanta can be found in 69.3

The sum of transmit and receive delays contributed by the 1000BASE-KX PCS, PMA, and PMD shall be no more than 328 bit times. It is assumed that the round-trip delay through the medium is 16 bit times.

70.5 PMD MDIO function mapping

The optional MDIO capability described in Clause 45 defines several variables that provide control and status information for and about the PMD. If the MDIO is implemented, it shall map MDIO control variables to PMD control variables as shown in Table 70–2, and MDIO status variables to PMD status variables as shown in Table 70–3.

Table 70–2—MDIO/PMD control variable mapping

MDIO control variable	PMA/PMD register name	Register/ bit number	PMD control variable
Reset	Control register 1	1.0.15	PMD_reset
PMD Transmit Disable	1000BASE-KX control register	1.160.0	PMD_transmit_disable

Table 70–3—MDIO/PMD status variable mapping

MDIO status variable	PMA/PMD register name	Register/ bit number	PMD status variable
Fault	Status register 1	1.1.7	PMD_fault
Transmit fault ability	1000BASE-KX status register	1.161.13	PMD_Transmit_fault_ability
Receive fault ability	1000BASE-KX status register	1.161.12	PMD_Receive_fault_ability
Transmit fault	1000BASE-KX status register	1.161.11	PMD_transmit_fault
Receive fault	1000BASE-KX status register	1.161.10	PMD_receive_fault
PMD transmit disable ability	1000BASE-KX status register	1.161.8	PMD_transmit_disable_ability
Signal detect from PMD	1000BASE-KX status register	1.161.0	PMD_signal_detect

70.6 PMD functional specifications

The 1000BASE-KX PMD performs the following three functions in support of the matching service interface primitives of 38.1.1: Transmit, Receive, and Signal Detect (see service interface definition in 70.2).

70.6.1 Link block diagram

For purposes of system conformance, the PMD sublayer is standardized at test points TP1 and TP4 as shown in Figure 70–1. The transmitter and receiver blocks include all off-chip components associated with the respective block. For example, external AC-coupling capacitors, if required, are to be included in the receiver block.

The electrical path from the transmitter block to TP1, and from TP4 to the receiver block, will affect link performance and the measured values of electrical parameters used to verify conformance to this specification. It is therefore recommended that this path be carefully designed.

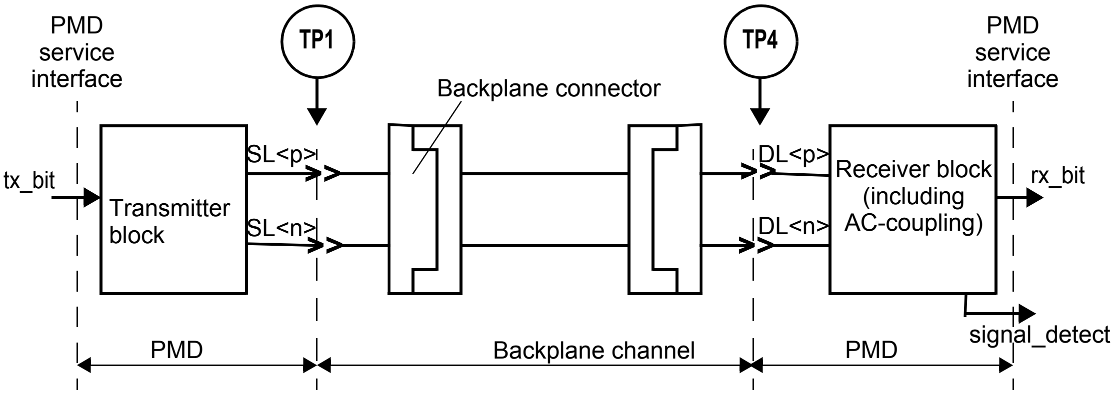


Figure 70–1—Link block diagram

70.6.2 PMD transmit function

The PMD Transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according electrical specifications in 70.7.1. A positive output voltage of SL<p> minus SL<n> (differential voltage) shall correspond to tx_bit = ONE.

70.6.3 PMD receive function

The PMD Receive function shall convey the bits received at the MDI in accordance with the electrical specifications of 70.7.2 to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). A positive input voltage of DL<p> minus DL<n> (differential voltage) shall correspond to rx_bit = ONE.

70.6.4 PMD signal detect function

For 1000BASE-KX operation PMD signal detect is mandatory if EEE is supported. When EEE is not supported, the PMD signal detect is optional for 1000BASE-KX and its definition is beyond the scope of this specification. When PMD signal detect is not implemented, the value of SIGNAL_DETECT shall be set to OK for purposes of management and signaling of the primitive.

If EEE is supported, a local PMD signal detect function shall report to the PMD service interface using the message PMD_SIGNAL.indication(SIGNAL_DETECT). This message is signaled continuously. For EEE, the SIGNAL_DETECT parameter can take on one of two values, OK or FAIL, indicating whether the PMD is detecting electrical energy at the receiver (OK) or not (FAIL). When SIGNAL_DETECT = FAIL, PMD_UNITDATA.indication is undefined. The signal energy from a compliant transmitter shall set SIGNAL_DETECT to OK within 750 ns when transitioning from LPI quiet to active and set SIGNAL_DETECT to FAIL within 750 ns when transitioning from active to LPI quiet.

70.6.5 PMD transmit disable function

The PMD_transmit_disable function is mandatory if EEE is supported and is otherwise optional. When implemented, it allows the transmitter to be disabled with a single variable.

a) When the PMD_transmit_disable variable is set to ONE, this function shall turn off the transmitter such that it drives a constant level (i.e., no transitions) and does not exceed the maximum differential peak-to-peak output voltage specified in Table 70–4.
b) If a PMD_fault (70.6.7) is detected, then the PMD may turn off the electrical transmitter.
c) Loopback, as defined in 70.6.6, shall not be affected by PMD_transmit_disable.
d) For EEE capability, the PMD_transmit_disable function shall turn off the transmitter after tx_quiet is asserted within the time and voltage level specified in 70.7.1.5. The PMD_transmit_disable function shall turn on the transmitter after tx_quiet is de-asserted within a time and voltage level specified in 70.7.1.5.

70.6.6 Loopback mode

Loopback mode shall be provided for the 1000BASE-KX PMA/PMD by the transmitter and receiver of a device as a test function to the device. When loopback mode is selected, transmission requests passed to the transmitter are shunted directly to the receiver, overriding any signal detected by the receiver on its attached link. Transmitter operation shall be independent of loopback mode. A device must be explicitly placed in loopback mode because loopback mode is not the normal mode of operation of a device. The method of implementing loopback mode is not defined by this standard.

Control of the loopback function is specified in 45.2.1.1.5.

NOTE 1—The signal path that is exercised in the loopback mode is implementation specific, but it is recommended that this signal path encompass as much of the circuitry as is practical. The intention of providing this loopback mode of operation is to permit diagnostic or self-test functions to test the transmit and receive data paths using actual data. Other loopback signal paths may also be enabled independently using loopback controls within other devices or sublayers.

NOTE 2—Placing a network port into loopback mode can be disruptive to a network.

70.6.7 PMD fault function

If the MDIO is implemented, and the PMD has detected a local fault, the PMD shall set PMD_fault to ONE; otherwise, the PMD shall set PMD_fault to ZERO.

70.6.8 PMD transmit fault function

If the MDIO is implemented, and the PMD has detected a local fault on the transmitter, the PMD shall set the PMD_transmit_fault variable to ONE; otherwise, the PMD shall set PMD_transmit_fault to ZERO.

70.6.9 PMD receive fault function

If the MDIO is implemented, and the PMD has detected a local fault on the receiver, the PMD shall set the PMD_receive_fault variable to ONE; otherwise, the PMD shall set PMD_receive_fault to ZERO.

70.6.10 PMD LPI function

The PMD LPI function responds to the transitions between Active, Sleep, Quiet, Refresh, and Wake states via the PMD_TXQUIET and PMD_RXQUIET requests. Implementation of the function is optional. EEE capabilities and parameters are advertised during the Backplane Auto-negotiation as described in 45.2.7.13. The transmitter on the local device informs the link partner's receiver when to sleep, refresh, and wake. The local receiver's transitions are controlled by the link partner's transmitter and change independently from the local transmitter's states and transitions.

The transmitter sends /LI/ ordered sets during the sleep and refresh states, disables the transmitter during quiet, and forwards /I/ during the wake phase.

If EEE is supported, the PMD transmit function enters into a low power mode when tx_quiet is set to TRUE and exits when tx_quiet is set to FALSE. While tx_quiet is TRUE the PMD transmitter functional blocks should be deactivated to conserve energy. The PMD receive function enters into a low power mode when rx_quiet is set to TRUE and exits when rx_quiet is set to FALSE. While rx_quiet is TRUE the PMD receiver functional blocks should be deactivated to conserve energy.

70.7 1000BASE-KX electrical characteristics

70.7.1 Transmitter characteristics

Transmitter characteristics at TP1 are summarized in Table 70–4 and detailed in 70.7.1.1 through 70.7.1.9.

Table 70–4—Transmitter characteristics for 1000BASE-KX

Parameter	Subclause reference	Value	Units
Signaling speed	70.7.1.3	1.25 ± 100 ppm	GBd
Differential peak-to-peak output voltage	70.7.1.5	800 to 1600	mV
Differential peak-to-peak output voltage (max.) with TX disabled	70.6.5	30	mV
DC common-mode voltage limits	70.7.1.5	–0.4 to 1.9	V
Common-mode voltage deviation (max) during LPI	70.7.1.5	150	mV
Differential output return loss (min.)	70.7.1.6	[See Equation (70–1) and Equation (70–2)]	dB
Transition time[a] (20%–80%)	70.7.1.7	60 to 320	ps
Output jitter (max. peak-to-peak) Deterministic jitter[b] Random jitter Total jitter[c]	70.7.1.8	 0.10 0.15 0.25	 UI UI UI

[a] Transition time parameters are recommended values, not compliance values.
[b] Deterministic jitter is already incorporated into the differential output template.
[c] At BER 10^{-12}.

70.7.1.1 Test fixtures

The test fixture of Figure 70–2, or its functional equivalent, is required for measuring the transmitter specifications described in 70.7.1, with the exception of return loss.

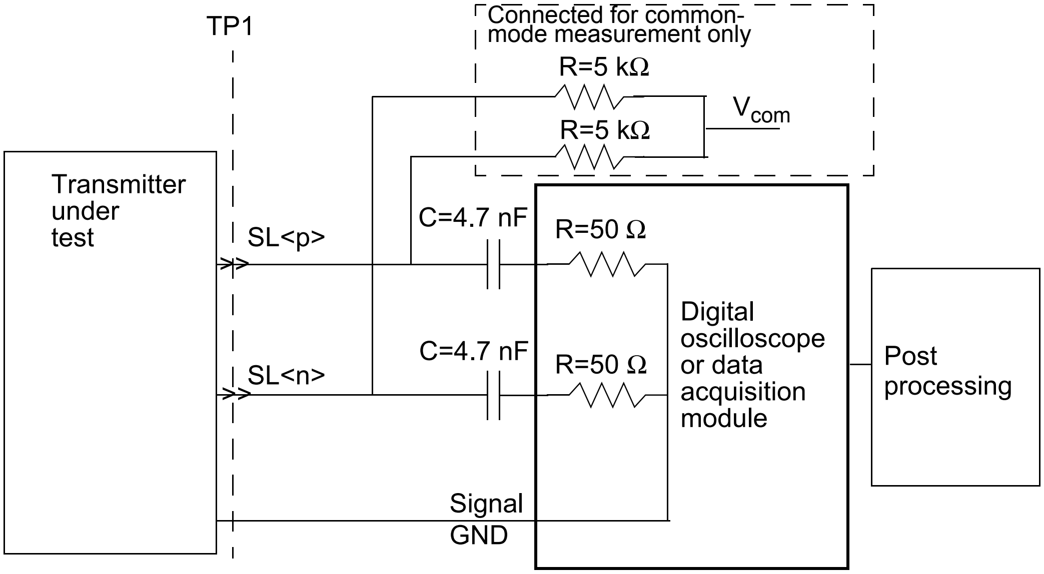


Figure 70–2—Transmit test fixture for 1000BASE-KX

70.7.1.2 Test fixture impedance

The differential load impedance applied to the transmitter output by the test fixture depicted in Figure 70–2 shall be 100 Ω with a return loss greater than 20 dB from 50 MHz to 625 MHz.

70.7.1.3 Signaling speed

The 1000BASE-KX signaling speed shall be 1.25 GBd ± 100 ppm.

70.7.1.4 Differential output eye mask

The transmitter differential output signal is defined at TP1, as shown in Figure 70–2. The transmitter output waveform shall fall within the eye mask shown in Figure 70–3 for the jitter test frame defined in 59.7.1. Voltage and time coordinates for mask points on Figure 70–3 are given in Table 70–5.

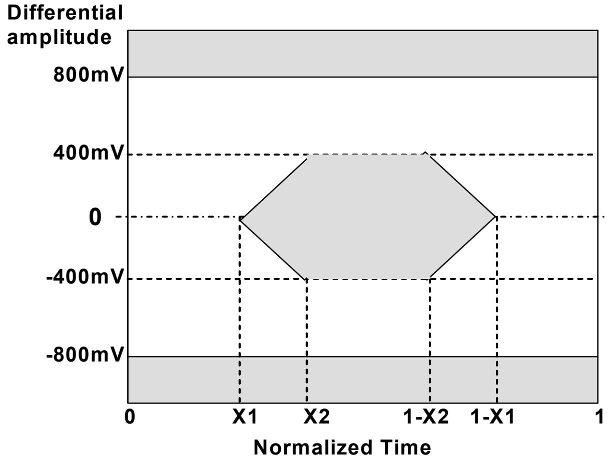


Figure 70–3—Absolute eye diagram mask at TP1 for 1000BASE-KX

Table 70–5—Transmitted eye mask at TP1 for 1000BASE-KX

Symbol	Value	Units
X1	0.125	Unit intervals (UI)
X2	0.325	Unit intervals (UI)

70.7.1.5 Output amplitude

While transmitting the test pattern specified in 36A.2, the transmitter differential peak-to-peak output voltage shall be between 800 mV and 1600 mV. See Figure 70–4 for an illustration of the definition of differential peak-to-peak output voltage. DC-referenced voltage levels are not defined since the receiver is AC-coupled. The common-mode voltage of SL<p> and SL<n> shall be between –0.4 V and 1.9 V with respect to signal ground as measured at V_{com} in Figure 70–2.

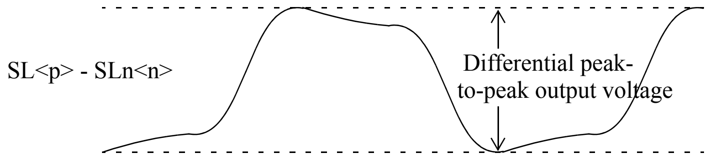


Figure 70–4—Transmitter differential peak-to-peak output voltage definition

NOTE—SL<p> and SL<n> are the positive and negative sides of the differential signal pair respectively.

For EEE capability, the transmitter's differential peak-to-peak output voltage shall be less than 30 mV within 500 ns of tx_quiet being asserted. Furthermore, the transmitters differential peak-to-peak output voltage shall be greater than 720 mV within 500 ns of tx_quiet being de-asserted. The transmitter output shall be fully compliant within 5 µs after tx_quiet is set to FALSE. During LPI, the common-mode shall be maintained to within ±150 mV of the pre-LPI value.

70.7.1.6 Differential output return loss

For frequencies from 50 MHz to 1250 MHz, the differential return loss, in dB with f in MHz, of the transmitter shall meet the requirements of Equation (70–1) and Equation (70–2). This output impedance requirement applies to all valid output levels. The reference impedance for differential return loss measurements shall be 100 Ω.

$$\mathrm{ReturnLoss}(f) \geq 10 \tag{70–1}$$

for 50 MHz ≤ f < 625 MHz and

$$\mathrm{ReturnLoss}(f) \geq 10 - 10 \times \log\left(\frac{f}{625}\right) \tag{70–2}$$

for 625 MHz ≤ f ≤ 1250 MHz.

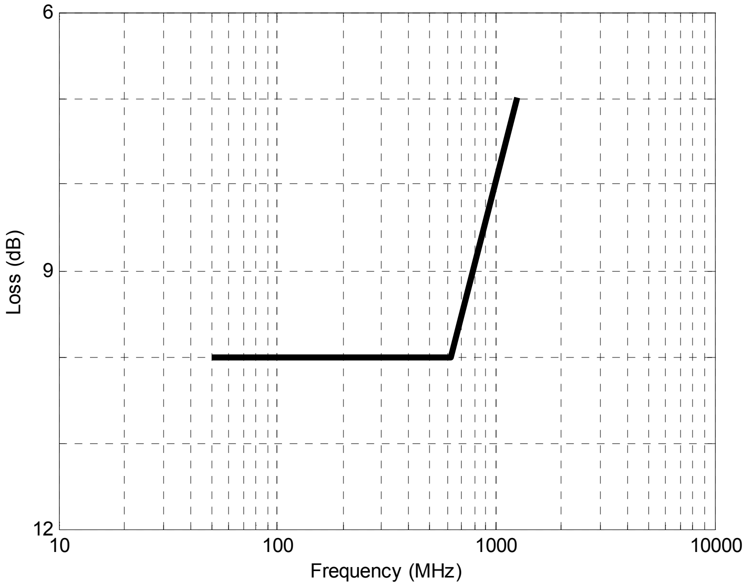


Figure 70–5—Differential return loss

70.7.1.7 Transition time

The rising edge transition time is recommended to be no less than 60 ps as measured at the 20% and 80% levels of the peak-to-peak differential value of the waveform using the high-frequency test pattern of 36A.1.

The falling edge transition time is recommended to be no less than 60 ps as measured at the 80% and 20% levels of the peak-to-peak differential value of the waveform using the high-frequency test pattern of 36A.1.

The maximum transition time is recommended to be no more than 320 ps.

70.7.1.8 Transmit jitter

The transmitter shall have a maximum total jitter of 0.25 UI peak-to-peak and a maximum deterministic component of 0.10 UI peak-to-peak. Jitter specifications include all but 10^{-12} of the jitter population. Transmit jitter test requirements are specified in 70.7.1.9.

70.7.1.9 Transmit jitter test requirements

Transmit jitter is defined with respect to a test procedure resulting in a BER bathtub curve such as that described in Annex 48B. For the purpose of jitter measurement, the effect of a single-pole high-pass filter with a 3 dB point at 750 kHz is applied to the jitter. The data pattern for jitter measurements shall be the jitter test frame described in 59.7.1. Crossing times are defined with respect to the mid-point (0 V) of the AC-coupled differential signal.

70.7.2 Receiver characteristics

Receiver characteristics at TP4 are summarized in Table 70–6 and detailed in 70.7.2.1 through 70.7.2.5.

Table 70–6—Receiver characteristics for 1000BASE-KX

Parameter	Subclause reference	Value	Units
Bit error ratio	70.7.2.1	10^{-12}	
Signaling speed	70.7.2.2	1.25 ± 100 ppm	GBd
Receiver coupling	70.7.2.3	AC	
Differential input peak-to-peak amplitude (max.)	70.7.2.4	1600	mV
Differential input return loss (min.)	70.7.2.5	[See Equation (70–1) and Equation (70–2)]	dB

70.7.2.1 Receiver interference tolerance

The receiver interference tolerance shall be measured as described in Annex 69A with the parameters specified in Table 70–7. The data pattern for the interference tolerance test shall be the jitter pattern test frame as defined in 59.7.1. The receiver shall satisfy the requirements for interference tolerance specified in Annex 69A.

Table 70–7—1000BASE-KX interference tolerance parameters

Parameter	Value	Units
Target BER	10^{-12}	
m_{TC}[a] (min.)	1.0	
Amplitude of broadband noise (min. RMS)	8.6	mV
Applied transition time (20%–80%, min.)	320	ps
Applied sinusoidal jitter (min. peak-to-peak)	0.10	UI
Applied random jitter (min. peak-to-peak)[b]	0.15	UI
Applied duty cycle distortion (min. peak-to-peak)	0.0	UI

[a] m_{TC} is defined in Equation (69A–6) of Annex 69A.
[b] Applied random jitter is specified at a BER of 10^{-12}.

70.7.2.2 Signaling speed range

A 1000BASE-KX receiver shall comply with the requirements of Table 70–7 for any signaling speed in the range 1.25 GBd ± 100 ppm. The corresponding unit interval is nominally 800 ps.

70.7.2.3 AC-coupling

The receiver shall be AC-coupled to the backplane to allow for maximum interoperability between various PMD components. AC-coupling is considered to be part of the receiver for the purposes of this specification unless explicitly stated otherwise. It should be noted that there may be various methods for AC-coupling in actual implementations.

NOTE—It is recommended that the maximum value of the coupling capacitors be limited to 4.7 nF. This will limit the inrush currents to the receiver that could damage the receiver circuits when repeatedly connected to transmit modules with a higher voltage level.

70.7.2.4 Input signal amplitude

Receivers shall accept differential input signal peak-to-peak amplitudes produced by compliant transmitters connected without attenuation to the receiver, and still meet the BER requirement specified in 70.7.2.1. Note that this may be larger than the 1600 mV differential maximum of 70.7.1.5 due to the actual transmitter output and receiver input impedances. The input impedance of a receiver can cause the minimum signal into a receiver to differ from that measured when the receiver is replaced with a 100 Ω test load. Since the receiver is AC-coupled, the absolute voltage levels with respect to the receiver ground are dependent on the receiver implementation.

70.7.2.5 Differential input return loss

For frequencies from 50 MHz to 1250 MHz, the differential return loss, in dB with f in MHz, of the receiver shall meet the requirements of Equation (70–1) and Equation (70–2). This return loss requirement applies to all valid input levels. The reference impedance for differential return loss measurements shall be 100 Ω.

70.8 Interconnect characteristics

Informative interconnect characteristics for 1000BASE-KX are provided in Annex 69B.

70.9 Environmental specifications

70.9.1 General safety

All equipment that meets the requirements of this standard shall conform to applicable sections (including isolation requirements) of IEC 60950-1.

70.9.2 Network safety

The designer is urged to consult the relevant local, national, and international safety regulations to ensure compliance with the appropriate requirements.

70.9.3 Installation and maintenance guidelines

It is recommended that sound installation practice, as defined by applicable local codes and regulations, be followed in every instance in which such practice is applicable.

70.9.4 Electromagnetic compatibility

A system integrating the 1000BASE-KX PHY shall comply with applicable local and national codes for the limitation of electromagnetic interference.

70.9.5 Temperature and humidity

A system integrating the 1000BASE-KX PHY is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling (such as shock and vibration). Specific requirements and values for these parameters are considered to be beyond the scope of this standard.

70.10 Protocol implementation conformance statement (PICS) proforma for Clause 70, Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-KX[26]

70.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3, Clause 70, Physical Medium Dependent (PMD) sublayer and baseband medium type 1000BASE-KX, shall complete the following protocol implementation conformance statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

70.10.2 Identification

70.10.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

70.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 70, Physical Medium Dependent (PMD) sublayer and baseband medium type 1000BASE-KX
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[26] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

70.10.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
GMII	GMII	70.1, 35	Interface is supported	O	Yes [ ] No [ ]
PCS	Support of 1000BASE-X PCS/PMA	70.1, 36		M	Yes [ ] No [ ]
AN	Auto-Negotiation for Backplane Ethernet	70.1, 73	Device implements Auto-Negotiation for Backplane Ethernet	M	Yes [ ]
FD	Full duplex operation	70.1	Clause 36 PCS/PMA when used with 1000GBASE-KX supports full-duplex operation only	M	Yes [ ]
DC	Delay Constraints	70.4	Device conforms to delay constraints	M	Yes [ ]
LPI	LPI	70.6.10	Capable of LPI	O	Yes [ ] No [ ]
*MD	MDIO interface	70.5	Device implements MDIO	O	Yes [ ] No [ ]
*SD	Signal Detect Generation	70.6.4	Signal detect implemented	O	Yes [ ] No [ ]
*TD	PMD_transmit_disable	70.6.5		O	Yes [ ] No [ ]

70.10.4 PICS proforma tables for Clause 70, Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-KX

70.10.4.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	Transmit function	70.6.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FS2	Transmitter signal	70.6.2	A positive differential voltage corresponds to tx_bit = ONE	M	Yes [ ]
FS3	Receive function	70.6.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FS4	Receiver signal	70.6.3	A positive differential voltage corresponds to rx_bit = ONE	M	Yes [ ]
FS5	PMD Signal Detect function	70.6.4	Continuously reported OK via PMD_SIGNAL.indication (SIGNAL_DETECT).	!SD:M	Yes [ ] No [ ]
FS6	PMD Signal Detect during LPI	70.6.4	Indicate signal energy during LPI	LPI:M	Yes [ ] N/A [ ]
FS7	Transmit Disable during LPI	70.6.5	Disable transmitter during tx_quiet	LPI:M	Yes [ ] N/A [ ]
FS8	Signal Detect for EEE	70.6.4	Transition timing to set SIGNAL_DETECT	LPI:M	Yes[ ] N/A [ ]
FS9	Transmit Disable	70.6.5	Disables Transmitter when PMD_Transmit_disable set to ONE	TD:M	Yes [ ] N/A [ ]
FS10	PMD_fault	70.6.5	Transmit disabled if detected	TD:O	Yes [ ] No [ ] N/A [ ]
FS11	PMD_transmit_disable	70.6.5	Loopback function not affected	TD:M	Yes [ ] N/A [ ]
FS12	tx_quiet disabled transmitter	70.7.1	Disables Transmitter when tx_quiet is asserted as specified in 70.7.1.5	LPI:M	Yes [ ] N/A [ ]
FS13	Loopback Function	70.6.6	Loopback function provided	M	Yes [ ]
FS14	Loopback affect on Transmitter	70.6.6	Loopback function does not disable transmitter	M	Yes [ ]

70.10.4.2 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
MF1	MDIO Variable Mapping	70.5	Per Table 70–2 and Table 70–3	MD:M	Yes [ ] N/A [ ]
MF2	PMD_fault function	70.6.7	Sets PMD_fault to a logical 1 if any local fault is detected; otherwise, set to 0	MD:M	Yes [ ] N/A [ ]
MF3	PMD_transmit_fault function	70.6.8	Sets PMD_transmit_fault to a logical 1 if any local fault is detected on the transmit path; otherwise, set to 0	MD:M	Yes [ ] N/A [ ]
MF4	PMD_receive_fault function	70.6.9	Sets PMD_receive_fault to a logical 1 if any local fault is detected on the receive path; otherwise, set to 0	MD:M	Yes [ ] N/A [ ]

70.10.4.3 Transmitter electrical characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
TC1	100 Ω differential test fixture	70.7.1.2	With return loss > 20 dB from 50 MHz to 625 MHz	M	Yes [ ]
TC2	Signaling speed	70.7.1.3	1.25 GBd ± 100ppm	M	Yes [ ]
TC3	Output waveform within template per Figure 70–3	70.7.1.4		M	Yes [ ]
TC4	Differential peak-to-peak output voltage	70.7.1.5	Between 800 mV and 1600 mV while transmitting test pattern specified in 36A.2	M	Yes [ ]
TC5	Common-mode output voltage	70.7.1.5	Between –0.4 V and 1.9 V	M	Yes [ ]
TC6	Output Return Loss	70.7.1.6	Per Equation (70–1) and Equation (70–2)	M	Yes [ ]
TC7	Reference Impedance	70.7.1.6	100 Ω for differential return loss measurements	M	Yes [ ]
TC8	Transmit jitter, peak-to-peak	70.7.1.8	Max TJ of 0.25 UI. Max DJ of 0.10 UI	M	Yes [ ]
TC9	Output Amplitude LPI voltage	70.7.1.5	Less than 30 mV within 500 ns of tx_quiet	LPI:M	Yes [ ] N/A [ ]
TC10	Output Amplitude ON voltage	70.7.1.5	Greater than 720 mV within 500 ns of tx_quiet de-asserted	LPI:M	Yes [ ] N/A [ ]
TC11	Jitter test patterns	70.7.1.9	Jitter test frame per 59.7.1	M	Yes [ ]

70.10.4.4 Receiver electrical characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
RC1	Receiver interference tolerance measurement method	70.7.2.1	Per Annex 69A with parameters specified in Table 70–7	M	Yes [ ]
RC2	Receiver interference tolerance test pattern	70.7.2.1	Per 70.7.2.1	M	Yes [ ]
RC3	Receiver interference tolerance requirements	70.7.2.1	Satisfy requirements per Annex 69A	M	Yes [ ]
RC4	Input signaling speed in the range of 1.25 GBd ± 100ppm	70.7.2.2	Receiver meets requirements of Table 70–7	M	Yes [ ]
RC5	Receiver AC-coupled	70.7.2.3		M	Yes [ ]
RC6	Input signal amplitude	70.7.2.4	BER still met when compliant transmitter is connected with no attenuation	M	Yes [ ]
RC7	Differential input return loss	70.7.2.5	Per Equation (70–1) and Equation (70–2)	M	Yes [ ]
RC8	Reference Impedance	70.7.2.5	100 Ω for differential return loss measurements	M	Yes [ ]

70.10.4.5 Environmental and safety specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	70.9.1	Conforms to IEC 60950-1	M	Yes [ ]
ES2	Electromagnetic compatibility	70.9.4	Comply with applicable local and national codes	M	Yes [ ]

71. Physical Medium Dependent sublayer and baseband medium, type 10GBASE-KX4

71.1 Overview

This clause specifies the 10GBASE-KX4 PMD and the baseband medium. When forming a complete PHY, a PMD shall be connected to the appropriate sublayers (see Table 71–1), and with the management functions that are optionally accessible through the management interface defined in Clause 45, or equivalent.

The XAUI, defined by Clause 47, is intended for chip-to-chip applications for lengths up to approximately 0.5 m. 10GBASE-KX4 is intended for backplane applications up to 1 m in length.

Table 71–1—Physical Layer clauses associated with the 10GBASE-KX4 PMD

Associated clause	10GBASE-KX4
46—XGMII[a]	Optional
47—XGXS and XAUI	Optional
48—10GBASE-X PCS/PMA	Required
73—Auto-Negotiation for Backplane Ethernet	Required
78—EEE	Optional

[a] The XGMII is an optional interface. However, if the XGMII is not implemented, a conforming implementation must behave functionally as though the RS and XGMII were present.

A 10GBASE-KX4 PHY with the optional Energy-Efficient Ethernet (EEE) capability may optionally enter the Low Power Idle (LPI) mode to conserve energy during periods of low link utilization. The “Assert LPI” request at the XGMII is encoded in the transmitted symbols. Detection of LPI signaling in the received symbols is indicated as “Assert LPI” at the XGMII. Upon the detection of “Assert LPI” at the XGMII, an energy-efficient 10GBASE-KX4 PHY continues transmitting for a predefined period, then ceases transmission and deactivates transmit functions to conserve energy. The PHY periodically transmits during this quiet period to allow the remote PHY to refresh its receiver state (e.g., timing recovery, adaptive filter coefficients) and thereby track long-term variations in the timing of the link or the underlying channel characteristics. If, during the quiet or refresh periods, normal interframes resume at the XGMII, the PHY reactivates transmit functions and initiates transmission. This transmission will be detected by the remote PHY, causing it to also exit the LPI mode.

71.2 Physical Medium Dependent (PMD) service interface

The 10GBASE-KX4 PMD utilizes the PMD service interface defined in 53.1.1.

The following primitives are defined on the PMD Service Interface when EEE is supported:

PMD_RXQUIET.request(rx_quiet)
PMD_TXQUIET.request(tx_quiet)

These messages are defined for the PCS in 48.2.6.1.7.

71.2.1 PMD_RXQUIET.request

This primitive is generated by the PCS Receive Process when EEE is supported to indicate that the input signal is quiet and the PMA and PMD receiver may go into a low power mode. When EEE is not supported, the primitive is never invoked and the PMD behaves as if rx_quiet = FALSE.

71.2.1.1 Semantics of the service primitive

PMD_RXQUIET.request (rx_quiet)

The rx_quiet parameter takes on one of two values: TRUE or FALSE.

71.2.1.2 When generated

The PCS generates this primitive to request the appropriate PMD receive LPI state.

71.2.1.3 Effect of receipt

This variable is from the Receive process of the PCS to control the power-saving function of the local receiver. The 10GBASE-KX4 PHY receiver should put unused functional blocks into a low power state to save energy.

71.2.2 PMD_TXQUIET.request

This primitive is generated by the PCS Transmit Process when EEE is supported to indicate that the PMA and PMD transmit functions may go into a low power mode and to disable the PMD transmitter. When EEE is not supported, the primitive is never invoked and the PMD behaves as if tx_quiet = FALSE.

71.2.2.1 Semantics of the service primitive

PMD_TXQUIET.request (tx_quiet)

The tx_quiet parameter takes on one of two values: TRUE or FALSE.

71.2.2.2 When generated

The PCS generates this primitive to request the appropriate PMD transmit LPI state.

71.2.2.3 Effect of receipt

This primitive affects operation of the PMD Transmit disable function as described in 71.6.6. The 10GBASE-KX4 PHY transmitter should put unused functional blocks into a lower power state to save energy.

71.3 PCS requirements for Auto-Negotiation (AN) service interface

The PCS associated with this PMD shall support the AN service interface primitive AN_LINK.indication defined in 73.9. (See 48.2.7.)

71.4 Delay constraints

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers must consider the delay maxima, and that network planners and administrators consider the delay constraints regarding the physical topology and concatenation of devices. A description of overall system delay constraints and the definitions for bit-times and pause_quanta can be found in 69.3.

The sum of transmit and receive delays contributed by the 10GBASE-KX4 PMD and medium shall be no more than 512 bit times or 1 pause_quanta. It is assumed that the round-trip delay through the medium is 160 bit times.

71.5 PMD MDIO function mapping

The optional MDIO capability described in Clause 45 defines several variables that provide control and status information for and about the PMD. If the MDIO is implemented, it shall map MDIO control variables to PMD control variables as shown in Table 71–2 and MDIO status variables to PMD status variables as shown in Table 71–3.

Table 71–2—MDIO/PMD control variable mapping

MDIO control variable	PMA/PMD register name	Register/ bit number	PMD control variable
Reset	Control register 1	1.0.15	PMD_reset
Global Transmit Disable	Transmit disable register	1.9.0	Global_PMD_transmit_disable
Transmit disable 3	Transmit disable register	1.9.4	PMD_transmit_disable_3
Transmit disable 2	Transmit disable register	1.9.3	PMD_transmit_disable_2
Transmit disable 1	Transmit disable register	1.9.2	PMD_transmit_disable_1
Transmit disable 0	Transmit disable register	1.9.1	PMD_transmit_disable_0

71.6 PMD functional specifications

The 10GBASE-KX4 PMD performs the transmit and receive functions that convey data between the PMD service interface and the MDI, and provides various management functions if the optional MDIO is implemented.

71.6.1 Link block diagram

For purposes of system conformance, the PMD sublayer is standardized at test points TP1 and TP4 as shown in Figure 71–1. The transmitter and receiver blocks include all off-chip components associated with the respective block. For example, external AC-coupling capacitors, if required, are to be included in the receiver block.

Table 71–3—MDIO/PMD status variable mapping

MDIO status variable	PMA/PMD register name	Register/ bit number	PMD status variable
Fault	Status register 1	1.1.7	PMD_fault
Transmit fault	Status register 2	1.8.11	PMD_transmit_fault
Receive fault	Status register 2	1.8.10	PMD_receive_fault
Global PMD Receive signal detect	Receive signal detect register	1.10.0	Global_PMD_signal_detect
PMD signal detect 3	Receive signal detect register	1.10.4	PMD_signal_detect_3
PMD signal detect 2	Receive signal detect register	1.10.3	PMD_signal_detect_2
PMD signal detect 1	Receive signal detect register	1.10.2	PMD_signal_detect_1
PMD signal detect 0	Receive signal detect register	1.10.1	PMD_signal_detect_0

The electrical path from the transmitter block to TP1, and from TP4 to the receiver block, will affect link performance and the measured values of electrical parameters used to verify conformance to this specification. It is therefore recommended that this path be carefully designed.

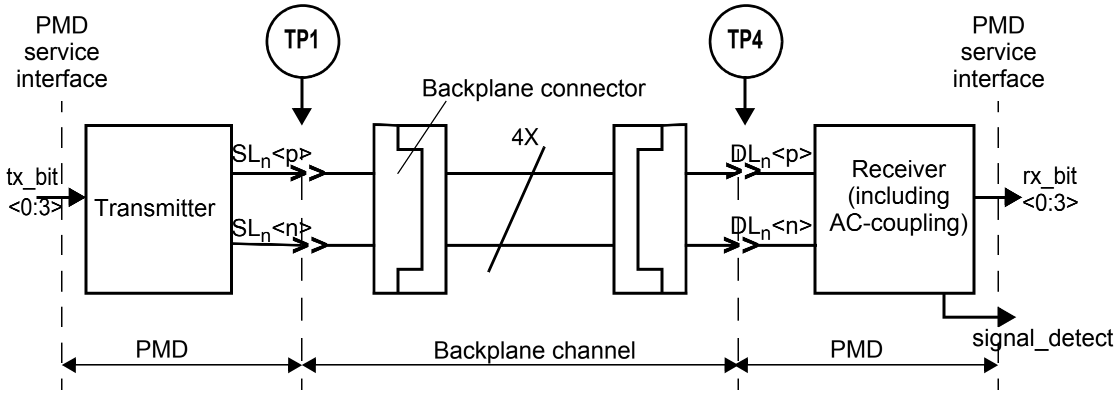

Figure 71–1—Link block diagram

71.6.2 PMD Transmit function

The PMD Transmit function shall convert the four logical bit streams requested by the PMD service interface message PMD_UNITDATA.request (tx_bit<0:3>) into four separate electrical signal streams. The four electrical signal streams shall then be delivered to the MDI, all according to the specifications in 71.7.1. A positive output voltage of SLn<p> minus SLn<n> (differential voltage) shall correspond to tx_bit = ONE.

The PMD shall convey the bits received from the PMD service interface using the message PMD_UNITDATA.request(tx_bit<0:3>) to the MDI lanes, where SL0<p>/<n> corresponds to tx_bit<0>, SL1<p>/<n> to tx_bit<1>, SL2<p>/<n> to tx_bit<2>, and SL3<p>/<n>) = tx_bit<3>.

71.6.3 PMD Receive function

The PMD Receive function shall convert the four electrical signal streams from the MDI into four logical bit streams for delivery to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit<0:3>), all according to the receive electrical specifications in 71.7.2. A positive input voltage level in each signal stream of DLn<p> minus DLn<n> (differential voltage) shall correspond to a rx_bit = ONE.

The PMD shall convey the bits received from the MDI lanes to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit<0:3>), where rx_bit<0:3> = (DL0<p>/<n>, DL1<p>/<n>, DL2<p>/<n>, DL3<p>/<n>).

71.6.4 Global PMD signal detect function

For 10GBASE-KX4 operation Global PMD signal detect is mandatory if EEE is supported. When EEE is not implemented, the PMD signal detect is optional for 10GBASE-KX4 and its definition is beyond the scope of this standard. When Global PMD signal detect is not implemented, the value of SIGNAL_DETECT shall be set to OK for purposes of management and signaling of the primitive.

If EEE is supported, a local PMD signal detect function shall report to the PMD service interface using the message PMD_SIGNAL.indication(SIGNAL_DETECT). This message is signaled continuously. For EEE, the SIGNAL_DETECT parameter can take on one of two values, OK or FAIL, indicating whether the PMD is detecting electrical energy at the receiver (OK) or not (FAIL). When SIGNAL_DETECT = FAIL, PMD_UNITDATA.indication(rx_lane<3:0>) is undefined. The signal energy from a compliant transmitter shall set SIGNAL_DETECT to OK within 750 ns when transitioning from LPI quiet to active and set SIGNAL_DETECT to FAIL within 750 ns when transitioning from active to LPI quiet.

71.6.5 PMD lane-by-lane signal detect function

When the MDIO is implemented, each PMD_signal_detect_n value, where n represents the lane number in the range 0:3, shall report the value of SIGNAL_DETECT for the corresponding lane when signal detect is implemented, or OK otherwise.

71.6.6 Global PMD transmit disable function

The Global_PMD_transmit_disable function is mandatory if EEE is supported and is otherwise optional. When implemented, it allows all of the transmitters to be disabled with a single variable.

a) When the Global_PMD_transmit_disable variable is set to ONE, this function shall turn off all of the transmitters such that each transmitter drives a constant level (i.e., no transitions) and does not exceed the maximum differential peak-to-peak output voltage specified in Table 71–4.
b) If a PMD_fault (71.6.9) is detected, then the PMD may turn off the electrical transmitter in all lanes.
c) Loopback, as defined in 71.6.8, shall not be affected by Global_PMD_transmit_disable.
d) For EEE capability, the PMD_transmit_disable function shall turn off all transmitter lanes after tx_quiet is asserted within a time and voltage level specified in 71.7.1.4. The PMD_transmit_disable function shall turn on all transmitter lanes after tx_quiet is de-asserted within a time and voltage level specified in 71.7.1.4.

71.6.7 PMD lane-by-lane transmit disable function

The PMD_transmit_disable_n function shall be implemented. It allows the electrical transmitters in each lane to be selectively disabled.

a) When a PMD_transmit_disable_n variable is set to ONE, this function shall turn off the transmitter associated with that variable such that the corresponding transmitter drives a constant level (i.e., no transitions) and does not exceed the maximum differential peak-to-peak output voltage specified in Table 71–4.
b) If a PMD_fault (71.6.9) is detected, then the PMD may turn off the electrical transmitter in all lanes.
c) Loopback, as defined in 71.6.8, shall not be affected by PMD_transmit_disable_n.

NOTE—Turning off a transmitter can be disruptive to a network.

71.6.8 Loopback mode

Loopback mode shall be provided for the 1000BASE-KX4 PMA/PMD by the transmitter and receiver of a device as a test function to the device. When loopback mode is selected, transmission requests passed to the transmitter are shunted directly to the receiver, overriding any signal detected by the receiver on its attached link. Transmitter operation shall be independent of loopback mode. A device must be explicitly placed in loopback mode because loopback mode is not the normal mode of operation of a device. The method of implementing loopback mode is not defined by this standard.

Control of the loopback function is specified in 45.2.1.1.5.

NOTE 1—The signal path that is exercised in the loopback mode is implementation specific, but it is recommended that this signal path encompass as much of the circuitry as is practical. The intention of providing this loopback mode of operation is to permit diagnostic or self-test functions to test the transmit and receive data paths using actual data. Other loopback signal paths may also be enabled independently using loopback controls within other devices or sublayers.

NOTE 2—Placing a network port into loopback mode can be disruptive to a network.

71.6.9 PMD fault function

If the MDIO is implemented, and the PMD has detected a local fault on any of the transmit or receive paths, the PMD shall set PMD_fault to ONE; otherwise, the PMD shall set PMD_fault to ZERO.

71.6.10 PMD transmit fault function

If the MDIO is implemented, and the PMD has detected a local fault on any transmit lane, the PMD shall set the PMD_transmit_fault variable to ONE; otherwise, the PMD shall set PMD_transmit_fault to ZERO.

71.6.11 PMD receive fault function

If the MDIO is implemented, and the PMD has detected a local fault on any receive lane, the PMD shall set the PMD_receive_fault variable to ONE; otherwise, the PMD shall set PMD_receive_fault to ZERO.

71.6.12 PMD LPI function

The PMD LPI function responds to transitions between Active, Sleep, Quiet, Refresh, and Wake states via the PMD_TXQUIET and PMD_RXQUIET requests. Implementation of the function is optional. EEE capabilities and parameters, as described in 45.2.7, is advertised during the Backplane Auto-negotiation. The transmitter on the local device will inform the link partner’s receiver when to sleep, refresh, and wake. The local receiver transitions are controlled by the link partner’s transmitter and can change independent of the local transmitter states and transitions.

The transmitter sends /LI/ ordered sets during the sleep and refresh states, disables the transmitter during quiet, and forwards ||I|| during the wake phase.

If EEE is supported, the PMD transmit function enters into a low power mode when tx_quiet is set to TRUE and exits when tx_quiet is set to FALSE. While tx_quiet is TRUE the PMD transmitter functional blocks should be deactivated to conserve energy. The PMD receive function enters into a low power mode when rx_quiet is set to TRUE and exits when rx_quiet is set to FALSE. While rx_quiet is TRUE, the PMD receiver functional blocks should be deactivated to conserve energy.

71.7 Electrical characteristics for 10GBASE-KX4

71.7.1 Transmitter characteristics

Transmitter characteristics at TP1 are summarized in Table 71–4.

Table 71–4—Transmitter characteristics for 10GBASE-KX4

Parameter	Subclause reference	Value	Units
Signaling speed, per lane	71.7.1.3	3.125 ± 100 ppm	GBd
Differential peak-to-peak output voltage	71.7.1.4	800 to 1200	mV
Differential peak-to-peak output voltage (max.) with TX disabled	71.6.6, 71.6.7	30	mV
Common-mode voltage limits	71.7.1.4	–0.4 to 1.9	V
Common-mode voltage deviation (max) during LPI	71.7.1.4	150	mV
Differential output return loss (min.)	71.7.1.5	[See Equation (71–1) and Equation (71–2)]	dB
Differential output template	71.7.1.6	[See Figure 71–5 and Table 71–5]	V
Transition time[a] (20%–80%)	71.7.1.7	60 to 130	ps
Output jitter (max. peak-to-peak) Random jitter Deterministic jitter Total jitter[b]	71.7.1.8	 0.27 0.17 0.35	 UI UI UI

[a] Transition time parameters are recommended values, not compliance values.
[b] At BER 10^{-12}.

71.7.1.1 Test fixtures

The test fixture of Figure 71–2, or its functional equivalent, is required for measuring the transmitter specifications described in 71.7.1, with the exception of return loss.

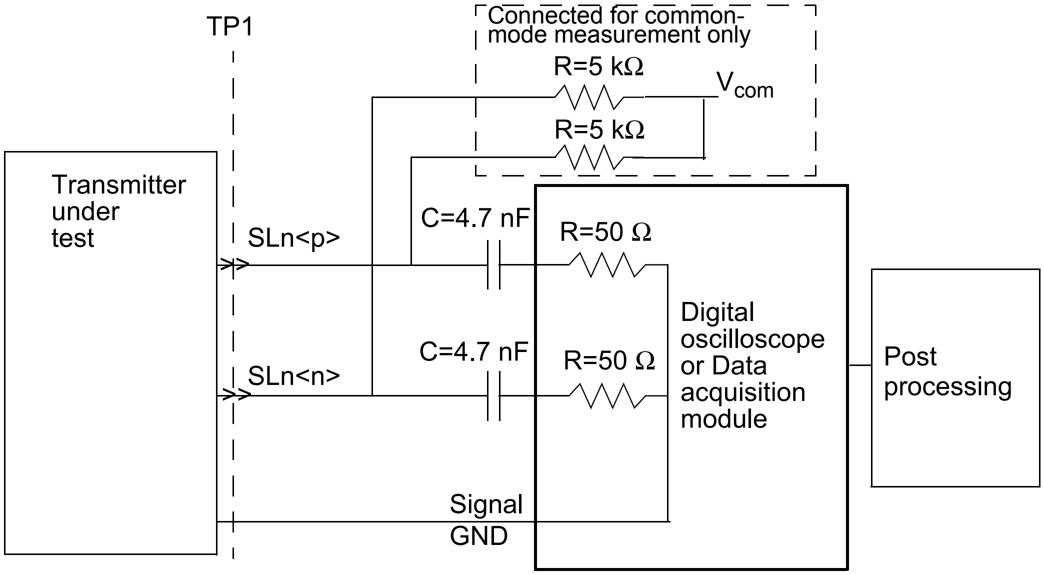

Figure 71–2—Transmit test fixture for 10GBASE-KX4

71.7.1.2 Test fixture impedance

The differential load impedance applied to the transmitter output by the test fixture depicted in Figure 71–2 shall be 100 Ω with a return loss greater than 20 dB from 100 MHz to 2000 MHz.

71.7.1.3 Signaling speed

The 10GBASE-KX4 signaling speed shall be 3.125 GBd ±100 ppm. The corresponding unit interval is nominally 320 ps.

71.7.1.4 Output amplitude

While transmitting the test pattern specified in 48A.2,

1) The transmitter maximum differential peak-to-peak output voltage shall be less than 1200 mV.
2) The minimum differential peak-to-peak output voltage shall be greater than 800 mV.
3) The maximum difference between any two lanes' differential peak-to-peak output voltage shall be less than or equal to 150 mV.

See Figure 71–3 for an illustration of the definition of differential peak-to-peak output voltage.

DC-referenced voltage levels are not defined since the receiver is AC-coupled. The common-mode voltage of SLn<p> and SLn<n> shall be between –0.4 V and 1.9 V with respect to signal ground as measured at V_{com} in Figure 71–2.

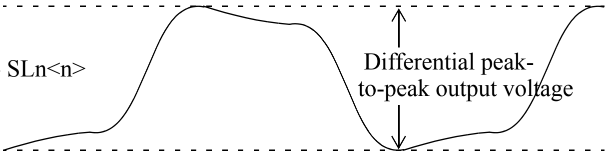

Figure 71–3—Transmitter differential peak-to-peak output voltage definition

NOTE—SLn<p> and SLn<n> are the positive and negative sides of the differential signal pair for Lane n (n = 0,1,2,3).

For EEE capability, the transmitter lane's differential peak-to-peak output voltage shall be less than 30 mV within 500 ns of tx_quiet being asserted. Furthermore, the transmitter lane's differential peak-to-peak output voltage shall be greater than 720 mV within 500 ns of tx_quiet being de-asserted. The transmitter output shall be fully compliant within 5 µs after tx_quiet is set to FALSE. During LPI, the common-mode shall be maintained to within ± 150 mV of the pre-LPI value.

71.7.1.5 Output return loss

For frequencies from 100 MHz to 2000 MHz, the differential return loss, in dB with f in MHz, of the transmitter shall meet the requirements of Equation (71–1) and Equation (71–2). This output impedance requirement applies to all valid output levels. The reference impedance for differential return loss measurements shall be 100 Ω.

$$\mathrm{ReturnLoss}(f) \geq 10 \tag{71–1}$$

for 100 MHz ≤ f < 625 MHz and

$$\mathrm{ReturnLoss}(f) \geq 10 - 10 \times \log_{10}\left(\frac{f}{625}\right) \tag{71–2}$$

for 625 MHz ≤ f ≤ 2000 MHz

The minimum differential output return loss is shown in Figure 71–4.

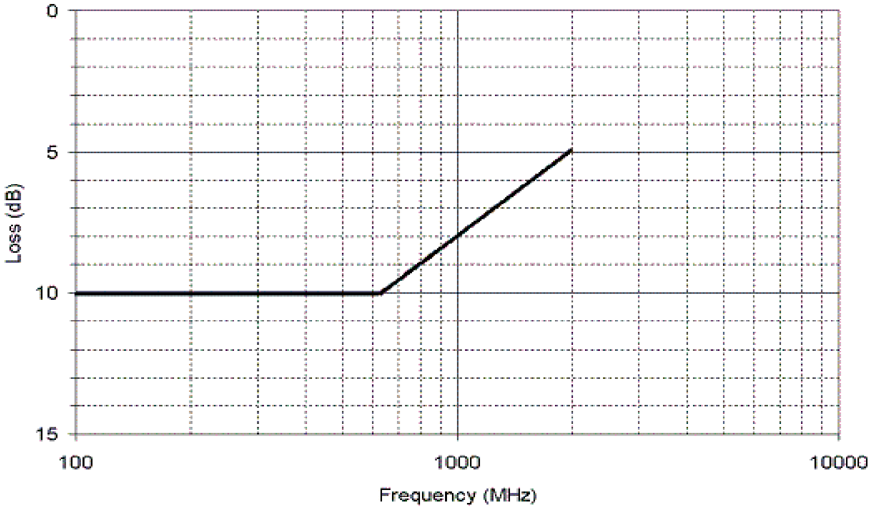

Figure 71–4—Minimum differential output return loss

71.7.1.6 Differential output template

The transmitter differential output signal is defined at TP1, as shown in Figure 71–2 and Figure 71–3. The transmitter shall provide equalization such that the output waveform falls within the template shown in Figure 71–5 for the test pattern specified in 48A.2, with all other transmitters active. All other transmitters shall be terminated with a load meeting the requirements described in 71.7.1.2. Voltage and time coordinates for inflection points on Figure 71–5 are given in Table 71–5. The waveform under test shall be normalized by using the following procedure:

a) Align the output waveform under test, to achieve the best fit along the horizontal time axis.
b) Calculate the +1 low frequency level as V_{lowp} = average of any two successive unit intervals (2UI) between 2.5 UI and 5.5 UI.
c) Calculate the 0 low frequency level as V_{lowm} = average of any two successive unit intervals (2UI) between 7.5 UI and 10.5 UI.
d) Calculate the vertical offset to be subtracted from the waveform as $V_{off} = (V_{lowp} + V_{lowm}) / 2$.
e) Calculate the vertical normalization factor for the waveform as $V_{norm} = (V_{lowp} – V_{lowm}) / 2$.
f) Calculate the normalized waveform as:
Normalized_Waveform = (Original_Waveform – V_{off}) × (0.69/V_{norm}).
g) Align the Normalized_Waveform under test, to achieve the best fit along the horizontal time axis.

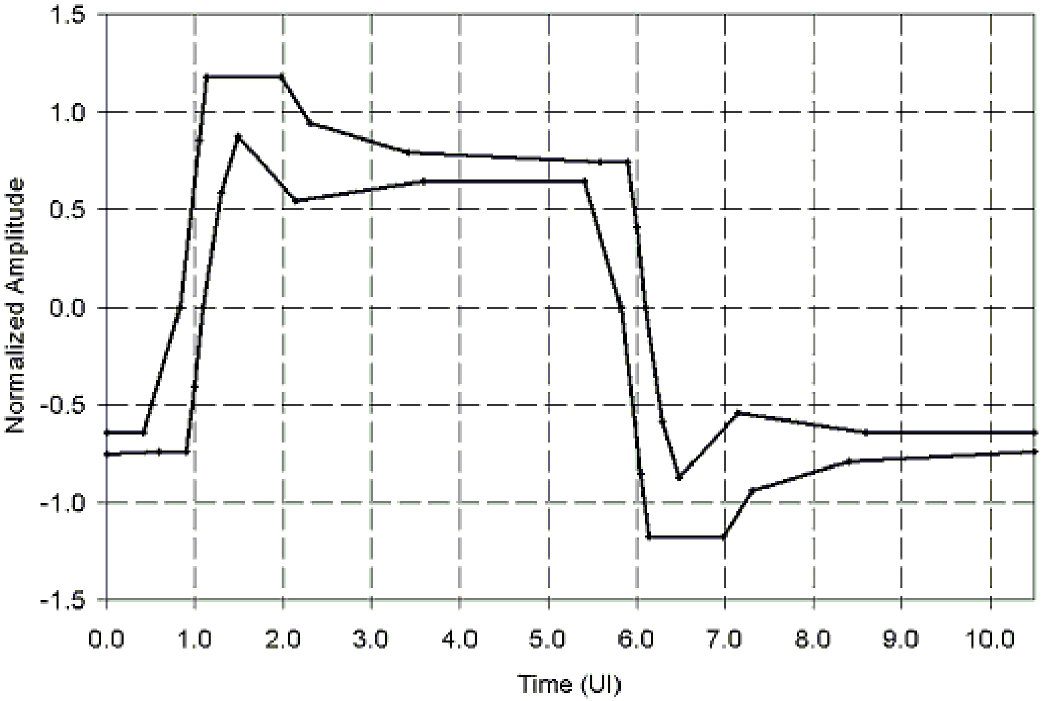

Figure 71–5—Normalized transmit template

Table 71–5—Normalized transmit time domain template

Upper limit				Lower limit			
Time (UI)	Amplitude	Time (UI)	Amplitude	Time (UI)	Amplitude	Time (UI)	Amplitude
0.000	–0.640	5.897	0.740	0.000	–0.754	5.409	0.640
0.409	–0.640	5.997	0.406	0.591	–0.740	5.828	0.000
0.828	0.000	6.094	0.000	0.897	–0.740	6.050	–0.856
1.050	0.856	6.294	–0.586	0.997	–0.406	6.134	–1.175
1.134	1.175	6.491	–0.870	1.094	0.000	6.975	–1.175
1.975	1.175	7.141	–0.546	1.294	0.586	7.309	–0.940
2.309	0.940	8.591	–0.640	1.491	0.870	8.500	–0.790
3.409	0.790	10.500	–0.640	2.141	0.546	10.500	–0.742
5.591	0.740			3.591	0.640		

71.7.1.7 Transition time

The rising edge transition time is recommended to be between 60 ps and 130 ps as measured at the 20% and 80% levels of the peak-to-peak differential value of the waveform using the high-frequency test pattern of 48A.1. The falling edge transition time is recommended to be between 60 ps and 130 ps as measured at the 80% and 20% levels of the peak-to-peak differential value of the waveform using the high-frequency test pattern of 48A.1.

71.7.1.8 Transmit jitter

The transmitter shall have a maximum total jitter of 0.350 UI peak-to-peak, a maximum deterministic component of 0.170 UI peak-to-peak, and a maximum random component of 0.270 UI peak-to-peak. Jitter specifications include all but 10^{-12} of the jitter population. Transmit jitter test requirements are specified in 71.7.1.9.

71.7.1.9 Transmit jitter test requirements

Transmit jitter is defined with respect to the transmitter differential output signal at TP1, as shown in Figure 71–2 and Figure 71–5, and the test procedure resulting in a BER bathtub curve such as that described in Annex 48B. For the purpose of jitter measurement, the effect of a single-pole high-pass filter with a 3 dB point at 1.875 MHz is applied to the jitter. The data pattern for jitter measurements shall be the jitter tolerance test pattern defined in Annex 48A.5. For this test, all other transmitters shall be active and terminated with a load meeting the requirements described in 71.7.1.2. Crossing times are defined with respect to the mid-point (0 V) of the AC-coupled differential signal.

71.7.2 Receiver characteristics

Receiver characteristics at TP4 are summarized in Table 71–6 and detailed in 71.7.2.1 through 71.7.2.5.

Table 71–6—Receiver characteristics

Parameter	Subclause reference	Value	Units
Bit error ratio	71.7.2.1	10^{-12}	
Signaling speed, per lane	71.7.2.2	3.125 ± 100 ppm	GBd
Unit interval (UI) nominal	71.7.2.2	320	ps
Receiver coupling	71.7.2.3	AC	
Differential input peak-to-peak amplitude (maximum)	71.7.2.4	1600	mV
EEE Signal Detect deactivation time (T_{SD}) from active to LPI quiet	71.6.4	750	ns
EEE Signal Detect activation time (T_{SA}) from LPI quiet to active	71.6.4	750	ns
Differential input return loss[a] (minimum)	71.7.2.5	[See Equation (71–1) and Equation (71–2)]	dB

[a] Relative to 100 Ω differential.

71.7.2.1 Receiver interference tolerance

The receiver interference tolerance shall be measured as described in Annex 69A with the parameters specified in Table 71–7. The data pattern for the interference tolerance test shall be the continuous jitter test pattern as defined in Annex 48A.5. The receiver shall satisfy the requirements for interference tolerance specified in Annex 69A.

Table 71–7—10GBASE-KX4 interference tolerance parameters

Parameter	Value	Units
Target BER	10^{-12}	
m_{TC}[a] (min.)	1.0	
Amplitude of broadband noise (min. RMS)	8.1	mV
Applied transition time (20%–80%, min.)	130	ps
Applied sinusoidal jitter (min. peak-to-peak)	0.17	UI
Applied random jitter (min. peak-to-peak)[b]	0.18	UI
Applied duty cycle distortion (min. peak-to-peak)	0.0	UI

[a] m_{TC} is defined in Equation (69A–6) of Annex 69A.
[b] Applied random jitter is specified at a BER of 10^{-12}.

71.7.2.2 Signaling speed

The 10GBASE-KX4 signaling speed shall be 3.125 GBd ± 100 ppm. The corresponding unit interval is nominally 320 ps.

71.7.2.3 AC-coupling

The 10GBASE-KX4 receiver shall be AC-coupled to the backplane to allow for maximum interoperability between various 10 Gb/s components. AC-coupling is considered to be part of the receiver for the purposes of this specification unless explicitly stated otherwise. It should be noted that there may be various methods for AC-coupling in actual implementations.

NOTE—It is recommended that the maximum value of the coupling capacitors be limited to 4.7 nF. This will limit the inrush currents to the receiver that could damage the receiver circuits when repeatedly connected to transmit modules with a higher voltage level.

71.7.2.4 Input signal amplitude

10GBASE-KX4 receivers shall accept differential input signal peak-to-peak amplitudes produced by compliant transmitters connected without attenuation to the receiver, and still meet the BER requirement specified in 71.7.2.1. Note that this may be larger than the 1200 mV differential maximum of 71.7.1.4 due to the actual transmitter output and receiver input impedances. The input impedance of a receiver can cause the minimum signal into a receiver to differ from that measured when the receiver is replaced with a 100 Ω test load. Since the channel is AC-coupled, the absolute voltage levels with respect to the receiver ground are dependent on the receiver implementation.

71.7.2.5 Differential input return loss

For frequencies from 100 MHz to 2000 MHz, the differential return loss, in dB with *f* in MHz, of the receiver shall be greater than or equal to Equation (71–1) and Equation (71–1). This return loss requirement applies to all valid input levels. The reference impedance for differential return loss measurements is 100 Ω.

71.8 Interconnect characteristics

Informative interconnect characteristics for 10GBASE-KX4 are provided in Annex 69B.

71.9 Environmental specifications

71.9.1 General safety

All equipment that meets the requirements of this standard shall conform to applicable sections (including isolation requirements) of IEC 60950-1.

71.9.2 Network safety

The designer is urged to consult the relevant local, national, and international safety regulations to ensure compliance with the appropriate requirements.

71.9.3 Installation and maintenance guidelines

It is recommended that sound installation practice, as defined by applicable local codes and regulations, be followed in every instance in which such practice is applicable.

71.9.4 Electromagnetic compatibility

A system integrating the 10GBASE-KX4 PHY shall comply with applicable local and national codes for the limitation of electromagnetic interference.

71.9.5 Temperature and humidity

A system integrating the 10GBASE-KX4 PHY is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling (such as shock and vibration). Specific requirements and values for these parameters are considered to be beyond the scope of this standard.

71.10 Protocol implementation conformance statement (PICS) proforma for Clause 71, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KX4[27]

71.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3, Clause 71, Physical Medium Dependent (PMD) sublayer and baseband medium type 10GBASE-KX4, shall complete the following protocol implementation conformance statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

71.10.2 Identification

71.10.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

71.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 71, Physical Medium Dependent (PMD) sublayer and baseband medium type 10GBASE-KX4
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[27] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

71.10.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
XGE	XGMII	71.1, 46	Interface is supported	O	Yes [ ] No [ ]
XGXS	XGXS and XAUI	71.1, 47		O	Yes [ ] No [ ]
PCS	Support of 10GBASE-X PCS/PMA	71.1, 48		M	Yes [ ]
AN	Auto-Negotiation for Backplane Ethernet	71.1, 73	Device implements Auto-Negotiation for Backplane Ethernet	M	Yes [ ]
DC	Delay Constraints	71.4	Device conforms to delay constraints	M	Yes [ ]
LPI	LPI function	71.6.12	LPI supported	O	Yes [ ] No [ ]
*MD	MDIO interface	71.5	Device implements MDIO	O	Yes [ ] No [ ]
*SD	Signal Detect Generation	71.6.4	Signal detect implemented	O	Yes [ ] No [ ]
*TD	Global_PMD_transmit_disable	71.6.6		O	Yes [ ] No [ ]

71.10.4 PICS proforma tables for Clause 71, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KX4

71.10.4.1 PCS requirements for AN service interface

Item	Feature	Subclause	Value/Comment	Status	Support
PR1	AN service interface primitive	71.3	The PCS associated with this PMD supports the AN service interface primitive AN_LINK.indication defined in 73.9	M	Yes [ ]

71.10.4.2 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	Transmit function	71.6.2	Convert the 4 logical signals requested by PMD_UNITDATA.request (tx_bit<0:3>) to 4 electrical signals	M	Yes [ ]
FS2	Delivery to the MDI	71.6.2	Supplies 4 electrical signal streams for delivery to the MDI per 71.7.1	M	Yes [ ]
FS3	Transmitter signal	71.6.2	A positive differential voltage corresponds to tx_bit = ONE	M	Yes [ ]
FS4	Transmit Signal order	71.6.2	PMD_UNITDATA.request(tx_bit<0:3>) = (SL0<p>/<n>, SL1<p>/<n>, SL2<p>/<n>, SL3<p>/<n>)	M	Yes [ ]
FS5	Receive function	71.6.3	Convert the 4 electrical signals received from the MDI to 4 logical signals PMD_UNITDATA.indication (rx_bit<0:3>) per 71.7.2	M	Yes [ ]
FS6	Receiver signal	71.6.3	A positive differential voltage corresponds to rx_bit = ONE	M	Yes [ ]
FS7	Receive Signal order	71.6.3	PMD_UNITDATA.request(rx_bit<0:3>) = (DL0<p>/<n>, DL1<p>/<n>, DL2<p>/<n>, DL3<p>/<n>)	M	Yes [ ]
FS8	Behavior when Global_PMD_signal_detect is not implemented	71.6.4	SIGNAL_DETECT = OK continuously	!SD:M	Yes [ ] N/A [ ]
FS9	Global_PMD_signal_detect function	71.6.4	Reported via PMD_SIGNAL.indication (SIGNAL_DETECT)	SD:M	Yes [ ] N/A [ ]
FS10	Global_PMD_signal_detect during LPI	71.6.4	Detect signal energy during LPI	LPI:M	Yes [ ] N/A [ ]
FS11	Signal Detect for EEE	71.6.4	Transition timing to set SIGNAL_DETECT	LPI:M	Yes [ ] N/A [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
FS12	Global_PMD_transmit_disable function	71.6.6	Disables all transmitters by forcing a constant level.	TD:M	Yes [ ] N/A [ ]
FS13	PMD_fault global effect	71.6.6	All transmitters disabled if detected	TD:O	Yes [ ] No [ ] N/A [ ]
FS14	Global_PMD_transmit_disable affect on loopback	71.6.6	Loopback function not affected	TD:M	Yes [ ] N/A [ ]
FS15	Global_PMD_transmit_disable during LPI	71.6.6	Disable transmitters during tx_quiet	LPI:M	Yes [ ] N/A [ ]
FS16	PMD_transmit_disable_n function implemented	71.6.7		M	Yes [ ]
FS17	PMD_transmit_disable_n action when enabled	71.6.7	Disables transmitter by forcing a constant level	M	Yes [ ]
FS18	PMD_transmit_disable_n affect on loopback	71.6.7	Loopback function not affected	M	Yes [ ]
FS19	Loopback Function	71.6.8	Loopback function provided	M	Yes [ ]
FS20	Loopback affect on transmitters	71.6.8	Loopback function does not disable transmitters	M	Yes [ ]
FS21	LPI function	71.6.12	PMD_RXQUIET.request and PMD_TXQUIET.request supported	LPI:M	Yes [ ] No [ ] N/A [ ]

71.10.4.3 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
MF1	MDIO Variable Mapping	71.5	Per Table 71–2 and Table 71–3	MD:M	Yes [ ] N/A [ ]
MF2	Lane-by-Lane Signal Detect function	71.6.5	Sets PMD_signal_detect_n values on a lane-by-lane basis per requirements of 71.6.5	MD*SD:M	Yes [ ] N/A [ ]
MF3	Lane-by-Lane Signal Detect function not implemented	71.6.5	PMD_signal_detect_n continuously indicated as OK	MD*!SD:M	Yes [ ] N/A [ ]
MF4	PMD_fault function	71.6.9	Sets PMD_fault to a logical 1 if any local fault is detected; otherwise, set to 0	MD:M	Yes [ ] N/A [ ]
MF5	PMD_transmit_fault function	71.6.10	Sets PMD_transmit_fault to a logical 1 if any local fault is detected on the transmit path; otherwise, set to 0	MD:M	Yes [ ] N/A [ ]
MF6	PMD_receive_fault function	71.6.11	Sets PMD_receive_fault to a logical 1 if any local fault is detected on the receive path; otherwise, set to 0	MD:M	Yes [ ] N/A [ ]

71.10.4.4 Transmitter electrical characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
TC1	100 Ω differential test fixture	71.7.1.2	With return loss > 20 dB from 100 MHz to 2000 MHz	M	Yes [ ]
TC2	Signaling speed	71.7.1.3	3.125 GBd ± 100 ppm	M	Yes [ ]
TC3	Maximum transmitter differential peak-to-peak voltage	71.7.1.4	Less than 1200 mV	M	Yes [ ]
TC4	Minimum transmitter differential peak-to-peak voltage	71.7.1.4	Greater than 800 mV	M	Yes [ ]
TC5	Maximum transmitter differential peak-to-peak voltage difference	71.7.1.4	Less than or equal to 150 mV	M	Yes [ ]
TC6	Common-mode output voltage	71.7.1.4	Between –0.4 V and 1.9 V	M	Yes [ ]
TC7	Output Amplitude LPI voltage	71.7.1.4	Less than 30 mV within 500 ns of tx_quiet	LPI:M	Yes [ ] N/A [ ]
TC8	Output Amplitude ON voltage	71.7.1.4	Greater than 720 mV within 500 ns of tx_quiet de-asserted	LPI:M	Yes [ ] N/A [ ]
TC9	Output Return Loss	71.7.1.5	Per Equation (71–1) and Equation (71–2)	M	Yes [ ]
TC10	Reference Impedance	71.7.1.5	100 Ω for differential return loss measurements	M	Yes [ ]
TC11	Output within transmit template per Figure 71–5	71.7.1.6	While sending pattern specified in 48A.2, with all other transmitters active	M	Yes [ ]
TC12	Other transmitters terminated	71.7.1.6	Per 71.7.1.2	M	Yes [ ]
TC13	Transmitter output normalization	71.7.1.6	Per defined process	M	Yes [ ]
TC14	Transmit jitter, peak-to-peak	71.7.1.8	See 71.7.1.9. Max TJ of 0.35 UI. Max DJ of 0.17 UI. Max RJ of 0.27 UI	M	Yes [ ]
TC15	Jitter test patterns	71.7.1.9	Per 48A.5	M	Yes [ ]
TC16	Other transmitters during jitter test	71.7.1.9	Other transmitters active and terminated per 71.7.1.2	M	Yes [ ]

71.10.4.5 Receiver electrical characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
RC1	Receiver interference tolerance	71.7.2.1	Per Annex 69A with parameters specified in Table 71–6	M	Yes [ ]
RC2	Receiver interference tolerance test pattern	71.7.2.1	Per 71.7.2.1	M	Yes [ ]
RC3	Receiver interference tolerance requirements	71.7.2.1	Satisfy requirements per Annex 69A	M	Yes [ ]
RC4	Signaling speed	71.7.2.2	3.125 GBd ±100 ppm	M	Yes [ ]
RC5	Receiver AC-coupled	71.7.2.3		M	Yes [ ]
RC6	Input signal amplitude	71.7.2.4	BER still met when compliant transmitter is connected with no attenuation	M	Yes [ ]
RC7	Differential return loss	71.7.2.5	Per Equation (71–1) and Equation (71–2)	M	Yes [ ]

71.10.4.6 Environmental and safety specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	71.9.1	Conforms to IEC 60950-1	M	Yes [ ]
ES2	Electromagnetic compatibility	71.9.4	Comply with applicable local and national codes	M	Yes [ ]

72. Physical Medium Dependent sublayer and baseband medium, type 10GBASE-KR

72.1 Overview

This clause specifies the 10GBASE-KR PMD and the baseband medium. When forming a complete PHY, a PMD shall be connected to the appropriate sublayers (see Table 72–1), and with the management functions that are optionally accessible through the management interface defined in Clause 45, or equivalent.

Table 72–1—Physical Layer clauses associated with the 10GBASE-KR PMD

Associated clause	10GBASE-KR
46—XGMII[a]	Optional
47—XGXS and XAUI	Optional
49—10GBASE-R PCS	Required
51—10-Gigabit Serial PMA	Required
73—Auto-Negotiation for Backplane Ethernet	Required
74—BASE-R FEC	Optional
78—Energy-Efficient Ethernet	Optional

[a] The XGMII is an optional interface. However, if the XGMII is not implemented, a conforming implementation must behave functionally as though the RS and XGMII were present.

A 10GBASE-KR PHY with the optional Energy-Efficient Ethernet (EEE) capability may optionally enter the Low Power Idle (LPI) mode to conserve energy during periods of low link utilization. The "Assert LPI" request at the XGMII is encoded in the transmitted symbols. Detection of LPI signaling in the received symbols is indicated as "Assert LPI" at the XGMII. Upon the detection of "Assert LPI" at the XGMII, an energy-efficient 10GBASE-KR PHY continues transmitting for a predefined period, then ceases transmission and deactivates transmit functions to conserve energy. The PHY periodically transmits during this quiet period to allow the remote PHY to refresh its receiver state (e.g., timing recovery, adaptive filter coefficients) and thereby track long-term variations in the timing of the link or the underlying channel characteristics. If, during the quiet or refresh periods, normal interframes resume at the XGMII, the PHY reactivates transmit functions and initiates transmission. This transmission will be detected by the remote PHY, causing it to also exit the LPI mode.

72.2 Physical Medium Dependent (PMD) service interface

The 10GBASE-KR PMD utilizes the PMD service interface defined in 52.1.1. The PMD service interface is summarized as follows:

a) PMD_UNITDATA.request (as defined in 52.1.1)
b) PMD_UNITDATA.indication (as defined in 52.1.1)
c) PMD_SIGNAL.indication

If EEE is supported, the following primitives are also defined on the PMD Service Interface:

PMD_RX_MODE.request(rx_mode)
PMD_TX_MODE.request(tx_mode)

These messages affect the PCS variables as described in 49.2.13.2.2.

72.2.1 PMD_RX_MODE.request

This primitive is generated by the PCS Receive Process when EEE is supported to indicate that the input signal is quiet and the PMA and PMD receiver may go into a low power mode. When EEE is not supported, the primitive is never invoked and the PMD behaves as if rx_mode = DATA.

72.2.1.1 Semantics of the service primitive

PMD_RX_MODE.request (rx_mode)

The rx_mode parameter takes on one of two values: QUIET or DATA.

72.2.1.2 When generated

The PCS generates this primitive to request the appropriate PMD receive LPI state.

72.2.1.3 Effect of receipt

When rx_mode is QUIET, the PMD receive function may deactivate functional blocks to conserve energy. When rx_mode is DATA, the PMD receive function operates normally.

72.2.2 PMD_TX_MODE.request

This primitive is generated by the PCS Transmit Process when EEE is supported to indicate that the PMA and PMD transmit functions may go into a low power mode and to disable the PMD transmitter. See subclause 72.6.5. When EEE is not supported, the primitive is never invoked and the PMD behaves as if tx_mode = DATA.

72.2.2.1 Semantics of the service primitive

PMD_TX_MODE.request (tx_mode)

The tx_mode parameter takes on one of three values: QUIET, ALERT, or DATA.

72.2.2.2 When generated

The PCS generates this primitive to request appropriate PMD transmit LPI state.

72.2.2.3 Effect of receipt

When tx_mode is QUIET, the PMD Transmit function may deactivate functional blocks to conserve energy. When tx_mode is ALERT, the PMD Transmit function transmits the alert pattern. And when it is DATA, the PMD Transmit function operates normally.

72.3 PCS requirements for Auto-Negotiation (AN) service interface

The PCS associated with this PMD shall support the AN service interface primitive AN_LINK.indication defined in 73.9. (See 49.2.16.)

72.4 Delay constraints

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers must consider the delay maxima, and that network planners and administrators consider the delay constraints regarding concatenation of devices. A description of overall system delay constraints and the definitions for bit-times and pause_quanta can be found in 69.3.

The sum of the transmit and the receive delays contributed by the 10GBASE-KR PMD and medium shall be no more than 1024 bit times. It is assumed that the round-trip delay through the medium is 160 bit times.

72.5 PMD MDIO function mapping

The optional MDIO capability described in Clause 45 defines several variables that provide control and status information for and about the PMD. If MDIO is implemented, it shall map MDIO control variables to PMD control variables as shown in Table 72–2, and MDIO status variables to PMD status variables as shown in Table 72–3.

Table 72–2—MDIO/PMD control variable mapping

MDIO control variable	PMA/PMD register name	Register/ bit number	PMD control variable
Reset	Control register 1	1.0.15	PMD_reset
Global PMD Transmit Disable	Transmit disable register	1.9.0	Global_PMD_transmit_disable
Restart training	BASE-R PMD control register	1.150.0	mr_restart_training
Training enable	BASE-R PMD control register	1.150.1	mr_training_enable

72.6 PMD functional specifications

72.6.1 Link block diagram

For purposes of system conformance, the PMD sublayer is standardized at test points TP1 and TP4 as shown in Figure 72–1. The transmitter and receiver blocks include all off-chip components associated with the respective block. For example, external AC-coupling capacitors, if required, are to be included in the receiver block.

The electrical path from the transmitter block to TP1, and from TP4 to the receiver block, will affect link performance and the measured values of electrical parameters used to verify conformance to this standard. Therefore, it is recommended that this path be carefully designed.

Table 72–3—MDIO/PMD status variable mapping

MDIO status variable	PMA/PMD register name	Register/ bit number	PMD status variable
Fault	Status register 1	1.1.7	PMD_fault
Transmit fault	Status register 2	1.8.11	PMD_transmit_fault
Receive fault	Status register 2	1.8.10	PMD_receive_fault
Global PMD Receive signal detect	Receive signal detect register	1.10.0	Global_PMD_signal_detect
Receiver status	BASE-R PMD status register	1.151.0	rx_trained
Frame lock	BASE-R PMD status register	1.151.1	frame_lock
Start-up protocol status	BASE-R PMD status register	1.151.2	training
Training failure	BASE-R PMD status register	1.151.3	training_failure

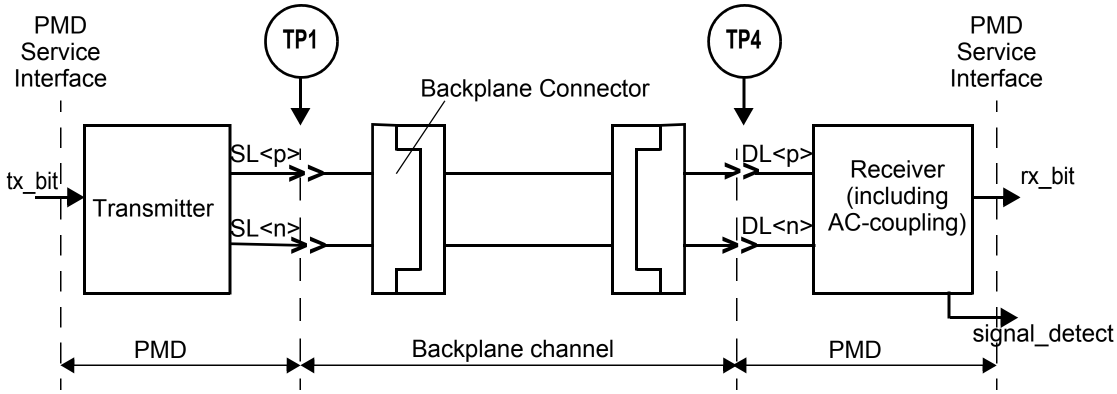

Figure 72–1—Link block diagram

72.6.2 PMD transmit function

The PMD Transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the specifications in this clause. A positive output voltage of SL<p> minus SL<n> (differential voltage) shall correspond to tx_bit = ONE.

If the optional Energy-Efficient Ethernet (EEE) capability is supported (see Clause 78) then when tx_mode is set to ALERT, the PMD will transmit a repeating 16-bit pattern, hexadecimal 0xFF00. When tx_mode is ALERT, the transmitter equalizer taps are set to the preset state specified in 72.6.10.2.3.1. When tx_mode is DATA, the driver coeffcients are restored to their states resolved during training.

72.6.3 PMD receive function

The PMD Receive function shall convey the bits received from the MDI according to the electrical specifications in this clause to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). A positive input voltage of DL<p> minus DL<n> (differential voltage) shall correspond to rx_bit = ONE.

72.6.4 PMD signal detect function

The Global PMD signal detect function shall report to the PMD service interface, using the message PMD_SIGNAL.indication(SIGNAL_DETECT), which is signaled continuously. PMD_SIGNAL.indication is used by 10GBASE-KR to indicate the successful completion of the start-up protocol. When the PHY supports the optional EEE capability, PMD_SIGNAL.indication is also used to indicate when the ALERT signal is detected, which corresponds to the beginning of a refresh or a wake. If the MDIO interface is implemented, then Global_PMD_signal_detect (1.10.0) shall be continuously set to the value of SIGNAL_DETECT as described in 45.2.1.9.7.

The value of the SIGNAL_DETECT is defined by the training state diagram shown in Figure 72–5 when the PHY does not support the EEE capability or if the PHY supports the EEE capability and rx_mode is set to DATA. When the PHY supports the EEE capability, SIGNAL_DETECT is set to FAIL following a transition from rx_mode = DATA to rx_mode = QUIET. When rx_mode = QUIET, SIGNAL_DETECT shall be set to OK within 500 ns following the application of a signal at the receiver input that is the output of a channel that satisfies the requirements of all the parameters of both interference tolerance test channels defined in 72.7.2.1 when driven by a square wave pattern with a period of 16 unit intervals and peak-to-peak differential output amplitude of 720 mV. While rx_mode = QUIET, SIGNAL_DETECT changes from FAIL to OK only after a valid ALERT signal is applied to the channel.

SIGNAL_DETECT shall be set to FAIL following system reset or the manual reset of the training state diagram. Upon completion of training, SIGNAL_DETECT shall be set to OK.

If training is disabled by management and EEE is not implemented, SIGNAL_DETECT shall be set to OK.

72.6.5 PMD transmit disable function

The Global_PMD_transmit_disable function is mandatory if EEE is supported and is otherwise optional. When this function is supported, it shall meet the requirements of this subclause.

a) When the Global_PMD_transmit_disable variable is set to ONE, this function shall turn off the transmitter such that it drives a constant level (i.e., no transitions) and does not exceed the maximum differential peak-to-peak output voltage specified in Table 72–6.
b) If a PMD_fault (72.6.7) is detected, then the PMD may turn off the electrical transmitter.
c) Loopback, as defined in 72.6.6, shall not be affected by Global_PMD_transmit_disable.
d) For EEE capability, the PMD_transmit_disable function shall turn off the transmitter after tx_mode is set to QUIET within a time and voltage level specified in 72.7.1.4. The PMD_transmit_disable function shall turn on the transmitter after tx_mode is set to DATA or ALERT within the time and voltage level specified in 72.7.1.4.

If the MDIO interface is implemented, then this function shall map to the Global_PMD_transmit_disable bit as specified in 45.2.1.8.7.

72.6.6 Loopback mode

Loopback mode shall be provided for the 10GBASE-KR PMD by the transmitter and receiver of a device as a test function to the device. When loopback mode is selected, transmission requests passed to the transmitter are shunted directly to the receiver, overriding any signal detected by the receiver on its attached link. Note, this bit does not affect the state of the transmitter. The method of implementing loopback mode is not defined by this standard.

Control of the loopback function is specified in 45.2.1.1.5.

NOTE 1—The signal path that is exercised in the loopback mode is implementation specific, but it is recommended that this signal path encompass as much of the circuitry as is practical. The intention of providing this loopback mode of operation is to permit diagnostic or self-test functions to test the transmit and receive data paths using actual data. Other loopback signal paths may also be enabled independently using loopback controls within other devices or sublayers.

NOTE 2—Placing a network port into loopback mode can be disruptive to a network.

72.6.7 PMD_fault function

If the MDIO is implemented, PMD_fault is the logical OR of PMD_receive_fault, PMD_transmit_fault, and any other implementation specific fault.

72.6.8 PMD transmit fault function

The PMD_transmit_fault function is optional. The faults detected by this function are implementation specific, but should not include the assertion of the Global_PMD_transmit_disable function.

If a PMD_transmit_fault (optional) is detected, then the Global_PMD_transmit_disable function should also be asserted.

If the MDIO interface is implemented, then this function shall be mapped to the PMD_transmit_fault bit as specified in 45.2.1.7.4.

72.6.9 PMD receive fault function

The PMD_receive_fault function is optional. The faults detected by this function are implementation specific.

If the MDIO interface is implemented, then this function shall contribute to PMA/PMD receive fault bit as specified in 45.2.1.7.5.

72.6.10 PMD control function

72.6.10.1 Overview

The PMD control function generates the control actions required to bring the PMD from initialization to a mode in which data may be exchanged with the link partner.

The PMD control function implements the 10GBASE-KR start-up protocol. This protocol facilitates timing recovery and equalization while also providing a mechanism through which the receiver can tune the transmit equalizer to optimize performance over the backplane interconnect. The protocol supports these mechanisms through the continuous exchange of fixed-length training frames.

If EEE is supported, the PMD control function responds to PCS requests to transition in and out of quiet states.

72.6.10.2 Training frame structure

The training frame is a fixed length structure that is sent continuously during training. The training frame, shown in Figure 72–2, is 548 octets in length and contains a control channel and training pattern.

The control channel is signaled using differential Manchester encoding (DME) at a signaling rate equal to one quarter of the 10GBASE-KR signaling rate. Since each DME symbol contains two DME transition positions and each transition position is four 10GBASE-KR UI, one control channel bit is transmitted every eight 10GBASE-KR UI.

Differential Manchester encoding guarantees transition density and DC balance while the reduced rate of transmission facilitates reception over non-optimally equalized channels.[28]

Training frames are delimited by a fixed 4 octet frame marker.

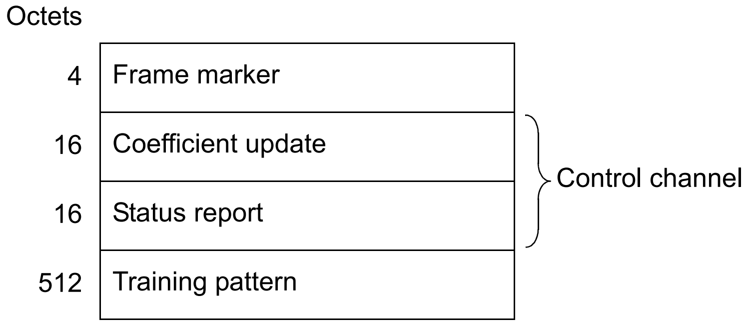

Figure 72–2—Training frame structure

72.6.10.2.1 Frame marker

Frames are delimited by the 32-bit pattern, hexadecimal 0xFFFF0000 (ones transmitted first), as expressed in 10.3125 Gbd symbols. This pattern does not appear in the control channel or the training pattern and therefore serves as a unique indicator of the start of a training frame.

72.6.10.2.2 Control channel encoding

The control channel shall be transmitted using differential Manchester encoding (DME). The rules of differential Manchester encoding are as follows:

a) A data transition shall occur at each cell boundary.
b) A mid-cell data transition shall be used to signal a logical one.
c) The absence of a mid-cell data transition shall be used to signal a logical zero.

If a coding violation is detected within the bounds of the control channel in a given training frame, the contents of the control channel for that frame shall be ignored.

The data cell length shall be 8 10GBASE-KR UI. Therefore, the total length of the control channel is 256 10GBASE-KR UI.

72.6.10.2.3 Coefficient update field

The coefficient update field carries correction information from the local receiver to the link partner transmit equalizer. The field consists of preset controls, initialization controls, and coefficient updates for three transmit equalizer taps. The format of the coefficient update field shall be as shown in Table 72–4. Cell 15 of the coefficient update field sent shall be transmitted first. The preset, initialize, and coefficient updates are set by the receiver adaptation process. The algorithm employed by the receiver adaptation process is beyond the scope of this standard.

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[28] The differential Manchester encoding defined for Backplane Ethernet is different from that defined in IEEE Std 802.5™.

Table 72–4—Coefficient update field

Cell(s)	Name	Description
15:14	Reserved	Transmitted as 0, ignored on reception.
13	Preset	1 = Preset coefficients 0 = Normal operation
12	Initialize	1 = Initialize coefficients 0 = Normal operation
11:6	Reserved	Transmitted as 0, ignored on reception.
5:4	Coefficient (+1) update	5 4 1 1 = reserved 0 1 = increment 1 0 = decrement 0 0 = hold
3:2	Coefficient (0) update	3 2 1 1 = reserved 0 1 = increment 1 0 = decrement 0 0 = hold
1:0	Coefficient (–1) update	1 0 1 1 = reserved 0 1 = increment 1 0 = decrement 0 0 = hold

72.6.10.2.3.1 Preset

The preset control is sent to request that the coefficients be set to a state where equalization is turned off. When received, the pre-cursor ($k = -1$) and post-cursor ($k = +1$) coefficients shall be set to a zero value and the main ($k = 0$) coefficient shall be set to its maximum value. The preset control shall only be initially sent when all coefficient status fields indicate not_updated, and will then continue to be sent until the status for all coefficients indicates updated or maximum. At that point, the outgoing preset control shall be set to zero. Maximum status shall be returned when the main coefficient is updated. Maximum status shall be returned for the pre-cursor and/or post-cursor coefficients when the coefficient is updated and zero is its maximum supported value. Updated status shall be returned for the pre-cursor and/or post-cursor coefficients when the coefficient is updated and it supports additional settings above the value zero.

A new request to preset or initialize shall not be sent until the incoming status messages for all coefficients revert to not_updated. Preset shall not be sent in combination with initialize or coefficient increment/decrement requests.

72.6.10.2.3.2 Initialize

The initialize control is sent to request that the coefficients be set to configure the transmit equalizer to its INITIALIZE state. When received, the taps shall be set such that the transmit output meets the conditions defined in 72.6.10.4.2. The initialize control shall only be initially sent when all coefficient status fields indicate not_updated, and will then continue to be sent until no coefficient status field indicates not_updated.

Updated status shall be returned for each coefficient when the coefficient update is completed. At that point, the outgoing initialize control shall be set to zero.

A new request to preset or initialize shall not be sent until the incoming status messages for all coefficients revert to not_updated. Initialize shall not be sent in combination with coefficient increment/decrement requests or preset.

72.6.10.2.3.3 Coefficient (*k*) update

Each coefficient, *k*, is assigned a 2-bit field describing a requested update. Three request encodings are defined: increment, decrement, and hold. The default state for a given tap is hold, which corresponds to no change in the coefficient. The increment or decrement encodings are transmitted to request that the corresponding coefficient be increased or decreased. The amount of change implemented by the transmitter in response to the coefficient update request shall meet the requirements of Table 72–7 and 72.7.1.10. An increment or decrement request shall continue to be transmitted until the update status for that tap (as defined in 72.6.10.2.4.5) indicates updated, maximum, or minimum. At that point, the outgoing requests for that tap shall be set to hold.

A new request to increment or decrement shall not be sent before the incoming status messages for that tap revert to not_updated. Coefficient increment/decrement shall not be sent in combination with initialize or preset.

The valid range for k is –1 to +1 where $k = 0$ denotes the main tap. The encoding of the coefficient update shall be as shown in Table 72–4.

72.6.10.2.4 Status report field

The status report field is used to signal state information from the local PMD to the link partner. The format of the status report field shall be as shown in Table 72–5. Cell 15 of the status report field shall be transmitted first.

Table 72–5—Status report field

Cell(s)	Name	Description
15	Receiver ready	1 = The local receiver has determined that training is complete and is prepared to receive data. 0 = The local receiver is requesting that training continue.
14:6	Reserved	Transmitted as 0, ignored on reception.
5:4	Coefficient (+1) status	5 4 1 1 = maximum 1 0 = minimum 0 1 = updated 0 0 = not_updated
3:2	Coefficient (0) status	3 2 1 1 = maximum 1 0 = minimum 0 1 = updated 0 0 = not_updated
1:0	Coefficient (–1) status	1 0 1 1 = maximum 1 0 = minimum 0 1 = updated 0 0 = not_updated

72.6.10.2.4.4 Receiver ready

The receiver ready bit is used to signal the local receiver state to the link partner. When asserted, the receiver ready bit indicates that the local receiver has concluded training and is prepared to receive data. When de-asserted, the receiver ready bit indicates that the local receiver is requesting that training continue. The format of the receiver ready bit shall be as shown in Table 72–5.

72.6.10.2.4.5 Coefficient (*k*) status

Each coefficient, *k*, is assigned a 2-bit field describing the status of pending updates to the coefficient. Four status encodings are defined: not updated, updated, maximum, and minimum.

These status encodings indicate the corresponding state of the coefficient update state diagram for coefficient *k*.

The valid range for *k* is –1 to +1 where *k* = 0 denotes the main tap. The encoding of the coefficient update shall be as shown in Table 72–5.

72.6.10.2.5 Coefficient update process

Each coefficient, k, has an associated coefficient update state diagram that controls updates of the coefficient and generates the tap update status field.

The default state for a given tap is not_updated. An increment or decrement request will only be acted upon when the state of the tap is not_updated. Upon execution of a received increment or decrement request, the status is reported as updated, maximum, or minimum. Maximum is reported if a received increment request causes the tap value to reach its maximum limit, or if it is already at that limit. Minimum is reported if a received decrement request causes the tap value to reach its minimum limit, or if it is already at that limit.

Once the updated, maximum, or minimum state is reported it continues to be reported until a hold request is received, after which the status reverts to not_updated.

The coefficient update process responds to coefficient requests as specified in the state diagram shown in Figure 72–6.

72.6.10.2.6 Training pattern

The training pattern shall be a 512 octet pattern consisting of 4094 bits from the output of a pseudo-random bit sequence of order 11 (PRBS11) generator followed by two zeros. The PRBS11 pattern generator shall produce the same result as the implementation shown in Figure 72–3. This implements the generator polynomial shown in Equation (72–1).

$$G(x) = 1 + x^9 + x^{11} \tag{72–1}$$

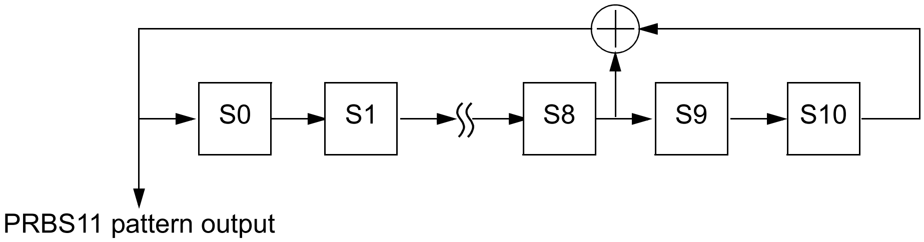

Figure 72–3—PRBS11 pattern generator

The pseudo-random generator shall have a random seed at the start of the training pattern. Each bit of the training pattern is transmitted as a single 10.3125 GBd symbol.

72.6.10.3 State variables

The notation used in the state diagrams follows the conventions of 21.5. State diagram timers follow the conventions of 14.2.3.2. The notation ++ after a counter or integer variable indicates that its value is to be incremented.

72.6.10.3.1 Variables

coefficient
Integer variable containing a value that should be used as the tap coefficient.

dec

Boolean variable that is set to TRUE when a training frame has been completely received and the coefficient update field of that frame for this coefficient is decrement, and is set to FALSE on reception of any other value.

frame_lock

Boolean variable that is set to TRUE when the receiver acquires training frame delineation and is set to FALSE otherwise.

frame_offset

Boolean variable that is set to TRUE after receiving one full training frame (548 octets) from the current frame start position. The Boolean variable is set to FALSE when the GET_NEW_MARKER state is entered. The current frame start position is indicated by a transition into the GET_NEW_MARKER state when the Boolean variable is set to FALSE.

hold

Boolean variable that is set to TRUE when a training frame has been completely received and the coefficient update field of that frame for this coefficient is hold, and neither preset or initialize are activated, and is set to FALSE on reception of any other value.

inc

Boolean variable that is set to TRUE when a training frame has been completely received and the coefficient update field of that frame for this coefficient is increment, and set to FALSE on reception of any other value.

initialize

Boolean variable that is set to TRUE when a training frame has been completely received and the initialize field of that frame is set to one and the preset field is set to zero, and is set to FALSE otherwise.

local_rx_ready

Boolean variable that is set to TRUE by the training state diagram when rx_trained is asserted and is set to FALSE otherwise. This value is transmitted as the receiver ready bit on all outgoing training frames.

marker_valid

Boolean variable that is set to TRUE when the candidate frame marker matches the specified frame marker pattern and is set to FALSE when the candidate frame marker does not match the specified frame marker pattern.

max_limit

Integer variable containing the maximum tap coefficient value, subject to the constraints detailed in 72.7.1.10.

min_limit

Integer variable containing the minimum tap coefficient value, subject to the constraints detailed in 72.7.1.10.

mr_restart_training

Boolean variable used by system management to restart the 10GBASE-KR start-up protocol. When set to TRUE, it forces the training state diagram to the INITIALIZE state.

mr_training_enable

Boolean variable used by system management to enable or disable the 10GBASE-KR start-up protocol. It is set to TRUE when the start-up protocol is enabled and set to FALSE when the start-up protocol is disabled.

new_coeff

Integer variable containing the result of increment/decrement operations on the coefficient value

new_marker

Boolean variable that is set to TRUE when a new candidate frame marker is available for testing and FALSE when the TEST_MARKER state is entered. A new marker is available for testing when the training frame lock process has accumulated one frame marker (4 octets) from a candidate frame start position.

preset

Boolean variable that is set to TRUE when a training frame has been completely received and the preset field of that frame is set to one and is set to FALSE if set to zero.

remote_rx_ready

Boolean variable that is set to FALSE upon entry into the SEND_TRAINING state. The value of remote_rx_ready shall not be set to TRUE until no fewer than three consecutive training frames have been received with the receiver ready bit asserted.

reset

Boolean variable that controls the resetting of the PMA/PMD. It is set to TRUE whenever a reset is necessary including when reset is initiated from the MDIO, during power on, and when the MDIO has put the PMA/PMD into low-power mode.

rx_trained

Boolean variable that is set to TRUE when the remote transmit and local receive equalizers have been optimized and normal data transmission may commence and set to FALSE otherwise.

signal_detect

Boolean variable that is set to TRUE when the training process is complete and is set to FALSE otherwise. The value of signal_detect is reported to the PMA sublayer via the PMD_SIGNAL.indication primitive.

slip_done

Boolean variable that is set to TRUE when the SLIP requested by the Frame Lock State Diagram has been completed indicating that the next candidate frame sync position can be tested.

training

Boolean variable that is set to TRUE to indicate that the 10GBASE-KR start-up protocol is in progress and is set to FALSE when training has completed.

training_failure

Boolean variable that is set to TRUE when the training state diagram has timed out due to expiration of the max_wait_timer while in the SEND_TRAINING, TRAIN_LOCAL, or TRAIN_REMOTE states and is set to FALSE otherwise.

update_status

Value to be transmitted in the Coefficient Status field for this coefficient in the next transmitted training frame, as defined in Table 72–8.

72.6.10.3.2 Timers

max_wait_timer

This timer is started in the INITIALIZE state of the training state diagram. If the max_wait_timer expires the training state diagram will enter the TRAINING_FAILURE state. The value of max_wait_timer shall be 500 ms ± 1%.

wait_timer

This timer is started when the local receiver is trained and detects that the remote receiver is ready to receive data. The local PMD will deliver wait_timer additional training frames to ensure that the link partner correctly detects the local receiver state. The value of wait_timer shall be between 100 and 300 training frames.

72.6.10.3.3 Counters

bad_markers

Count of the number of consecutive frame marker mis-matches.

good_markers

Count of the number of consecutive frame marker matches.

72.6.10.3.4 Functions

COEFF_UPDATE(coefficient, preset, initialize, inc, dec)

Returns an updated coefficient based on the contents of the coefficient update field in the training frame. Sets a fixed coefficient value, or adds, or subtracts from the current coefficient value to create the updated coefficient. If multiple actions are requested in the coefficient update field, then the priority is:

1) preset
2) initialize
3) inc/dec

Values: preset; If preset is TRUE then the function returns the coefficient value equivalent to no equalization [$c(-1)$ and $c(1)$ coefficients are set to zero, $c(0)$ set to maximum].
initialize; If initialize is TRUE, then the function returns the coefficient value such that the transmit output meets the conditions defined in 72.6.10.4.2.
inc; If inc is TRUE then the function returns (coefficient + step).
dec; If dec is TRUE then the function returns (coefficient – step).

The requirements for the value of step are defined in 72.7.1.10 and Table 72–7.

SLIP

Causes the next candidate frame sync position to be tested. The precise method for determining the next candidate frame sync position is not specified and is implementation dependent. However, an implementation shall ensure that all possible bit positions are evaluated.

TRANSMIT(TRAINING, DATA)

Controls the output of the TRANSMIT functional block.

Values: TRAINING; the transmit block output is a continuous stream of training frames as defined in 72.6.10.2.
DATA; the transmit block output is determined by the value of the input tx_bit.

72.6.10.4 State diagrams

72.6.10.4.1 Frame lock

The 10GBASE-KR PMD shall implement the Frame Lock state diagram as depicted in Figure 72–4 including compliance with the associated state variables as specified in 72.6.10.3. The frame lock state diagram determines when the PMD control function has detected the frame boundaries in the received data stream.

72.6.10.4.2 Training

The 10GBASE-KR PMD shall implement the Training state diagram as depicted in Figure 72–5 including compliance with the associated state variables as specified in 72.6.10.3. The training state diagram defines the operation of the 10GBASE-KR start-up protocol. When the training state diagram enters the INITIALIZE state, the transmitter equalizer shall be configured such that R_{pre} and R_{pst} are 1.29 ± 10% and 2.57 ± 10% respectively. R_{pre} and R_{pst} are defined in 72.7.1.11. At the start of training the initial value of c(0) shall be set such that the constraints of 72.7.1.11 are satisfied and the peak-to-peak differential output voltage shall be greater than or equal to 800 mV for a 1010 pattern.

72.6.10.4.3 Coefficient update

For each tap, the 10GBASE-KR PMD shall implement an instance of the coefficient update state diagram as depicted in Figure 72–6 including compliance with the associated state variables as specified in 72.6.10.3. The coefficient update state diagram defines the process for updating transmit equalizer coefficients in response to requests from the link partner, and also defines the coefficient update status to be reported in outgoing training frames.

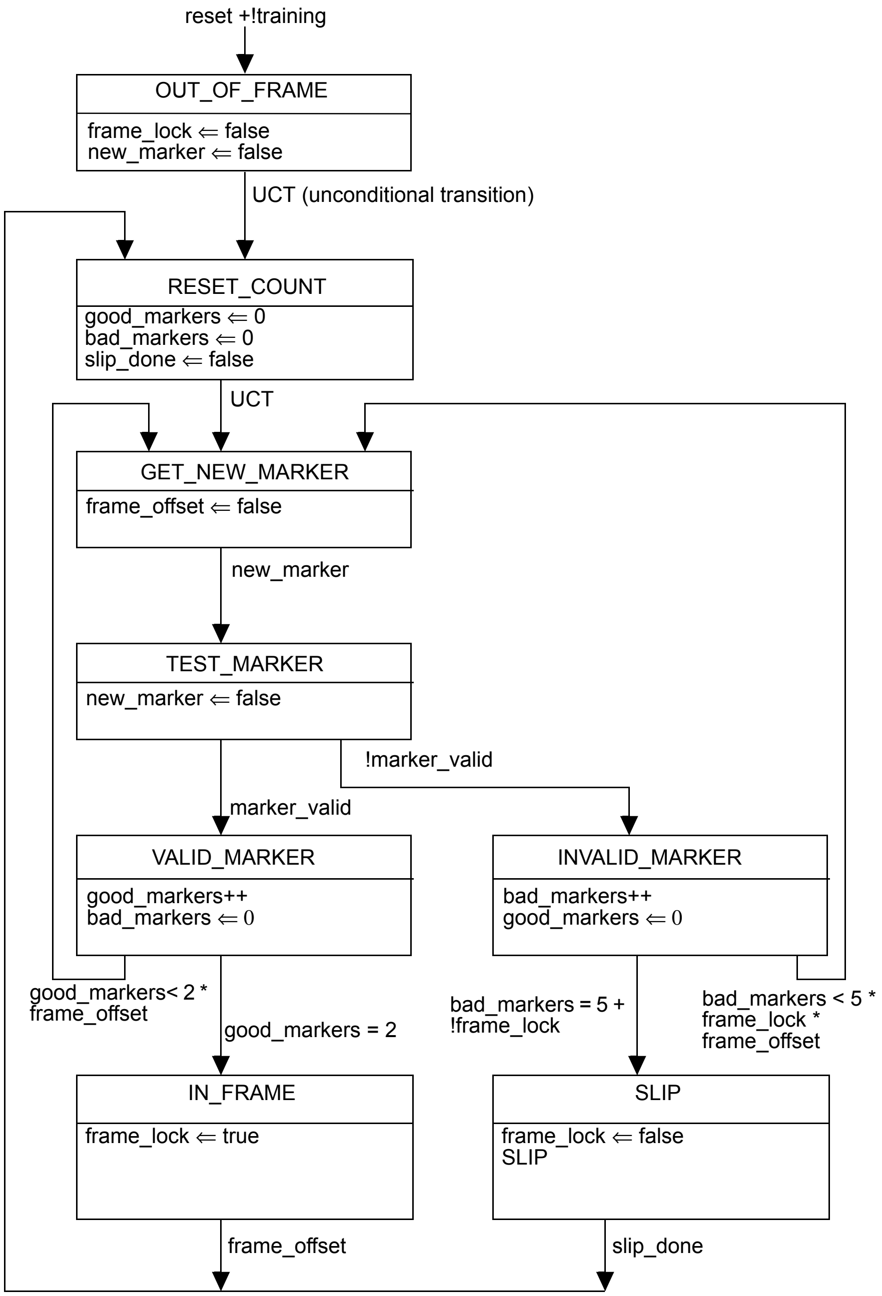

Figure 72–4—Frame lock state diagram

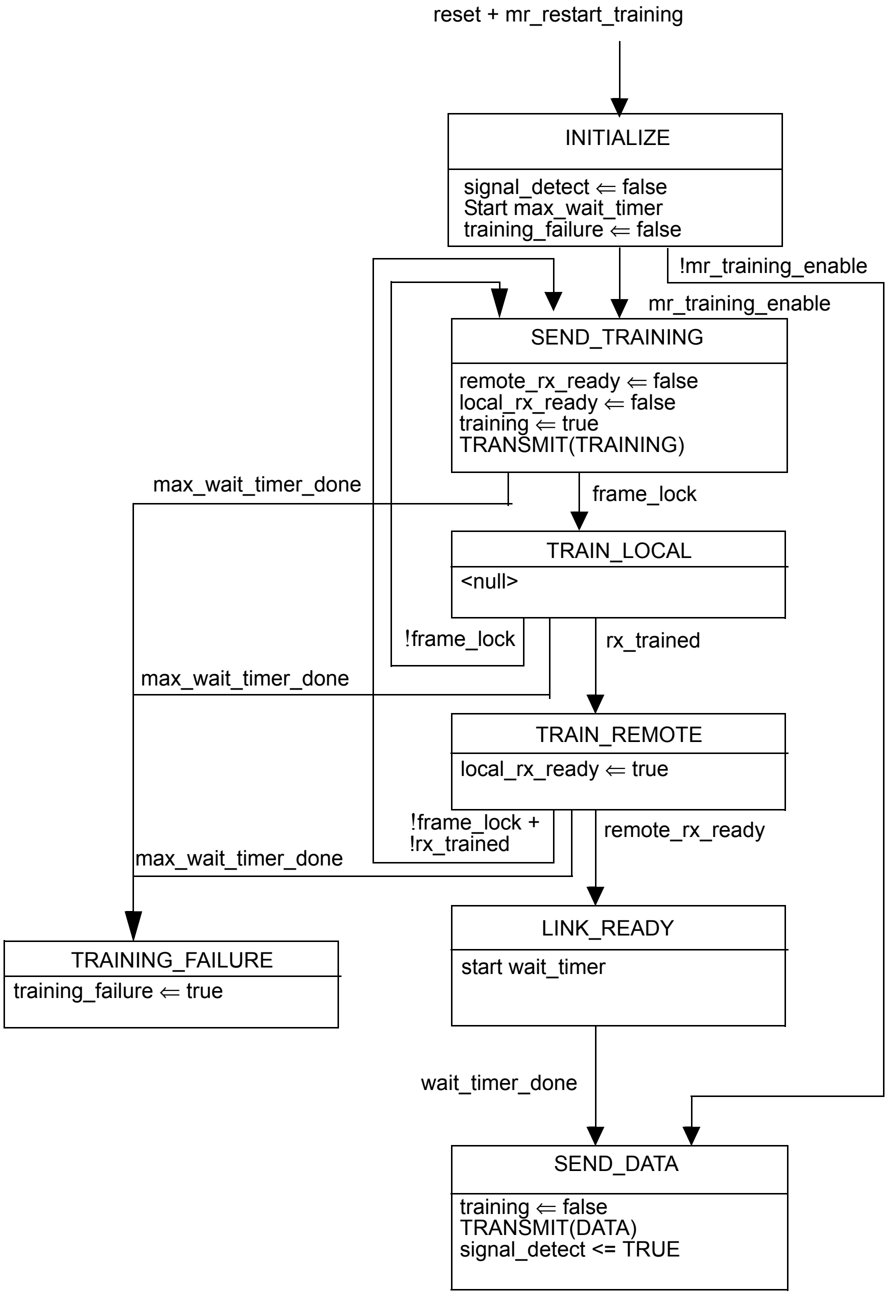

Figure 72–5—Training state diagram

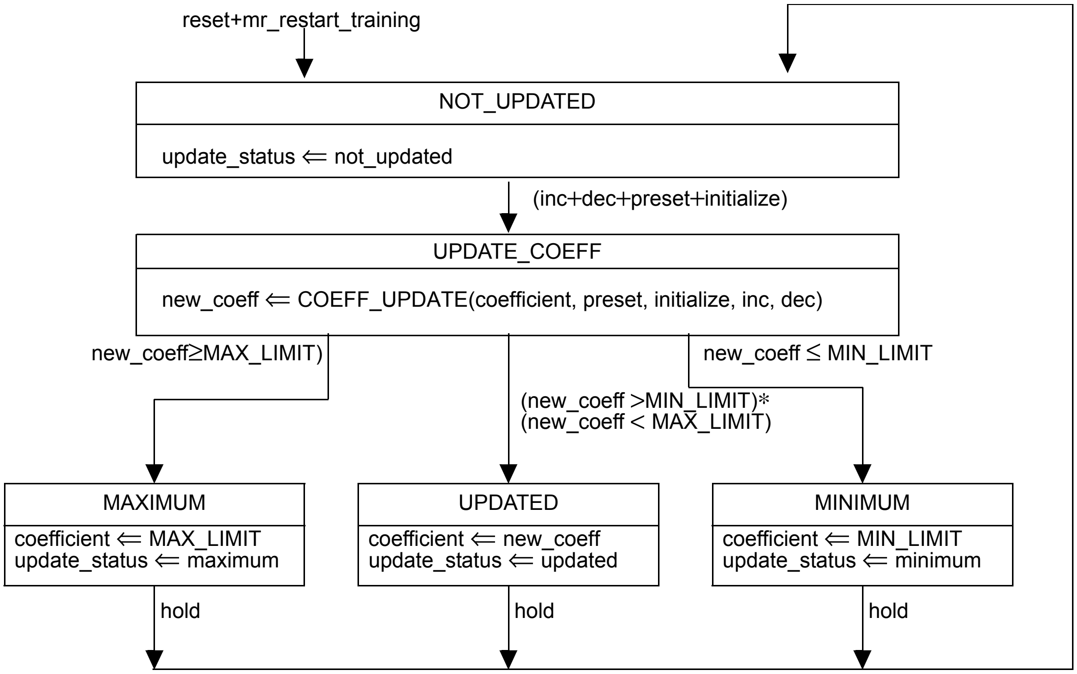

Figure 72–6—Coefficient update state diagram

72.6.11 PMD LPI function

The PMD LPI function responds to the transitions between Active, Sleep, Quiet, Refresh, and Wake states via the PMD_TX_MODE and PMD_RX_MODE requests. Implementation of the function is optional. EEE capabilities and parameters will be advertised during the Backplane Auto-negotiation, as described in 45.2.7.13. The transmitter on the local device will inform the link partner's receiver when to sleep, refresh and wake. The local receiver transitions are controlled by the link partner's transmitter and can change independent of the local transmitter states and transitions.

72.7 10GBASE-KR electrical characteristics

72.7.1 Transmitter characteristics

Transmitter characteristics at TP1 are summarized in Table 72–6 and detailed in 72.7.1.1 through 72.7.1.11.

Table 72–6—Transmitter characteristics for 10GBASE-KR

Parameter	Subclause reference	Value	Units
Signaling speed	72.7.1.3	10.3125 ± 100 ppm	GBd
Differential peak-to-peak output voltage (max.)	72.7.1.4	1200	mV
Differential peak-to-peak output voltage (max.) with TX disabled	72.6.5	30	mV
Common-mode voltage limits	72.7.1.4	0 to 1.9	V
Common-mode voltage deviation (max) during LPI	72.7.1.4	150	mV
Differential output return loss (min.)	72.7.1.5	[See Equation (72–4) and Equation (72–5)]	dB
Common-mode output return loss (min.)	72.7.1.6	[See Equation (72–6) and Equation (72–7)]	dB
Transition time (20%–80%)	72.7.1.7	24 to 47	ps
Max output jitter (peak-to-peak) Random jitter[a] Deterministic jitter Duty Cycle Distortion[b] Total jitter	72.7.1.9	 0.15 0.15 0.035 0.28	 UI UI UI UI

[a] Jitter is specified at BER 10^{-12}.
[b] Duty Cycle Distortion is considered part of the deterministic jitter distribution.

72.7.1.1 Test fixture

The test fixture of Figure 72–7 or its functional equivalent, is required for measuring the transmitter specifications described in 72.7.1, with the exception of return loss.

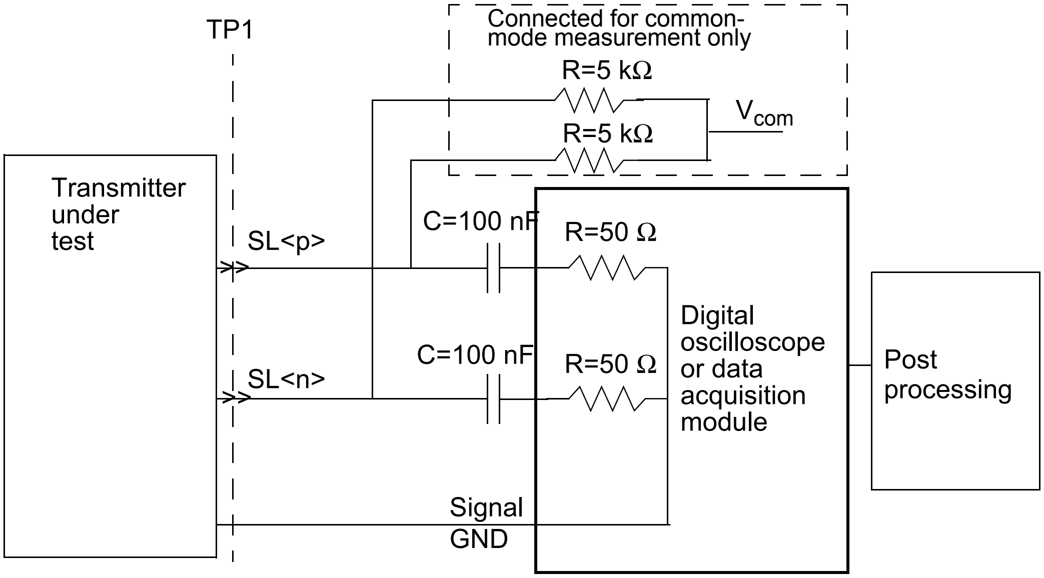

Figure 72–7—Transmit test fixture for 10GBASE-KR

72.7.1.2 Test fixture impedance

The differential load impedance applied to the transmitter output by the test fixture depicted in Figure 72–7 shall be 100 Ω. The differential return loss, in dB with f in MHz, of the test fixture shall meet the requirements of Equation (72–2) and Equation (72–3).

$$ReturnLoss(f) \geq 15 \tag{72–2}$$

for 100 MHz ≤ f < 5000 MHz

$$ReturnLoss(f) \geq 15 - 26.57\log_{10}\left(\frac{f}{5000\ \text{MHz}}\right) \tag{72–3}$$

for 5000 MHz ≤ f ≤ 10000 MHz

72.7.1.3 Signaling speed

The 10GBASE-KR signaling speed shall be 10.3125 GBd ± 100 ppm.

72.7.1.4 Output amplitude

The differential output voltage is constrained via the transmitter output waveform requirements specified in 72.7.1.10. For a 1010 pattern, the peak-to-peak differential output voltage shall be less than 1200 mV, regardless of equalization setting. The transmitter output voltage shall be less than 30 mV peak-to-peak when disabled. The differential output voltage test pattern shall consist of no fewer than eight symbols of alternating polarity.

NOTE 1—The required test patterns may be found in the training pattern field of the training frames or test patterns 2 or 3 as defined in 52.9.1.1.

NOTE 2—See Figure 72–8 for an illustration of the definition of differential peak-to-peak output voltage.

DC-referenced voltage levels are not defined since the receiver is AC-coupled. The common-mode voltage of SL<p> and SL<n> shall be between 0 V and 1.9 V with respect to signal ground as measured at V_{com} in Figure 72–7.

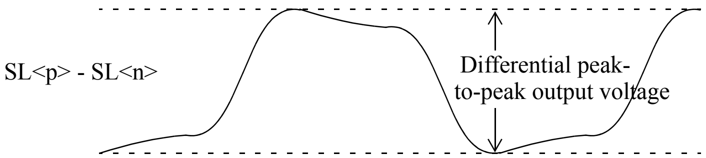

Figure 72–8—Transmitter differential peak-to-peak output voltage definition

NOTE—SL<p> and SL<n> are the positive and negative sides of the differential signal pair.

For EEE capability, the transmitter's differential peak-to-peak output voltage shall be less than 30 mV within 500 ns of tx_mode being set to QUIET and remain so while tx_mode is set to QUIET. Furthermore, the transmitter's differential peak-to-peak output voltage shall be greater than 720 mV within 500 ns of tx_mode being set to ALERT. The transmitter output shall be fully compliant within 5 µs after tx_mode is set to DATA. During LPI mode, the common-mode shall be maintained to within ± 150 mV of the pre-LPI value.

72.7.1.5 Differential output return loss

For frequencies from 50 MHz to 7500 MHz, the differential return loss, in dB with f in MHz, of the transmitter shall meet the requirements of Equation (72–4) and Equation (72–5). This output impedance requirement applies to all valid output levels. The reference impedance for differential return loss measurements shall be 100 Ω.

$$ReturnLoss(f) \geq 9 \tag{72–4}$$

for 50 MHz $\leq f <$ 2500 MHz

$$ReturnLoss(f) \geq 9 - 12\log_{10}\left(\frac{f}{2500\text{ MHz}}\right) \tag{72–5}$$

for 2500 MHz $\leq f \leq$ 7500 MHz

The minimum differential output return loss is shown in Figure 72–9.

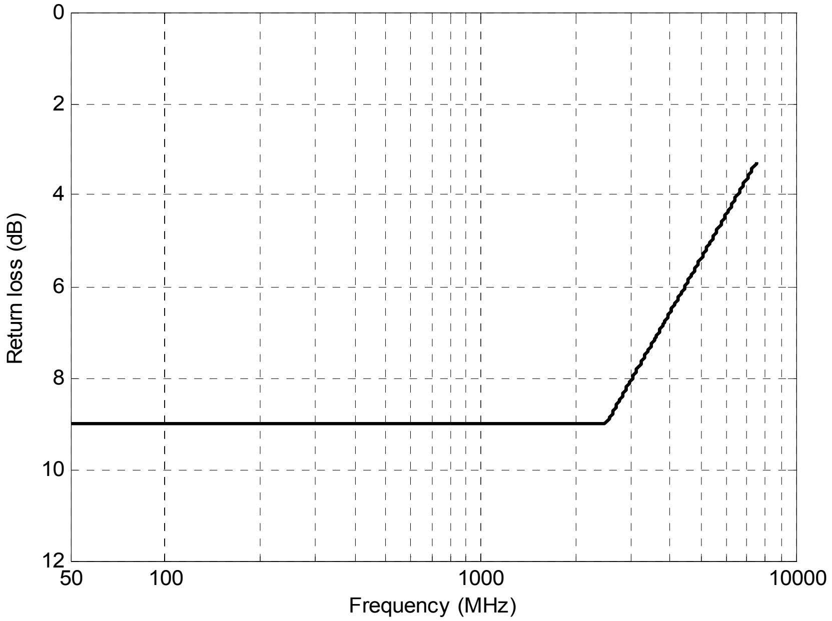

Figure 72–9—Minimum differential output return loss

72.7.1.6 Common-mode output return loss

The transmitter common-mode return loss shall meet the requirements of Equation (72–6) and Equation (72–7). The reference impedance for common-mode return loss measurements is 25 Ω.

$$ReturnLoss(f) \geq 6 \tag{72–6}$$

for 50 MHz ≤ f < 2500 MHz

$$ReturnLoss(f) \geq 6 - 12\log_{10}\left(\frac{f}{2500\text{ MHz}}\right) \tag{72–7}$$

for 2500 MHz ≤ f ≤ 7500 MHz

The minimum common-mode output return loss is shown in Figure 72–10.

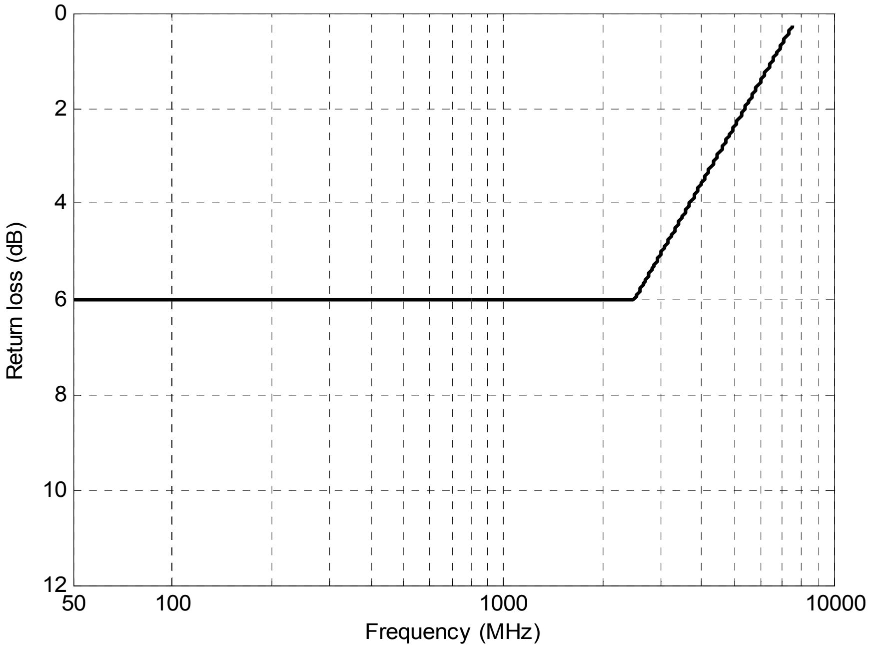

Figure 72–10—Minimum common-mode output return loss

72.7.1.7 Transition time

The rising and falling edge transition times shall be between 24 ps and 47 ps as measured at the 20% and 80% levels referenced to v_2 and v_5 as defined in 72.7.1.11. Measurement is done using the square wave test pattern defined in 52.9.1.2, with no equalization and a run of at least eight consecutive ones. Transmit equalization may be disabled by asserting the preset control defined in Table 45–62 and 45.2.1.82.3.

72.7.1.8 Transmit jitter test requirements

Transmit jitter is defined with respect to a test procedure resulting in a BER bathtub curve such as that described in Annex 48B.3. For the purpose of jitter measurement, the effect of a single-pole high-pass filter with a 3 dB point at 4 MHz is applied to the jitter. The data pattern for jitter measurements shall be test patterns 2 or 3 as defined in 52.9.1.1. Crossing times are defined with respect to the mid-point (0 V) of the AC-coupled differential signal. Equalization shall be off during jitter testing. Transmit equalization may be disabled by asserting the preset control defined in Table 45–62 and 45.2.1.82.3.

The duty cycle distortion test pattern shall consist of no fewer than eight symbols of alternating polarity.

NOTE—The required test patterns may be found in the training pattern field of the training frames or test patterns 2 or 3 as defined in 52.9.1.1.

72.7.1.9 Transmit jitter

The transmitter shall have a maximum total jitter of 0.28 UI peak-to-peak, composed of a maximum deterministic component of 0.15 UI peak-to-peak and a maximum random component of 0.15 UI peak-to-peak. Duty cycle distortion (DCD) is considered a component of deterministic jitter and shall not exceed 0.035 UI peak-to-peak. The peak-to-peak duty cycle distortion is defined as the absolute value of the difference in the mean pulse width of a 1 pulse or the mean pulse width of a 0 pulse (as measured at the mean of the high- and low-voltage levels in a clock-like repeating 0101 bit sequence) and the nominal pulse width. Jitter specifications are specified for BER 10^{-12}. Transmit jitter test requirements are specified in 72.7.1.8.

72.7.1.10 Transmitter output waveform

The 10GBASE-KR transmitter includes programmable equalization to compensate for frequency-dependent loss in the backplane channel and facilitate data recovery at the receiver. This equalization may be accomplished with a three-tap finite impulse response (FIR) structure as shown in Figure 72–11. The actual implementation of the transmit equalizer, including the incorporation of additional taps, is beyond the scope of this standard.

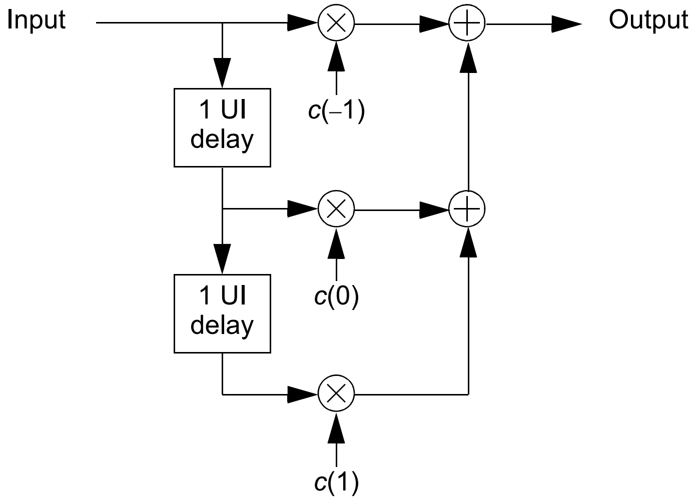

Figure 72–11—Transmit equalizer example

Transmit equalizer performance is specified in terms of the voltages defined in 72.7.1.11. It should be noted that the valid ranges of the $c(1)$ and $c(-1)$ coefficients may include positive and negative values. A value of zero is used to turn off equalization for the tap.

72.7.1.11 Transmitter output waveform requirements

The test pattern for the transmitter output waveform is the square wave test pattern defined in 52.9.1.2, with a run of at least eight consecutive ones. The transmitter output waveform test is based on the voltages v_1 through v_6, Δv_2, and Δv_5, which shall be measured as shown in Figure 72–12 and described below.

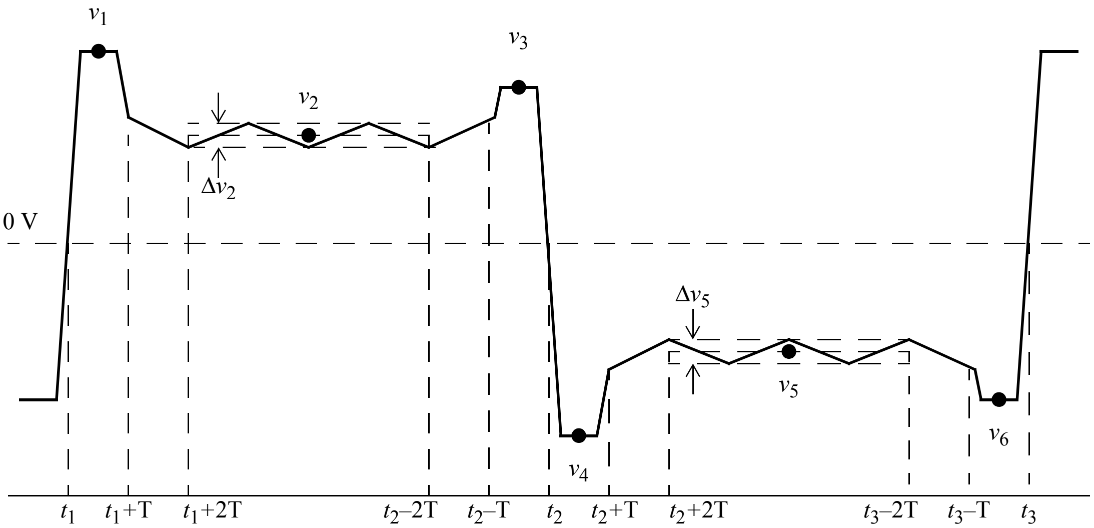

Figure 72–12—Transmitter output waveform

T = symbol period
t_1 = zero-crossing point of the first rising edge of the AC-coupled signal
t_2 = zero-crossing point of the falling edge of the AC-coupled signal
t_3 = zero-crossing point of the second rising edge of the AC-coupled signal
v_1 = maximum voltage measured in the interval t_1 to $t_1 + \mathrm{T}$
v_2 = positive steady-state voltage measured as the average voltage in the interval $t_1 + 2\mathrm{T}$ to $t_2 - 2\mathrm{T}$
v_3 = maximum voltage measured in the interval $t_2 - \mathrm{T}$ to t_2
v_4 = minimum voltage measured in the interval t_2 to $t_2 + \mathrm{T}$
v_5 = negative steady-state voltage measured as the average voltage in the interval $t_2 + 2\mathrm{T}$ to $t_3 - 2\mathrm{T}$
v_6 = minimum voltage measured in the interval $t_3 - \mathrm{T}$ to t_3
Δv_2 = positive voltage ripple measured as the peak-to-peak value of the difference between the voltage in the range $t_1 + 2\mathrm{T}$ to $t_2 - 2\mathrm{T}$ and v_2
Δv_5 = negative voltage ripple measured as the peak-to-peak value of the difference between the voltage in the range $t_2 + 2\mathrm{T}$ to $t_3 - 2\mathrm{T}$ and v_5

From these voltages, the pre- and post-cursor equalization ratios R_{pre} and R_{pst} are derived from Equation (72–8) and Equation (72–9).

$$R_{\mathrm{pre}} = \frac{v_3}{v_2} \tag{72–8}$$

$$R_{\mathrm{pst}} = \frac{v_1}{v_2} \tag{72–9}$$

The state of the transmitter equalizer and hence the transmitter output waveform is manipulated via the protocol defined in 72.6.10 or via management. The changes in the transmitter output waveform resulting from coefficient update requests shall meet the requirements stated in Table 72–7. The coefficient update requests in Table 72–7 are to be followed by a coefficient update equal to hold for all taps. The results shall be verified after the coefficient status for all taps is reported as not_updated.

Table 72–7—Transmitter output waveform requirements related to coefficient update

Coefficient update[a]			Requirements[b]		
c(1)	*c*(0)	*c*(–1)	$v_1(k) - v_1(k-1)$ (mV)	$v_2(k) - v_2(k-1)$ (mV)	$v_3(k) - v_3(k-1)$ (mV)
increment	hold	hold	–20 to –5	5 to 20	5 to 20
decrement	hold	hold	5 to 20	–20 to –5	–20 to –5
hold	increment	hold	5 to 20	5 to 20	5 to 20
hold	decrement	hold	–20 to –5	–20 to –5	–20 to –5
hold	hold	increment	5 to 20	5 to 20	–20 to –5
hold	hold	decrement	–20 to –5	–20 to –5	5 to 20

[a] Step size requirements for the tap under test apply regardless of the current value of the other taps.
[b] This difference is measured relative to the voltage prior to the assertion coefficient update *k* equal to hold.

For any coefficient update, the magnitudes of the changes in v_1, v_2, and v_3 shall be within 5 mV of each other. When sufficient increment or decrement updates have been applied to a given tap, it will reach a maximum or minimum limit governed by the coefficient range or by restrictions placed on minimum steady-state or maximum peak voltage, and the coefficient status is reported accordingly. The transmitter output waveform shall meet the requirements of Table 72–8 for all of the limiting cases represented in the table. Implementation of *c*(–1) or *c*(1) coefficient values greater than zero or less than the minimum defined by R_{pre} (min) and R_{pst} (min) is optional. A coefficient may be disabled by first asserting the preset control defined in Table 45–101 and 45.2.1.82, then manipulating the other coefficients as required by the test.

Table 72–8—Transmitter output waveform requirements related to coefficient status

Coefficient status			Requirements		
c(1)	*c*(0)	*c*(–1)	R_{pre}	R_{pst}	v_2 (mV)
disabled	minimum	disabled	0.90 to 1.10	0.90 to 1.10	220 to 330
disabled	maximum	disabled	0.95 to 1.05	0.95 to 1.05	400 to 600
minimum	minimum	disabled	—	4.00 (min)	—
disabled	minimum	minimum	1.54 (min)	—	—

In addition:

a) The quantities Δv_2 and Δv_5 shall not exceed 40 mV peak-to-peak.

b) The positive and negative voltages shall match such that each of the quantities $(v_1 + v_4)/v_1$, $(v_2 + v_5)/v_2$, and $(v_3 + v_6)/v_3$ does not exceed 0.05.
c) The quantity v_2 shall be greater than or equal to 40 mV.
d) Any coefficient update equal to decrement applied to any tap that would result in v_2 less than 40 mV shall return a coefficient status value minimum.
e) Any coefficient update equal to decrement that would result in a violation of 72.7.1.4 shall return a coefficient status value minimum for that coefficient.
f) Any coefficient update equal to increment that would result in a violation of 72.7.1.4 shall return a coefficient status value maximum for that coefficient.

72.7.2 Receiver characteristics

Receiver characteristics at TP4 are summarized in Table 72–9 and detailed in 72.7.2.1 through 72.7.2.5.

Table 72–9—Receiver characteristics for 10GBASE-KR

Parameter	Subclause reference	Value	Units
Bit error ratio	72.7.2.1	10^{-12}	
Signaling speed	72.7.2.2	10.3125 ± 100 ppm	GBd
Receiver coupling	72.7.2.3	AC	
Differential input peak-to-peak amplitude (maximum)	72.7.2.4	1200[a]	mV
Differential input return loss (minimum)[b]	72.7.2.5	[See Equation (72–4) and Equation (72–5)]	dB

[a] The receiver shall tolerate amplitudes up to 1600 mV without permanent damage.
[b] Relative to 100 Ω differential.

72.7.2.1 Receiver interference tolerance

The receiver interference tolerance shall consist of two separate tests as described in Annex 69A with the parameters specified in Table 72–10. The data pattern for the interference tolerance test shall be the test patterns 2 or 3 as defined in 52.9.1.1. The receiver shall satisfy the requirements for interference tolerance specified in Annex 69A for both tests.

Table 72–10—10GBASE-KR interference tolerance parameters

Parameter	Test 1 values	Test 2 values	Units
Target BER	10^{-12}	10^{-12}	
m_{TC} (min.)[a]	1.0	0.5	
Amplitude of broadband noise (min. RMS)	5.2	12	mV
Applied transition time (20%–80%, min.)	47	47	ps
Applied Sinusoidal jitter (min. peak-to-peak)	0.115	0.115	UI
Applied random jitter (min. peak-to-peak)[b]	0.130	0.130	UI
Applied Duty Cycle Distortion (min. peak-to-peak)	0.035	0.035	UI

[a] m_{TC} is defined in Equation (69A–6) of Annex 69A.
[b] Applied random jitter is specified at a BER of 10^{-12}.

72.7.2.2 Signaling speed range

A 10GBASE-KR receiver shall comply with the requirements of Table 72–9 for any signaling speed in the range 10.3125 GBd ± 100 ppm.

72.7.2.3 AC-coupling

The 10GBASE-KR receiver shall be AC-coupled to the backplane to allow for maximum interoperability between various 10 Gb/s components. AC-coupling is considered to be part of the receiver for the purposes of this specification unless explicitly stated otherwise. It should be noted that there may be various methods for AC-coupling in actual implementations.

NOTE—It is recommended that the maximum value of the coupling capacitors be limited to 100 nF. This will limit the inrush currents to the receiver that could damage the receiver circuits when repeatedly connected to transmit modules with a higher voltage level.

72.7.2.4 Input signal amplitude

10GBASE-KR receivers shall accept differential input signal peak-to-peak amplitudes produced by compliant transmitters connected without attenuation to the receiver, and still meet the BER requirement specified in 72.7.2.1. Note that this may be larger than the 1200 mV differential maximum of 72.7.1.4 due to the actual transmitter output and receiver input impedances. The input impedance of a receiver can cause the minimum signal into a receiver to differ from that measured when the receiver is replaced with a 100 Ω test load. Since the channel is AC-coupled, the absolute voltage levels with respect to the receiver ground are dependent on the receiver implementation.

72.7.2.5 Differential input return loss

For frequencies from 100 MHz to 7500 MHz, the differential return loss, in dB with f in MHz, of the receiver shall be greater than or equal to Equation (72–4) and Equation (72–5). This return loss requirement applies at all valid input levels. The reference impedance for differential return loss measurements is 100 Ω.

72.8 Interconnect characteristics

Informative interconnect characteristics for 10GBASE-KR are provided in Annex 69B.

72.9 Environmental specifications

72.9.1 General safety

All equipment that meets the requirements of this standard shall conform to applicable sections (including isolation requirements) of IEC 60950-1.

72.9.2 Network safety

The designer is urged to consult the relevant local, national, and international safety regulations to ensure compliance with the appropriate requirements.

72.9.3 Installation and maintenance guidelines

It is recommended that sound installation practice, as defined by applicable local codes and regulations, be followed in every instance in which such practice is applicable.

72.9.4 Electromagnetic compatibility

A system integrating the 10GBASE-KR PHY shall comply with applicable local and national codes for the limitation of electromagnetic interference.

72.9.5 Temperature and humidity

A system integrating the 10GBASE-KR PHY is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling (such as shock and vibration). Specific requirements and values for these parameters are considered to be beyond the scope of this standard.

72.10 Protocol implementation conformance statement (PICS) proforma for Clause 72, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KR[29]

72.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3, Clause 72, Physical Medium Dependent (PMD) sublayer and baseband medium type 10GBASE-KR, shall complete the following protocol implementation conformance statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

72.10.2 Identification

72.10.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

72.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 72, Physical Medium Dependent (PMD) sublayer and baseband medium type 10GBASE-KR
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[29] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

72.10.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
XGE	XGMII	72.1, 46	Interface is supported	O	Yes [ ] No [ ]
XGXS	XGXS and XAUI	72.1, 47		O	Yes [ ] No [ ]
PCS	Support of 10GBASE-R PCS	72.1, 49		M	Yes [ ]
PMA	Support of 10 Gigabit serial PMA	72.1, 51		M	Yes [ ]
AN	Auto-Negotiation for Backplane Ethernet	72.1, 73	Device implements Auto-Negotiation for Backplane Ethernet	M	Yes [ ]
FEC	Forward Error Correction	72.1, 74	Device implements 10GBASE-R Forward Error Correction	O	Yes [ ] No [ ]
DC	Delay Constraints	72.4	Device conforms to delay constraints	M	Yes [ ]
LPI	LPI	72.6.11	LPI	O	Yes [ ] No [ ]
*MD	MDIO interface	72.5	Device implements MDIO	O	Yes [ ] No [ ]
*TD	Global_PMD_transmit_disable	72.6.5		O	Yes [ ] No [ ]

72.10.4 PICS proforma tables for Clause 72, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KR

72.10.4.1 PCS requirements for AN service interface

Item	Feature	Subclause	Value/Comment	Status	Support
PR1	AN service interface primitive	72.3	The PCS associated with this PMD supports the AN service interface primitive AN_LINK.indication defined in 73.9	M	Yes [ ]

72.10.4.2 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	Transmit function	72.6.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FS2	Transmitter signal	72.6.2	A positive differential voltage corresponds to tx_bit = ONE	M	Yes [ ]
FS3	Receive function	72.6.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FS4	Receiver signal	72.6.3	A positive differential voltage corresponds to rx_bit = ONE	M	Yes [ ]
FS5	Signal detect	72.6.4	Report to PMD service interface	M	Yes [ ]
FS6	Global signal detect	72.6.4	Value described in 45.2.1.9.7	M	Yes [ ]
FS7	SIGNAL_DETECT value	72.6.4	Set to FAIL	M	Yes [ ]
FS8	SIGNAL_DETECT value	72.6.4	Set to OK when traning is complete	M	Yes [ ]
FS9	SIGNAL_DETECT value	72.6.4	Set to OK when training disabled	M	Yes [ ]
FS10	Signal detect during LPI	72.6.4	Detect signal energy during LPI	LPI:M	Yes [ ] N/A[ ]
FS11	Signal detect for EEE	72.6.4	Transition timing to set SIGNAL_DETECT	LPI:M	Yes [ ] N/A [ ]
FS12	Transmit disable requirements	72.6.5	Requirements of 72.6.5 and Table 72–6	TD:M	Yes [ ] N/A[ ]
FS13	Transmit disable during LPI	72.6.5	Disable transmitter during tx_mode = QUIET	LPI:M	Yes [ ] N/A[ ]
FS14	Loopback support	72.6.6	Provided for 10GBASE-KR PMD by transmitter and receiver	M	Yes [ ]

72.10.4.3 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
MF1	MDIO Variable Mapping	72.5	Per Table 72–2 and Table 72–3	MD:M	Yes [ ] N/A [ ]
MF2	PMD_transmit_fault function	72.6.8	Sets PMD_transmit_fault as specified in 45.2.1.7.4	MD:M	Yes [ ] N/A [ ]
MF3	PMD_receive_fault function	72.6.9	Sets PMD_receive_fault as specified in 45.2.1.7.5	MD:M	Yes [ ] N/A [ ]

72.10.4.4 PMD Control functions

Item	Feature	Subclause	Value/Comment	Status	Support
CF1	Control Channel Encoding	72.6.10.2.2	Control channel transmitted using differential Manchester encoding (DME)	M	Yes [ ]
CF2	Differential Manchester Encoding rules	72.6.10.2.2	Transitions at cell boundary.	M	Yes [ ]
CF3	Differential Manchester Encoding rules	72.6.10.2.2	Presence of a mid-cell transition to signal logic 1	M	Yes [ ]
CF4	Differential Manchester Encoding rules	72.6.10.2.2	Absence of a mid-cell transition to signal logic 0	M	Yes [ ]
CF5	Coding violation	72.6.10.2.2	Ignore contents of control channel if coding violation found	M	Yes [ ]
CF6	Coefficient update field format	72.6.10.2.3	Format of the coefficient update field per Table 72–4	M	Yes [ ]
CF7	Cell 15 of the coefficient update field	72.6.10.2.3	Transmitted first	M	Yes [ ]
CF8	Preset control	72.6.10.2.3.1	When received, pre-cursor and post-cursor coefficients set to zero	M	Yes [ ]
CF9	Preset control	72.6.10.2.3.1	When received, main coefficient set to maximum value	M	Yes [ ]
CF10	Preset control initially sent	72.6.10.2.3.1	Only when all coefficient status fields indicate not_updated and continues until all coefficients indicate updated or maximum	M	Yes [ ]
CF11	Outgoing initialize control	72.6.10.2.3.1	Set to zero when all coefficients indicate updated or maximum following preset	M	Yes [ ]
CF12	Maximum status	72.6.10.2.3.1	Returned when the main coefficient is updated	M	Yes [ ]
CF13	Maximum status	72.6.10.2.3.1	Returned for pre-cursor and/or post-cursor coefficients when coefficient updated and zero is its maximum value	M	Yes [ ]
CF14	Updated status	72.6.10.2.3.1	Returned for pre-cursor and/or post-cursor coefficients when the coefficient is updated and it supports additional settings above the value zero	M	Yes [ ]
CF15	New Preset or Initialize requests	72.6.10.2.3.1	Not sent until the incoming status for all coefficients revert to not_updated	M	Yes [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
CF16	Preset	72.6.10.2.3.1	Not sent in combination with initialize or ceofficient increment/decrement requests	M	Yes [ ]
CF17	Initalize control	72.6.10.2.3.2	When received, taps set to meet conditions of 72.6.10.4.2	M	Yes [ ]
CF18	Initalize control initially sent	72.6.10.2.3.2	Only when all coefficient status fields indicate not_updated and continues until all coefficients indicate updated	M	Yes [ ]
CF19	Updated status	72.6.10.2.3.2	Returned for each coefficient when the coefficient update is complete	M	Yes [ ]
CF20	Outgoing initalize field	72.6.10.2.3.2	Set to zero when all coefficients indicate update complete following initialize	M	Yes [ ]
CF21	New Preset or Initialize requests	72.6.10.2.3.2	Not sent until the incoming status for all coefficients revert to not_updated	M	Yes [ ]
CF22	Initialize	72.6.10.2.3.2	Not sent in combination with coefficient increment/decrement requests	M	Yes [ ]
CF23	Increment or decrement encodings transmitted	72.6.10.2.3.3	Transmitted until status indicates: updated, maximum, or minimum	M	Yes [ ]
CF24	Outgoing requests	72.6.10.2.3.3	Set to hold once update status for tap indicates updated, maximum or minimum	M	Yes [ ]
CF25	Increment or decrement request	72.6.10.2.3.3	Not sent before status reverts to not_updated	M	Yes [ ]
CF26	Encoding of coefficient update	72.6.10.2.3.3	Per Table 72–4	M	Yes [ ]
CF27	Format of status report field	72.6.10.2.4	Per Table 72–5	M	
CF28	Cell 15 of the status report field	72.6.10.2.4	Transmitted first	M	
CF29	Receiver ready indication	72.6.10.2.4.4	Per Table 72–5	M	Yes [ ]
CF30	Coefficient status	72.6.10.2.4.5	Per Table 72–5	M	Yes [ ]
CF31	Training pattern length	72.6.10.2.6	512 octets	M	Yes [ ]
CF32	Training pattern generator	72.6.10.2.6	Per Figure 72–3	M	Yes [ ]
CF33	Training pattern seed	72.6.10.2.6	The pseudo-random generator shall have a random seed at the start of the training pattern	M	Yes [ ]
CF34	Remote_rx_ready	72.6.10.3.1	TRUE after three or more consecutive training frames received with receiver ready indicated	M	Yes [ ]
CF35	Wait Timer	72.6.10.3.2	100 to 300 training frames	M	Yes [ ]
CF36	Max Wait Timer	72.6.10.3.2	500 ms ± 1%	M	Yes [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
CF37	Slip function to find framesync	72.6.10.3.2	Evaluates all possible positions	M	Yes [ ]
CF38	Frame Lock state diagram	72.6.10.4.1	Meets requirements of Figure 72–4	M	Yes [ ]
CF39	Training state diagram	72.6.10.4.2	Meets requirements of Figure 72–5	M	Yes [ ]
CF40	Entry to INITIALIZE state	72.6.10.4.2	Transmitter equalizer configured per 72.6.10.4.2	M	Yes [ ]
CF41	Initial value of c(0) at the start of training	72.6.10.4.2	Meets the requirements of 72.6.10.4.2	M	Yes [ ]
CF42	Coefficient Update state diagram	72.6.10.4.3	Meets requirements of Figure 72–6	M	Yes [ ]

72.10.4.5 Transmitter electrical characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
TC1	Test fixture impedance	72.7.1.2	100 Ω	M	Yes [ ]
TC2	Differential return loss of test fixture	72.7.1.2	Per Equation (72–2) and Equation (72–3)	M	Yes [ ]
TC3	Signaling speed	72.7.1.3	10.3125 GBd ± 100 ppm	M	Yes [ ]
TC4	Maximum transmitter differential peak-to-peak voltage	72.7.1.4	Less than 1200 mV for a 1010 pattern	M	Yes [ ]
TC5	Maximum transmitter differential peak-to-peak voltage when TX disabled	72.7.1.4	Less than 30 mV	M	Yes [ ]
TC6	Common-mode output voltage	72.7.1.4	Between 0 and 1.9 V	M	Yes [ ]
TC7	Output Amplitude LPI voltage	72.7.1.4	Less than 30 mV within 500 ns of tx_quiet	LPI:M	Yes [ ] N/A [ ]
TC8	Output Amplitude ON voltage	72.7.1.4	Greater than 90% of previous level within 500 ns of tx_quiet de-asserted	LPI:M	Yes [ ] N/A [ ]
TC9	Differential output return loss	72.7.1.5	Per Equation (72–4) and Equation (72–5)	M	Yes [ ]
TC10	Differential output reference impedance	72.7.1.5	100 Ω	M	Yes [ ]
TC11	Common-mode output return loss	72.7.1.6	Per Equation (72–6) and Equation (72–7)	M	Yes [ ]
TC12	Rising edge transition time	72.7.1.7	Between 24 ps and 47 ps measured at the 20% and 80% levels of the peak-to-peak differential value of the waveform	M	Yes [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
TC13	Falling edge transition time	72.7.1.7	Between 24 ps and 47 ps measured at the 80% and 20% levels of the peak-to-peak differential value of the waveform	M	Yes [ ]
TC14	Transmit jitter, peak-to-peak	72.7.1.9	See 72.7.1.8. Max TJ of 0.28 UI. Max DJ of 0.15 UI. Max RJ of 0.15 UI	M	Yes [ ]
TC15	Duty Cycle Distortion	72.7.1.9	Not to exceed 0.035 UI	M	Yes [ ]
TC16	Jitter test patterns	72.7.1.8	Test patterns 2 or 3 as defined in 52.9.1.1	M	Yes [ ]
TC17	During jitter testing	72.7.1.8	Equalization turned off	M	Yes [ ]
TC18	Changes in transmit output waveform resulting from coefficient updates	72.7.1.10	Meet requirements of Table 72–7	M	Yes [ ]
TC19	Verification of coefficient updates	72.7.1.10	After the coefficient status for all taps is reported as not_updated	M	Yes [ ]
TC20	Transmit output waveform	72.7.1.10	Meet requirements of Table 72–8	M	Yes [ ]
TC21	v_2	72.7.1.10	Greater than or equal to 40 mV for all transmit equalizer configurations	M	Yes [ ]
TC22	Coefficient status value minimum	72.7.1.10	Returned for any coefficient update equal to decrement applied to any tap that would result in Δv_2 or Δv_5 less than 40 mV	M	Yes [ ]
TC23	Coefficient status value maximum	72.7.1.10	Returned for any coefficient update equal to decrement applied to c(-1) or c(1) that would result in a violation of 72.7.1.4	M	Yes [ ]
TC24	Coefficient status value maximum	72.7.1.10	Returned for any coefficient update equal to increment applied to c(0) that would result in a violation of 72.7.1.4	M	Yes [ ]
TC25	Transmitter output waveform	72.7.1.11	Verified with test patterns 2 or 3 as defined in 52.9.1.1	M	Yes [ ]
TC26	v_1, v_2, Δv_2, v_3, v_4, v_5, Δv_5, v_6	72.7.1.11, 72.7.1.10	Measured per Figure 72–12. The absolute value of v_6 and v_3 must be within 5%. The absolute value of v_1 and v_4 must be within 5% and the absolute value of v_2 and v_5 must be within 5%. The maximum peak-to-peak value of Δv_2 and Δv_5 shall not exceed 40 mV	M	Yes [ ]

72.10.4.6 Receiver electrical characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
RC1	Receiver amplitude tolerance	72.7.2	Amplitudes up to 1600 mV without permanent damage	M	Yes [ ]
RC2	Receiver interference tolerance	72.7.2.1	Measured as described in Annex 69A with parameters in Table 72–10	M	Yes [ ]
RC3	Receiver interference tolerance	72.7.2.1	Receiver interference tolerance test pattern per 72.7.2.1	M	Yes [ ]
RC4	Receiver interference tolerance	72.7.2.1	Satisfy the requirements specified in Annex 69A	M	Yes [ ]
RC5	Signaling speed	72.7.2.2	10.3125 GBd ±100 ppm	M	Yes [ ]
RC6	Receiver coupling	72.7.2.3	AC-coupled	M	Yes [ ]
RC7	Input signal amplitude	72.7.2.4	BER still met when compliant transmitter is connected with no attenuation	M	Yes [ ]
RC8	Differential return loss	72.7.2.5	Per Equation (72–4) and Equation (72–5)	M	Yes [ ]

72.10.4.7 Environmental specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	72.9.1	Complies with applicable section of IEC 60950-1	M	Yes [ ]
ES2	Electromagnetic interference	72.9.4	Complies with applicable local and national codes	M	Yes [ ]

73. Auto-Negotiation for backplane and copper cable assembly

Auto-Negotiation, as defined in this clause, is specified for use with Ethernet PHYs operating over a backplane and for use with certain Ethernet PHYs operating over a copper cable assembly.

73.1 Auto-Negotiation introduction

While implementation of Auto-Negotiation is mandatory for Backplane Ethernet PHYs, the use of Auto-Negotiation is optional. Parallel detection shall be provided for legacy devices that do not support Auto-Negotiation.

The Auto-Negotiation function allows an Ethernet device to advertise modes of operation it possesses to another device at the remote end of a Backplane Ethernet link and to detect corresponding operational modes the other device may be advertising.

The objective of this Auto-Negotiation function is to provide the means to exchange information between two devices that share a link across a backplane and to automatically configure both devices to take maximum advantage of their abilities. It has the additional objective of supporting a digital signal detect to ensure that the device is attached to a link partner rather than detecting signal due to crosstalk.

Auto-Negotiation is performed using differential Manchester encoding (DME) pages. DME provides a DC-balanced signal. DME does not add packet or upper layer overhead to the network devices.

Auto-Negotiation does not test the link segment characteristics.

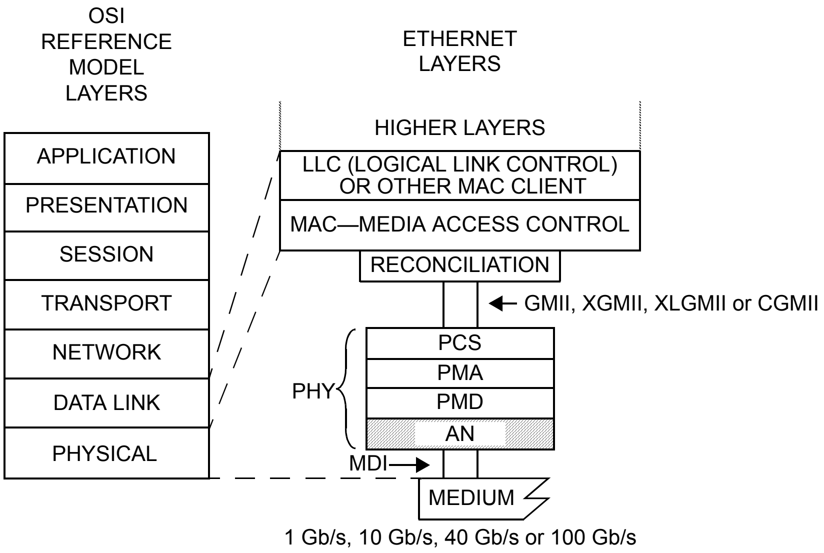
This function allows the devices at both ends of a link segment to advertise abilities, acknowledge receipt and discover the common modes of operation that both devices share, and to reject the use of operational modes that are not shared by both devices. Where more than one common mode exists between the two devices, a mechanism is provided to allow the devices to resolve to a single mode of operation using a predetermined priority resolution function. The Auto-Negotiation function allows the devices to switch between the various operational modes in an orderly fashion, permits management to disable or enable the Auto-Negotiation function, and allows management to select a specific operational mode. The Auto-Negotiation function also provides a parallel detection function to allow Backplane Ethernet devices to connect to other Backplane Ethernet devices that have Auto-Negotiation disabled and interoperate with legacy devices that do not support Clause 73 Auto-Negotiation.

It is recommended that a device that has negotiated 1000BASE-KX operation through this clause not perform Clause 37 Auto-Negotiation. A device that performs Clause 37 Auto-Negotiation after having negotiated 1000BASE-KX operation through Clause 73 Auto-Negotiation will not interoperate with a device that does not perform Clause 37 Auto-Negotiation. Therefore, a device that intends to enable Clause 37 Auto-Negotiation after Clause 73 Auto-Negotiation has completed shall ensure through an implementation-specific mechanism that the link partner supports Clause 37 Auto-Negotiation and intends to enable it. If Clause 37 Auto-Negotiation is performed after Clause 73 Auto-Negotiation, then the advertised abilities used in the Clause 37 Auto-Negotiation shall match those advertised abilities used in the Clause 73 Auto-Negotiation.

The Auto-Negotiation functions are listed in 73.3.

73.2 Relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model

The Auto-Negotiation function is provided at the Physical Layer of the ISO/IEC OSI reference model as shown in Figure 73–1. A device that supports multiple modes of operation may advertise its capabilities using the Auto-Negotiation function. The actual transfer of information is observed only at the MDI or on the backplane medium.



AN = AUTO-NEGOTIATION
CGMII = 100 Gb/s MEDIA INDEPENDENT INTERFACE
GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
XGMII = 10 Gb/s MEDIA INDEPENDENT INTERFACE
XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE

Figure 73–1—Location of Auto-Negotiation function within the ISO/IEC OSI reference model

73.3 Functional specifications

The Auto-Negotiation function provides a mechanism to control connection of a single MDI to a single PHY type, where more than one PHY type may exist. A management interface provides control and status of Auto-Negotiation, but the presence of a management agent is not required.

The Auto-Negotiation function shall provide the following:

a) Auto-Negotiation transmit
b) Auto-Negotiation receive
c) Auto-Negotiation arbitration

These functions shall comply with the state diagrams from Figure 73–9 through Figure 73–11. The Auto-Negotiation functions shall interact with the technology-dependent PHYs through the Technology-Dependent interface (see 73.9). Technology-Dependent PHYs include 1000BASE-KX,

10GBASE-KX4, 10GBASE-KR, 40GBASE-KR4, 40GBASE-CR4, 100GBASE-CR10, 100GBASE-KP4, 100GBASE-KR4, and 100GBASE-CR4.

When the MDI supports multiple lanes, then lane 0 of the MDI shall be used for Auto-Negotiation and for connection of any single-lane PHYs (e.g., 1000BASE-KX or 10GBASE-KR).

73.4 Transmit function requirements

The Transmit function provides the ability to transmit pages. The first pages exchanged by the local device and its link partner after Power-On, link restart, or renegotiation contain the base link codeword defined in Figure 73–6. The local device may modify the link codeword to disable an ability it possesses, but will not transmit an ability it does not possess. This makes possible the distinction between local abilities and advertised abilities so that multi-ability devices may Auto-Negotiate to a mode lower in priority than the highest common ability.

73.5 DME transmission

Auto-Negotiation's method of communication builds upon the encoding mechanism known as differential Manchester encoding (DME). The DME page encodes the data that is used to control the Auto-Negotiation function. DME pages shall not be transmitted when Auto-Negotiation is complete and the highest common denominator PHY has been enabled.

73.5.1 DME electrical specifications

Transmitter characteristics shall meet the specifications in Table 73–1 at TP1 while transmitting DME pages. Receiver characteristics shall meet the specifications in Table 73–1 at TP4 while receiving DME pages.

Table 73–1—DME electrical characteristics

Parameter	Value	Units
Transmit differential peak-to-peak output voltage	600 to 1200	mV
Receive differential peak-to-peak input voltage	200 to 1200	mV

For any multi-lane PHY, DME pages shall be transmitted only on lane 0. The transmitters on other lanes should be disabled as specified in 71.6.7, 84.7.7, 85.7.7, 92.7.7, 93.7.7, or 94.3.6.7.

73.5.2 DME page encoding

A DME page carries a 48-bit Auto-Negotiation page. It consists of 106 evenly spaced transition positions that contain a Manchester violation delimiter, the 48-bit page, and a single pseudo-random bit. The odd-numbered transition positions represent clock information. The even numbered transition positions represent data information. DME pages are transmitted continuously without any idle or gap.

The first eight transition positions contain the Manchester violation delimiter, which marks the beginning of the page. The Manchester violation contains a transition at position 1 and position 5 and no transitions at the remaining positions. The Manchester violation delimiter is the only place where four intervals occur between transitions. This allows the receiver to obtain page synchronization.

Each of the remaining 49 odd-numbered transition positions shall contain a transition. The remaining 49 even-numbered transition positions shall represent data information as follows:

- A transition present in an even-numbered transition position represents a logical one
- A transition absent from an even-numbered transition position represents a logical zero

The first 48 of these positions shall carry the data of the Auto-Negotiation page. The final position carries the pseudo-random bit. The value of the pseudo-random bit shall be derived from a pseudo-random generator as shown in Figure 73–2.

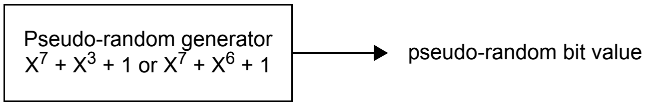


Figure 73–2—DME page bit 49 randomizer

The counter shall increment once per DME page.

The purpose of the 49th bit is to remove the spectral peaks that would otherwise occur when sending the same AN page repeatedly. Randomly choosing between 0 or 1 for one of the DME bits results in randomly inverting or not inverting the encoded page so that repetitions of the same page no longer produce a periodic signal.

Clock transition positions are differentiated from data transition positions by the spacing between them, as shown in Figure 73–3 and enumerated in Table 73–2.

The encoding of data using DME bits in an DME page is illustrated in Figure 73–3.

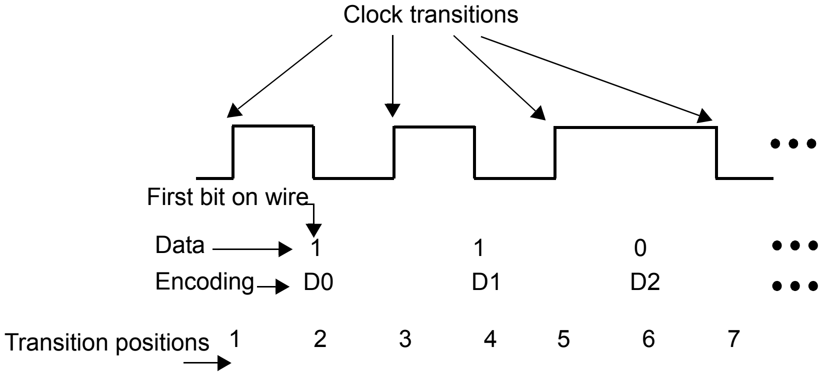


Figure 73–3—Data bit encoding within DME pages

73.5.3 DME page timing

The timing parameters for DME pages shall be followed as in Table 73–2. The transition positions within a DME page are spaced with a period of T1. T2 is the separation between clock transitions. T3 is the time from a clock transition to a data transition representing a one. The period, T1, shall be 3.2 ns ± 0.01%. Transitions shall occur within ± 0.2 ns of their ideal positions.

T5 specifies the duration of a DME page. Since DME pages are sent continuously during Auto-Negotiation, T5 is also the time from the start of one DME page to the start of the next DME page.

The minimum number of transitions and maximum number of transitions in a page is represented by T4.

Table 73–2 summarizes the timing parameters. The transition timing parameters are illustrated in Figure 73–4.

Table 73–2— DME page timing summary

	Parameter	Min.	Typ.	Max.	Units
T1	Transition position spacing (period)	3.2 –0.01%	3.2	3.2 +0.01%	ns
T2	Clock transition to clock transition	6.2	6.4	6.6	ns
T3	Clock transition to data transition (data = 1)	3.0	3.2	3.4	ns
T4	Transitions in a DME page	51	—	100	—
T5	DME page width	338.8	339.2	339.6	ns
T6	DME Manchester violation delimiter width	12.6	12.8	13.0	ns

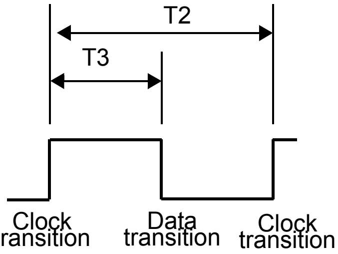


Figure 73–4—DME page transition timing

73.5.3.1 Manchester violation delimiter

A violation is signaled as shown in Figure 73–5.

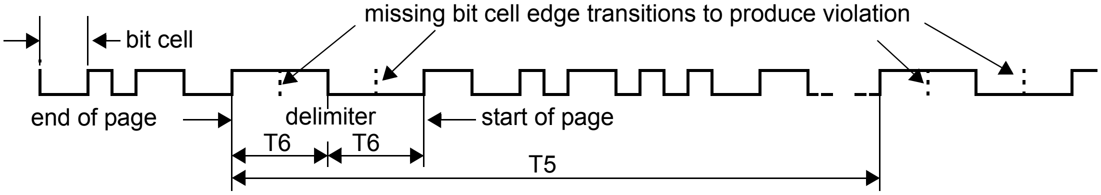


Figure 73–5—Manchester violation

73.6 Link codeword encoding

The base link codeword (Base Page) transmitted within a DME page shall convey the encoding shown in Figure 73–6. The Auto-Negotiation function supports additional pages using the Next Page function. Encoding for the link codeword(s) used in the Next Page exchange are defined in 73.7.7. In a DME page, D0 shall be the first bit transmitted.

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
S0	S1	S2	S3	S4	E0	E1	E2	E3	E4	C0	C1	C2	RF	Ack	NP

D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D45	D46	D47
T0	T1	T2	T3	T4	A0	A1	A2	A3	A4	A5	A6	A7	A24	F0	F1

Figure 73–6—Link codeword Base Page

D[4:0] contains the Selector Field. D[9:5] contains the Echoed Nonce field. D[12:10] contains capability bits to advertise capabilities not related to the PHY. C[1:0] is used to advertise pause capability. The remaining capability bit C[2] is reserved. D[15:13] contains the RF, Ack, and NP bits. These bits shall function as specified in 28.2.1.2. D[20:16] contains the Transmitted Nonce field. D[45:21] contains the Technology Ability Field. D[47:46] contains FEC capability (see 73.6.5).

73.6.1 Selector Field

Selector Field (S[4:0]) is a five-bit wide field, encoding 32 possible messages. Selector Field encoding definitions are shown in Annex 28A. Combinations not specified are reserved for future use. Reserved combinations of the Selector Field shall not be transmitted.

The Selector Field for IEEE Std 802.3 is shown in Table 73–3.

Table 73–3—Selector Field Encoding

S4	S3	S2	S1	S0	Selector description
0	0	0	0	1	IEEE Std 802.3

73.6.2 Echoed Nonce Field

Echoed Nonce Field (E[4:0]) is a 5-bit wide field containing the nonce received from the link partner. When Acknowledge is set to logical zero, the bits in this field shall contain logical zeros. When Acknowledge is set to logical one, the bits in this field shall contain the value received in the Transmitted Nonce Field from the link partner.

73.6.3 Transmitted Nonce Field

Transmitted Nonce Field (T[4:0]) is a 5-bit wide field containing a random or pseudo-random number. A new value shall be generated for each entry to the Ability Detect state. The method of generating the nonce is left to the implementer. The transmitted nonce should have a uniform distribution in the range from 0 to $2^5 - 1$. The method used to generate the value should be designed to minimize correlation to the values generated by other devices.

73.6.4 Technology Ability Field

Technology Ability Field (A[24:0]) is a 25-bit wide field containing information indicating supported technologies specific to the selector field value when used with the Auto-Negotiation for Backplane Ethernet. These bits are mapped to individual technologies such that abilities are advertised in parallel for a single selector field value. The Technology Ability Field encoding for the IEEE 802.3 selector with Auto-Negotiation for Backplane Ethernet is described in Table 73–4.

Table 73–4—Technology Ability Field encoding

Bit	Technology
A0	1000BASE-KX
A1	10GBASE-KX4
A2	10GBASE-KR
A3	40GBASE-KR4
A4	40GBASE-CR4
A5	100GBASE-CR10
A6	100GBASE-KP4
A7	100GBASE-KR4
A8	100GBASE-CR4
A9 through A24	Reserved for future technology

Multiple technologies may be advertised in the link codeword. A device shall support the data service ability for a technology it advertises. It is the responsibility of the Arbitration function to determine the common mode of operation shared by a link partner and to resolve multiple common modes.

A PHY for operation over an electrical backplane (e.g., 1000BASE-KX, 10GBASE-KX4, 10GBASE-KR, 40GBASE-KR4, 100GBASE-KP4, 100GBASE-KR4) shall not be advertised simultaneously with a PHY for operation over a copper cable assembly (e.g., 40GBASE-CR4, 100GBASE-CR10, 100GBASE-CR4) as the MDI and physical medium are different.

The fields A[24:9] are reserved for future use. Reserved fields shall be sent as zero and ignored on receive.

73.6.5 FEC capability

FEC (F0:F1) is encoded in bits D46:D47 of the base link codeword. The two FEC bits are used as follows:

a) F0 is FEC ability
b) F1 is FEC requested

When the FEC ability bit is set to logical one, it indicates that the PHY has FEC ability (see Clause 74). When the FEC requested bit is set to logical one, it indicates a request to enable FEC on the link.

Since the local device and the link partner may have set the FEC capability bits differently, the priority resolution function is used to enable FEC in the respective PHYs. The FEC function shall be enabled on the link if 10GBASE-KR, 40GBASE-KR4, 40GBASE-CR4, or 100GBASE-CR10 is the HCD technology (see 73.7.6), both devices advertise FEC ability on the F0 bits, and at least one device requests FEC on the F1 bits; otherwise FEC shall not be enabled.

The variable an_baser_fec_control indicates that BASE-R FEC operation has been negotiated. If the value is false, then BASE-R FEC has not been negotiated. If the value is true, then BASE-R FEC has been negotiated. The mapping of this variable to an MDIO bit is defined in Table 73–6.

If mr_autoneg_enable (see 73.10.1) is false, the FEC function is controlled by implementation-dependent means.

73.6.6 Pause Ability

Pause (C0:C1) is encoded in bits D11:D10 of the base link codeword. The two-bit Pause is encoded as follows:

a) C0 is the same as PAUSE as defined in Annex 28B
b) C1 is the same as ASM_DIR as defined in Annex 28B

The Pause encoding is defined in Clause 28B.2, Table 28B–2. The PAUSE bit indicates that the device is capable of providing the symmetric PAUSE functions as defined in Annex 31B. The ASM_DIR bit indicates that asymmetric PAUSE is supported. The value of the PAUSE bit when the ASM_DIR bit is set indicates the direction the PAUSE frames are supported for flow across the link. Asymmetric PAUSE configuration results in independent enabling of the PAUSE receive and PAUSE transmit functions as defined by Annex 31B. See 28B.3 regarding PAUSE configuration resolution.

73.6.7 Remote Fault

Remote Fault (RF) is encoded in bit D13 of the base link codeword. The default value is logical zero. The Remote Fault bit provides a standard transport mechanism for the transmission of simple fault information. When the RF bit in the AN advertisement register (Register 7.16.13) is set to logical one, the RF bit in the transmitted base link codeword is set to logical one. When the RF bit in the received base link codeword is set to logical one, the Remote Fault bit in the AN LP Base Page ability register (Register 7.19.13) will be set to logical one, if the management function is present.

73.6.8 Acknowledge

Acknowledge (Ack) is used by the Auto-Negotiation function to indicate that a device has successfully received its link partner’s link codeword. The Acknowledge Bit is encoded in bit D14 of link codeword. If no Next Page information is to be sent, this bit shall be set to logical one in the link codeword after the reception of at least three consecutive and consistent DME pages (ignoring the Acknowledge bit value). If Next Page information is to be sent, this bit shall be set to logical one after the device has successfully received at least three consecutive and matching DME pages (ignoring the Acknowledge bit value), and will remain set until the Next Page information has been loaded into the AN XNP transmit register (Registers 7.22, 7.23, 7.24). In order to save the current received link codeword, it must be read from the AN LP XNP ability register (Register 7.25, 7.26, 7.27) before the Next Page of transmit information is loaded into the AN XNP transmit register. After the COMPLETE ACKNOWLEDGE state has been entered, the link codeword will be transmitted at least six times.

73.6.9 Next Page

Next Page (NP) is encoded in bit D15 of link codeword. Support of Next Pages is mandatory. If the device does not have any Next Pages to send, the NP bit shall be set to logical zero. If a device wishes to engage in Next Page exchange, it shall set the NP bit to logical one. If a device has no Next Pages to send and its link partner has set the NP bit to logical one, it shall transmit Next Pages with Null message codes and the NP bit set to logical zero while its link partner transmits valid Next Pages. Next page exchanges will occur if either the device or its link partner sets the Next Page bit to logical one. The Next Page function is defined in 73.7.7.

73.6.10 Transmit Switch function

During Auto-Negotiation and prior to entry into the AN_GOOD_CHECK state, the Transmit Switch function shall connect only the DME page generator controlled by the Transmit State Diagram to the MDI.

Upon entry into the AN_GOOD_CHECK state, the Transmit Switch function shall connect the transmit path from a single technology-dependent (highest common denominator) PHY to the MDI.

When a PHY is connected to the MDI through the Transmit Switch function, the signals at the MDI shall conform to all of the PHY’s specifications within 20 ms.

73.7 Receive function requirements

The receive function detects the DME page sequence, decodes the information contained within, and stores the data in rx_link_code_word[48:1]. The receive function incorporates a receive switch to control connection of the DME page receiver or a PHY to the MDI.

73.7.1 DME page reception

To be able to detect the DME bits, the receiver should have the capability to receive DME signals sent with the electrical specifications of the PHY (1000BASE-KX, 10GBASE-KX4, 10GBASE-KR, 40GBASE-KR4, 40GBASE-CR4, 100GBASE-CR10, 100GBASE-KP4, 100GBASE-KR4, or 100GBASE-CR4). The DME transmit signal level and receive sensitivity are specified in 73.5.1.

73.7.2 Receive Switch function

During Auto-Negotiation and prior to entry into the AN_GOOD_CHECK state, the Receive Switch function shall connect the DME page receiver to the MDI. For the Parallel Detection function, the Receive Switch function shall also connect the receive path of the 1000BASE-KX and 10GBASE-KX4 PHY to the MDI when those PHYs are present.

Upon entry into the AN_GOOD_CHECK state, the Receive Switch function shall connect the receive path from a single technology-dependent (highest common denominator) PHY to the MDI.

73.7.3 Link codeword matching

The Receive function shall generate ability_match, acknowledge_match, and consistency_match variables as defined in Arbitration state diagram Figure 73–11.

73.7.4 Arbitration function requirements

The Arbitration function is described in Figure 73–11 and ensures proper sequencing of the Auto-Negotiation function using the Transmit function and Receive function. The Arbitration function enables the Transmit function to advertise and acknowledge abilities. Upon indication of acknowledgement, the Arbitration function determines the highest common denominator using the priority resolution function and enables the appropriate technology-dependent PHY via the link_control_[x] variables.

If mr_autoneg_enable (see 73.10.1) is false, enabling the desired technology-dependent PHY is controlled by implementation-dependent means.

73.7.4.1 Parallel Detection function

The local device detects a link partner that supports Auto-Negotiation by DME page detection. The Parallel Detection function allows detection of link partners that support 1000BASE-KX and 10GBASE-KX4 but have disabled Auto-Negotiation, and detection of legacy devices that can interoperate with 1000BASE-KX and 10GBASE-KX4 devices, but do not provide Clause 73 Auto-Negotiation.

A local device shall provide Parallel Detection for 1000BASE-KX and 10GBASE-KX4 if it supports those PHYs. Additionally, parallel detection may be used for 10GBASE-CX4. Parallel detection of 10GBASE-CX4 will be indicated by the setting of the Negotiated Port Type to “10GBASE-KX4 or 10GBASE-CX4” in the management register bit 7.48.2. The means to distinguish between 10GBASE-KX4 and 10GBASE-CX4 is implementation dependent. Parallel Detection shall be performed by directing the MDI receive activity to the PHY. This detection may be done in sequence between detection of DME pages and detection of each supported PHY. If at least one of the 1000BASE-KX, or 10GBASE-KX4 establishes link_status=OK, the LINK STATUS CHECK state is entered and the autoneg_wait_timer is started. If exactly one link_status=OK indication is present when the autoneg_wait_timer expires, then Auto-Negotiation shall set link_control=ENABLE for the PHY indicating link_status=OK. If a PHY is enabled, the Arbitration function shall set link_control=DISABLE to all other PHYs and indicate that Auto-Negotiation has completed. On transition to the AN GOOD CHECK state from the LINK STATUS CHECK state, the Parallel Detection function shall set the bit in the AN LP Base Page ability registers (see 45.2.7.7) corresponding to the technology detected by the Parallel Detection function.

If Auto-Negotiation detects link_status=OK from any of the technology-dependent PHYs prior to DME page detection, the autoneg_wait_timer shall start. If more than one technology-dependent PHYs indicate link_status=OK when the autoneg_wait_timer expires, Auto-Negotiation will not allow any data service to be enabled and may signal this as a remote fault to the link partner using the Base Page and will flag this in the local device by setting the Parallel Detection fault bit (45.2.7.2) in the AN Status register.

73.7.5 Renegotiation function

A renegotiation request from any entity, such as a management agent, shall cause the Arbitration function to disable all technology-dependent PHYs and halt any transmit data and link transition activity until the break_link_timer expires. Consequently, the link partner will go into link fail and normal Auto-Negotiation resumes. The local device shall resume Auto-Negotiation after the break_link_timer has expired by issuing DME pages with the Base Page valid in tx_link_code_word[48:1]. Once Auto-Negotiation has completed, renegotiation will take place if the Highest Common Denominator technology that receives link_control=ENABLE returns link_status=FAIL. To allow the PHY an opportunity to determine link integrity using its own link integrity test function, the link_fail_inhibit_timer qualifies the link_status=FAIL indication such that renegotiation takes place if the link_fail_inhibit_timer has expired and the PHY still indicates link_status=FAIL.

73.7.6 Priority Resolution function

Since a local device and a link partner may have multiple common abilities, a mechanism to resolve which mode to configure is required. The mechanism used by Auto-Negotiation is a Priority Resolution function that predefines the hierarchy of supported technologies. The single PHY enabled to connect to the MDI by Auto-Negotiation shall be the technology corresponding to the bit in the Technology Ability Field common to the local device and link partner that has the highest priority as defined in Table 73–5 (listed from highest priority to lowest priority).

Table 73–5—Priority Resolution

Priority	Technology	Capability
1	100GBASE-CR4	100 Gb/s 4 lane, highest priority
2	100GBASE-KR4	100 Gb/s 4 lane
3	100GBASE-KP4	100 Gb/s 4 lane
4	100GBASE-CR10	100 Gb/s 10 lane
5	40GBASE-CR4	40 Gb/s 4 lane
6	40GBASE-KR4	40 Gb/s 4 lane
7	10GBASE-KR	10 Gb/s 1 lane
8	10GBASE-KX4	10 Gb/s 4 lane
9	1000BASE-KX	1 Gb/s 1 lane, lowest priority

The common technology is referred to as the highest common denominator, or HCD, technology. If the local device receives a Technology Ability Field with a bit set that is reserved, the local device shall ignore that bit for priority resolution. Determination of the HCD technology occurs on entrance to the AN GOOD CHECK state. In the event that a technology is chosen through the parallel detection function, that technology shall be considered the highest common denominator (HCD) technology. In the event that there is no common technology, HCD shall have a value of “NULL”, indicating that no PHY receives link_control=ENABLE and link_status[HCD]=FAIL.

NOTE—If both local device and link partner are Backplane Ethernet compliant PHYs, then both ends use abilities exchanged through Clause 73 Auto-Negotiation function. If the Link partner is a legacy device (or has disabled Auto-Negotiation) as indicated by the parallel detect function, then the peer 1 Gb/s devices can opt to use abilities exchanged through Clause 37. This will ensure there are no interoperability issues when connected to a Backplane Ethernet PHY.

73.7.7 Next Page function

The Next Page function uses the Auto-Negotiation arbitration mechanisms to allow exchange of Next Pages of information, which may follow the transmission and acknowledgment procedures used for the base link codeword. The Next Page has both Message code field and Unformatted code fields.

A dual acknowledgment system is used. Acknowledge (Ack) is used to acknowledge receipt of the information; Acknowledge 2 (Ack2) is used to indicate that the receiver is able to act on the information (or perform the task) defined in the message.

The Toggle bit is used to ensure proper synchronization between the local device and the link partner.

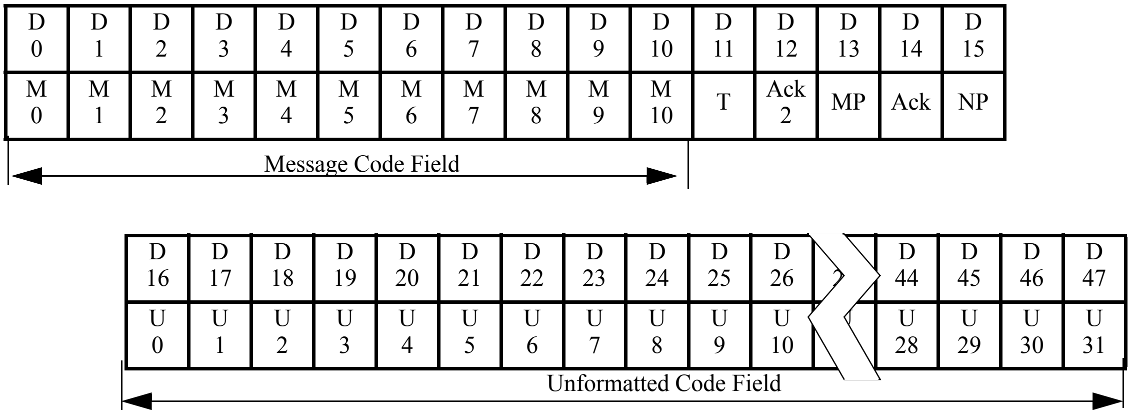
Next page exchange occurs after the base link codewords have been exchanged if either end of the link segment set the Next Page bit to logical one indicating that it had at least one Next Page to send. Next page exchange consists of using the normal Auto-Negotiation arbitration process to send Next Page messages.

The Next Page contains two message encodings. The message encodings are defined as follows: message code, which contain predefined 11-bit codes, and unformatted code contains 32 bit codes. Multiple Next Pages with appropriate message codes and unformatted codes can be transmitted to send extended messages. Each series of Next Pages shall have a Message code that defines how the Unformatted codes will be interpreted. Any number of Next Pages may be sent in any order; however, it is recommended that the total number of Next Pages sent be kept small to minimize the link startup time.

Next page transmission ends when both ends of a link segment set their Next Page bits to logical zero, indicating that neither has anything additional to transmit. It is possible for one device to have more pages to transmit than the other device. Once a device has completed transmission of its Next Page information, it shall transmit Next Pages with Null message codes and the NP bit set to logical zero while its link partner continues to transmit valid Next Pages. An Auto-Negotiation able device shall recognize reception of Message Pages with Null message codes as the end of its link partner's Next Page information.

73.7.7.1 Next page encodings

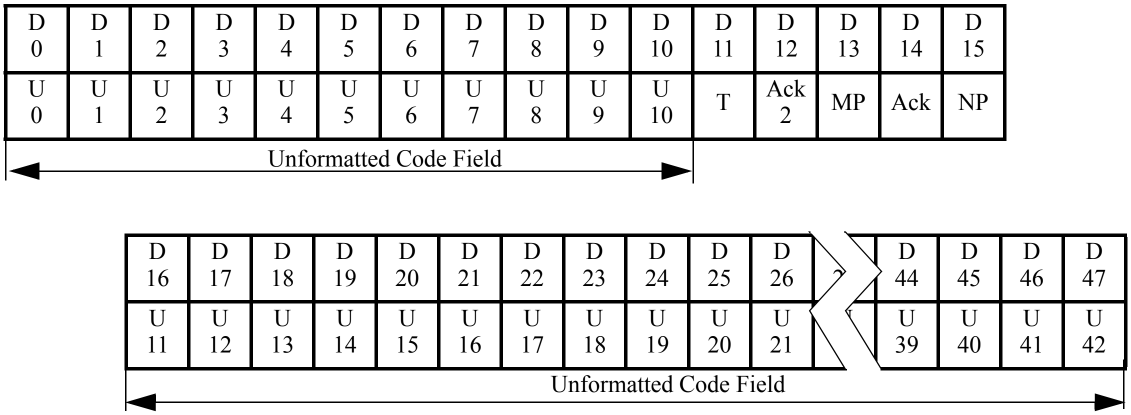
The Next Page shall use the encoding shown in Figure 73–7 and Figure 73–8 for the NP, Ack, MP, Ack2, and T bits. These bits shall function as specified in 28.2.3.4. There are two types of Next Page encodings—message and unformatted. For message Next Pages, the MP bit shall be set to logical one, the 11-bit field D[10:0] shall be encoded as a Message Code Field and D[47:16] shall be encoded as Unformatted Code Field. For Unformatted Next Pages, the MP bit shall be set to logical zero; D[10:0] and D[47:16] shall be encoded as the Unformatted Code Field.



D 0	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
M 0	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	T	Ack 2	MP	Ack	NP

D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23	D 24	D 25	D 26		D 44	D 45	D 46	D 47
U 0	U 1	U 2	U 3	U 4	U 5	U 6	U 7	U 8	U 9	U 10		U 28	U 29	U 30	U 31

Figure 73–7—Message Next Page



D 0	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15
U 0	U 1	U 2	U 3	U 4	U 5	U 6	U 7	U 8	U 9	U 10	T	Ack 2	MP	Ack	NP

D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23	D 24	D 25	D 26	D 44	D 45	D 46	D 47
U 11	U 12	U 13	U 14	U 15	U 16	U 17	U 18	U 19	U 20	U 21	U 39	U 40	U 41	U 42

Figure 73–8—Unformatted Next Page

73.7.7.2 Use of Next Pages

Next page exchange will commence after the Base Page exchange if either device requests it by setting the NP bit to logical one.

Next page exchange shall continue until neither device on a link has more pages to transmit as indicated by the NP bit. A Next Page with a Null Message Code Field value shall be sent if the device has no other information to transmit.

A message code can carry either a specific message or information that defines how the corresponding unformatted codes should be interpreted.

73.8 Management register requirements

The management interface is used to communicate Auto-Negotiation information to the management entity. MMD7 of the Clause 45 Management Data Input/Output (MDIO) interface shall be provided as the logical interface to access the device registers for Auto-Negotiation and other management purposes. The Clause 45 MDIO electrical interface is optional. Where no physical embodiment of the MDIO exists, provision of an equivalent mechanism to access the registers is recommended. Table 73–6 provides the mapping of Backplane Ethernet Auto-Negotiation variables to management registers.

Table 73–6—Backplane Ethernet Auto-Negotiation variable to MDIO register mapping

Variable	Description
mr_adv_ability[48:1]	{7.18.15:0, 7.17.15:0, 7.16.15:0} AN advertisement registers
mr_autoneg_complete	7.1.5 Auto-Negotiation Complete
mr_autoneg_enable	7.0.12 Auto-Negotiation Enable
mr_lp_adv_ability[48:1]	For Base Page: {7.21.15:0, 7.20.15:0, 7.19.15:0} AN LP Base Page ability registers For Next Page(s): {7.27.15:0, 7.26.15:0, 7.25.15:0} AN LP XNP ability registers
mr_lp_autoneg_able	7.1.0 LP Auto-Negotiation Able
mr_main_reset	7.0.15 Reset
mr_next_page_loaded	Set on write to AN XNP Transmit registers; cleared by Arbitration state diagram
mr_np_tx[48:1]	{7.24.15:0, 7.23.15:0, 7.22.15:0} AN XNP Transmit registers
mr_page_rx	7.1.6 Page Received
mr_parallel_detection_fault	7.1.9 Parallel detection Fault
mr_restart_negotiation	7.0.9 Auto-Negotiation Restart
set to 1	7.1.3 Auto-Negotiation Ability
link_control_[x]	{7.48.11:8, 7.48.6:5, 7.48.3:1} Negotiated Port Type
an_baser_fec_control	7.48.4 BASE-R FEC negotiated

73.9 Technology-Dependent interface

The Technology-Dependent interface is the communication mechanism between each technology's PCS and the Auto-Negotiation function. Auto-Negotiation can support multiple technologies, all of which need not be implemented in a given device. Each of these technologies may utilize its own technology-dependent link integrity test function.

73.9.1 AN_LINK.indication

This primitive is generated by the PCS to indicate the status of the underlying medium. The purpose of this primitive is to give the Auto-Negotiation function a means of determining the validity of received code elements.

73.9.1.1 Semantics of the service primitive

AN_LINK.indication(link_status)

The link_status parameter shall assume one of two values: OK or FAIL, indicating whether the underlying receive channel is intact and enabled (OK) or not intact (FAIL).

73.9.1.2 When generated

A technology-dependent PCS generates this primitive to indicate a change in the value of link_status.

73.9.1.3 Effect of receipt

The effect of receipt of this primitive shall be governed by the state diagram of Figure 73–11.

73.10 State diagrams and variable definitions

The notation used in state diagrams follows the conventions in Clause 28. Variables in a state diagram with default values evaluate to the variable default in each state where the variable value is not explicitly set.

Auto-Negotiation shall implement the Transmit state diagram, Receive state diagram and Arbitration state diagram. Additional requirements to these state diagrams are made in the respective functional requirements sections. Options to these state diagrams clearly stated as such in the functional requirements sections or state diagrams shall be allowed. In the case of any ambiguity between stated requirements and the state diagrams, the state diagrams shall take precedence.

73.10.1 State diagram variables

A variable with "_[x]" appended to the end of the variable name indicates a variable or set of variables as defined by "x". "x" may be as follows:

all;	represents all specific technology-dependent PMDs supported in the local device.
1GKX;	represents the 1000BASE-KX PMD.
10GKR;	represents the 10GBASE-KR PMD.
10GKX4;	represents the 10GBASE-KX4 or 10GBASE-CX4 PMD.
40GKR4;	represents the 40GBASE-KR4 PMD.
40GCR4;	represents the 40GBASE-CR4 PMD.
100GCR10;	represents the 100GBASE-CR10 PMD.
100GKP4;	represents the 100GBASE-KP4 PMD.
100GKR4;	represents the 100GBASE-KR4 PMD.
100GCR4;	represents the 100GBASE-CR4 PMD.
HCD;	represents the single technology-dependent PMD chosen by Auto-Negotiation as the highest common denominator technology through the Priority Resolution or parallel detection function.
notHCD;	represents all technology-dependent PMDs not chosen by Auto-Negotiation as the highest common denominator technology through the Priority Resolution or parallel detection function.
PD;	represents all of the following that are present: 1000BASE-KX PMD and 10GBASE-KX4 (or 10GBASE-CX4) PMD.

Variables with [48:1] appended to the end of the variable name indicate arrays that can be directly mapped to 48-bit registers. For these variables, "[x]" indexes an element or set of elements in the array, where "[x]" may be as follows:

a) Any integer
b) Any range of integers
c) Any variable that takes on integer values
d) NP; represents the index of the Next Page bit
e) ACK; represents the index of the Acknowledge bit
f) RF; represents the index of the Remote Fault bit

Variables of the form “mr_x”, where x is a label, comprise a management interface that is intended to be connected to the Management function. However, an implementation-specific management interface may provide the control and status function of these bits.

ability_match

Indicates that three consecutive link codewords match, ignoring the Acknowledge bit. Three consecutive words are any three words received one after the other, regardless of whether the word has already been used in a word-match comparison or not.

Values: false; three matching consecutive link codewords have not been received, ignoring the Acknowledge bit (default).
true; three matching consecutive link codewords have been received, ignoring the Acknowledge bit.

NOTE—This variable is set by this variable definition; it is not set explicitly in the state diagrams.

ability_match_word [48:1]

A 48-bit array that is loaded upon transition to Acknowledge Detect state with the value of the link codeword that caused ability_match = true for that transition. For each element in the array transmitted.

Values: zero; data bit is logical zero.
one; data bit is logical one.

NOTE—This variable is set by this variable definition; it is not set explicitly in the state diagrams.

ack_finished

Status indicating that the final remaining_ack_cnt link codewords with the Ack bit set have been transmitted.

Values: false; more link codewords with the Ack bit set to logical one must be transmitted.
true; all remaining link codewords with the Ack bit set to logical one have been transmitted.

ack_nonce_match

Indicates whether the echoed nonce received from the link partner matches the transmitted nonce field sent by the local device. The echoed nonce value from the DME page that caused acknowledge_match to be set is used for this test.

Values false; link partner echoed nonce does not equal local device transmitted nonce.
true; link partner echoed nonce equals local device transmitted nonce.

acknowledge_match

Indicates that three consecutive link codewords match and have the Acknowledge bit set. Three consecutive words are any three words received one after the other, regardless of whether the word has already been used in a word match comparison or not.

Values: false; three matching and consecutive link codewords have not been received with the

Acknowledge bit set (default).
true; three matching and consecutive link codewords have been received with the Acknowledge bit set.

NOTE—This variable is set by this variable definition; it is not set explicitly in the state diagrams.

an_link_good

Indicates that Auto-Negotiation has completed.

Values: false; negotiation is in progress (default).
true; negotiation is complete, forcing the Transmit and Receive functions to IDLE.

an_receive_idle

Indicates that the Receive state diagram is in the IDLE or DELIMITER DETECT state.

Values: false; the Receive state diagram is not in the IDLE or DELIMITER DETECT state (default).
true; the Receive state diagram is in the IDLE or DELIMITER DETECT state.

base_page

Status indicating that the page currently being transmitted by Auto-Negotiation is the initial link codeword encoding used to communicate the device’s abilities.

Values: false; a page other than base link codeword is being transmitted.
true; the base link codeword is being transmitted.

code_sel

A Boolean random or pseudo-random value uniformly distributed. A new value is generated each time the variable code_sel is used.

Values: zero; a zero has been assigned.
one; a one has been assigned.

complete_ack

Controls the counting of transmitted link codewords that have their Acknowledge bit set.

Values: false; transmitted link codewords with the Acknowledge bit set are not counted (default).
true; transmitted link codewords with the Acknowledge bit set are counted.

consistency_match

Indicates that the ability_match_word same as the link codeword that caused acknowledge_match to be set.

Values: false; the link codeword that caused ability_match to be set is not the same as the link codeword that caused acknowledge_match to be set, ignoring the Acknowledge bit value and the echoed nonce value.
true; the link codeword that caused ability_match to be set is the same as the link codeword that caused acknowledge_match to be set, ignoring the Acknowledge bit value and the echoed nonce value.

NOTE—This variable is set by this variable definition; it is not set explicitly in the state diagrams.

detect_mv_pair

Status indicating that the receiver has detected the pair of Manchester violations forming a Manchester Violation delimiter—a sequence of three consecutive transitions with 12.8 ns ± 200 ps between each pair of transitions.

Values: false; set to false after any Receive State Diagram state transition (default).

true; Manchester violation pair has been detected.

detect_transition
Status indicating that the receiver has detected a transtion.

Values: false; set to false after any Receive State Diagram state transition (default).
true; set to true when a transition is received.

incompatible_link
Parameter used following Priority Resolution to indicate the resolved link is incompatible with the local device settings. A device's ability to set this variable to true is optional.

Values: false; A compatible link exists between the local device and link partner (default).
true; Optional indication that Priority Resolution has determined no highest common denominator exists following the most recent negotiation.

NOTE—This variable is set by this variable definition; it is not set explicitly in the state diagrams.

link_control_[x]
Controls the connection of each PMD to the MDI. When all PMD transmitters are isolated from the MDI, the AN transmitter is connected to the MDI.

Values: DISABLE; isolates the PMD from the MDI.
SCAN_FOR_CARRIER; connects the PMD receiver to the MDI and isolates the PMD transmitter from the link.
ENABLE; connects the PMD (both transmit and receive) to the MDI.

link_status_[x]
This variable is defined in 73.9.1.

mr_autoneg_complete
Status indicating whether Auto-Negotiation has completed or not.

Values: false; Auto-Negotiation has not completed.
true; Auto-Negotiation has completed.

mr_autoneg_enable
Controls the enabling and disabling of the Auto-Negotiation function.

Values: false; Auto-Negotiation is disabled.
true; Auto-Negotiation is enabled.

mr_adv_ability[48:1]
A 48-bit array that contains the Advertised Abilities link codeword.
For each element within the array:

Values: zero; data bit is logical zero.
one; data bit is logical one.

mr_lp_adv_ability[48:1]
A 48-bit array that contains the link partner's Advertised Abilities link codeword.
For each element within the array:

Values: zero; data bit is logical zero.
one; data bit is logical one.

mr_lp_autoneg_able
Status indicating whether the link partner supports Auto-Negotiation.

Values: false; the link partner does not support Auto-Negotiation.

true; the link partner supports Auto-Negotiation.

mr_main_reset

Controls the resetting of the Auto-Negotiation state diagrams.

Values: false; do not reset the Auto-Negotiation state diagrams.
true; reset the Auto-Negotiation state diagrams.

mr_next_page_loaded

Status indicating whether a new page has been loaded into the AN XNP transmit register (45.2.7.8).

Values: false; a New Page has not been loaded.
true; a New Page has been loaded.

mr_np_tx[48:1]

A 48-bit array that contains the new Next Page to transmit.
For each element within the array:

Values: zero; data bit is logical zero.
one; data bit is logical one.

mr_page_rx

Status indicating whether a New Page has been received. A New Page has been successfully received when acknowledge_match=true and consistency_match=true and the link codeword has been written to mr_lp_adv_ability[48:1].

Values: false; a New Page has not been received.
true; a New Page has been received.

mr_parallel_detection_fault

Error condition indicating that while performing parallel detection, either an_receive_idle = false, or zero or more than one of the following indications were present when the autoneg_wait_timer expired. This signal is cleared on read of the AN status register (Register 7.1).

1) link_status_ [1GKX] = OK
2) link_status_[10GKX4] = OK

Values: false; Exactly one of the above two indications was true when the autoneg_wait_timer expired, and an_receive_idle = true.
true; either zero or more than one of the above two indications was true when the autoneg_wait_timer expired, or an_receive_idle = false.

mr_restart_negotiation

Controls the entrance to the TRANSMIT DISABLE state to break the link before Auto-Negotiation is allowed to renegotiate via management control.

Values: false; renegotiation is not taking place.
true; renegotiation is started.

nonce_match

Indicates whether the transmitted nonce received from the link partner matches the transmitted nonce field sent by the local device.

Values false; link partner transmitted nonce does not equal local device transmitted nonce.
true; link partner transmitted nonce equals local device transmitted nonce.

np_rx

Flag to hold the value of rx_link_code_word[NP] upon entry to the COMPLETE

ACKNOWLEDGE state. This value is associated with the value of rx_link_code_word[NP] when acknowledge_match was last set.

Values zero; local device np_rx bit equals a logical zero.
one; local device np_rx bit equals a logical one.

power_on

Condition that is true until such time as the power supply for the device that contains the Auto-Negotiation state diagrams has reached the operating region or the device has low-power mode set via MMD control register bit 1.120.12.

Values: false; the device is completely powered (default).
true; the device has not been completely powered.

pulse_too_long

Indicates that the receiver has detected successive transitions spaced too far apart for a valid DME page. Transitions separated by more than 20 ns shall cause this indication to be true. Valid Manchester violation delimiters shall not cause this indication to be true.

Values: false; excessively long pulses have not been detected.
true; excessively long pulses have been detected.

pulse_too_short

Indicates that the receiver has detected successive transitions spaced too closely for a valid DME page. Transitions separated by less than 1.6 ns shall cause this indication to be true. Valid Manchester transitions shall not cause this indication to be true.

Values: false; excessively short pulses have not been detected.
true; excessively short pulses have been detected.

rx_link_code_word[48:1]

A 48-bit array that contains the data bits to be received from a DME page.
For each element within the array:

Values: zero; data bit is a logical zero.
one; data bit is a logical one.

rx_nonce[4:0]

A 5-bit array that contains the transmitted nonce received from the DME page that caused ability_match=true.
For each element within the array:

Values: zero; data bit is a logical zero.
one; data bit is a logical one.

single_link_ready

Status indicating that an_receive_idle = true and only one the of the following indications is being received:

1) link_status_[1GKX] = OK
2) link_status_[10GKX4] = OK
3) link_status_[10GKR] = OK
4) link_status_[40GKR4] = OK
5) link_status_[40GCR4] = OK
6) link_status_[100GCR10] = OK
7) link_status_[100GKP4] = OK
8) link_status_[100GKR4] = OK
9) link_status_[100GCR4] = OK

Values: false; either zero or more than one of the above indications are true or an_receive_idle = false.
true; Exactly one of the above indications is true and an_receive_idle = true.

NOTE—This variable is set by this variable definition; it is not set explicitly in the state diagrams.

TD_AUTONEG

Controls the signal sent by Auto-Negotiation on the TD_AUTONEG circuit.

Values: disable; transmission of Auto-Negotiation signals is disabled
idle; Auto-Negotiation maintains the current signal level on the MDI.
mv_delimiter; Auto-Negotiation causes the transmission of the Manchester violation delimiter on the MDI.
transition; Auto-Negotiation causes a transition in the level on the MDI.

toggle_rx

Flag to keep track of the state of the link partner’s Toggle bit.

Values: zero; link partner’s Toggle bit equals logical zero.
one; link partner’s Toggle bit equals logical one.

toggle_tx

Flag to keep track of the state of the local device’s Toggle bit.

Values: zero; local device’s Toggle bit equals logical zero.
one; local device’s Toggle bit equals logical one.

transmit_ability

Controls the transmission of the link codeword containing tx_link_code_word[48:1].

Values: false; any transmission of tx_link_code_word[48:1] is halted (default).
true; the transmit state diagram begins sending tx_link_code_word[48:1].

transmit_ack

Controls the setting of the Acknowledge bit in the tx_link_code_word[48:1] to be transmitted.

Values: false; sets the Acknowledge bit in the transmitted tx_link_code_word[48:1] to a logical zero (default).
true; sets the Acknowledge bit in the transmitted tx_link_code_word[48:1] to a logical one.

transmit_disable

Controls the transmission of tx_link_code_word[48:1].

Values: false; tx_link_code_word[48:1] transmission is allowed (default).
true; tx_link_code_word[48:1] transmission is halted.

transmit_mv_done

Status indicating that the transmission of the Manchester violation delimiter has been completed.

Values: false; transmission of the Manchester violation is in progress.
true; transmission of the Manchester violation has been completed.

tx_link_code_word[49:1]

A 49-bit array that contains the data bits to be transmitted in an DME page.
tx_link_code_word[48:1] contains the Auto-Negotiation page to be transmitted.
tx_link_code_word[49] contains the pseudo-random bit. This array may be loaded from mr_adv_ability or mr_np_tx.

For each element within the array:

Values: zero; data bit is logical zero.
one; data bit is logical one.

73.10.2 State diagram timers

All timers operate in the manner described in 14.2.3.2.

autoneg_wait_timer
Timer for the amount of time to wait before evaluating the number of link integrity test functions with link_status=OK asserted. The autoneg_wait_timer shall expire 25 ms to 50 ms from the assertion of link_status=OK from the PCS.

break_link_timer
Timer for the amount of time to wait in order to assure that the link partner enters a Link Fail state. The timer shall expire 60 ms to 75 ms after being started.

clock_detect_min_timer
Timer for the minimum time between detection of differential Manchester clock transitions. The clock_detect_min_timer shall expire 4.8 ns to 6.2 ns after being started or restarted.

clock_detect_max_timer
Timer for the maximum time between detection of differential Manchester clock transitions. The clock_detect_max_timer shall expire 6.6 ns to 8.0 ns after being started or restarted.

data_detect_max_timer
Timer for the maximum time between a clock transition and the following data transition. This timer is used in conjunction with the data_detect_min_timer to detect whether the data bit between two clock transitions is a logical zero or a logical one. The data_detect_max_timer shall expire 3.4 ns to 4.8 ns from the last clock transition.

data_detect_min_timer
Timer for the minimum time between a clock transition and the following data transition. This timer is used in conjunction with the data_detect_max_timer to detect whether the data bit between two clock transitions is a logical zero or a logical one. The data_detect_min_timer shall expire 1.6 ns 3.0 ns from the last clock transition.

interval_timer
Timer for the separation of a transmitted clock pulse from a data bit. The interval_timer shall expire 3.2 ns ± 0.01% from each clock pulse and data bit.

link_fail_inhibit_timer
Timer for qualifying a link_status=FAIL indication or a link_status=OK indication when a specific technology link is first being established. A link will only be considered “failed” if the link_fail_inhibit_timer has expired and the link has still not gone into the link_status=OK state. The link_fail_inhibit_timer shall expire 40 ms to 50 ms after entering the AN LINK GOOD CHECK state when the link is 1000BASE-KX or 10GBASE-KX4. Otherwise the link_fail_inhibit_timer shall expire 500 ms to 510 ms after entering the AN LINK GOOD CHECK state.

NOTE—The link_fail_inhibit_timer expiration value must be greater than the time required for the link partner to complete Auto-Negotiation after the local device has completed Auto-Negotiation plus the time required for the specific technology to enter the link_status=OK state.

page_test_max_timer
Timer for the maximum time between detection of Manchester violation delimiters. This timer is used in conjunction with the page_test_min_timer to detect whether the link partner is transmitting

DME pages. The page_test_max_timer shall expire 350 ns to 375 ns after being started or restarted.

page_test_min_timer

Timer for the minimum time between detection of Manchester violation delimiters. This timer is used in conjunction with the page_test_max_timer to detect whether the link partner is transmitting DME pages. The page_test_min_timer shall expire 305 ns 330 ns after being started or restarted.

Table 73–7—Timer min/max value summary

Parameter	Min	Value and tolerance	Max	Units
autoneg_wait_timer	25		50	ms
break_link_timer	60		75	ms
clock_detect_min_timer	4.8		6.2	ns
clock_detect_max_timer	6.6		8.0	ns
data_detect_min_timer	1.6		3.0	ns
data_detect_max_timer	3.4		4.8	ns
interval_timer		3.2 ± 0.01%		ns
link_fail_inhibit_timer (when the link is neither 1000BASE-KX nor 10GBASE-KX4)	500		510	ms
link_fail_inhibit_timer (when the link is 1000BASE-KX or 10GBASE-KX4)	40		50	ms
page_test_min_timer	305		330	ns
page_test_max_timer	350		375	ns

73.10.3 State diagram counters

remaining_ack_cnt

A counter that may take on integer values from 0 to 8. The number of additional link codewords with the Acknowledge Bit set to logical one to be sent to ensure that the link partner receives the acknowledgment.

Values: not_done; positive integers between 0 and 5 inclusive.
done; positive integers 6 to 8 inclusive (default).
init; counter is reset to zero.

rx_bit_cnt

A counter that may take on integer values from 0 to 49. This counter is used to keep a count of data bits received from a DME page and to ensure that when erroneous extra transitions are received, the first 48 bits are kept while the rest are ignored. When this variable reaches 49, enough data bits have been received. This counter does not increment beyond 49 and does not return to 0 until it is reinitialized.

Values: not_done; 0 to 48 inclusive.
done; 49
init; counter is reset to zero.

tx_bit_cnt

A counter that may take on integer values from 1 to 50. This counter is used to keep a count of data bits sent within a DME page. When this variable reaches 50, all data bits have been sent.

Values: not_done; 1 to 49 inclusive.
done; 50.
init; counter is initialized to 1.

73.10.4 State diagrams

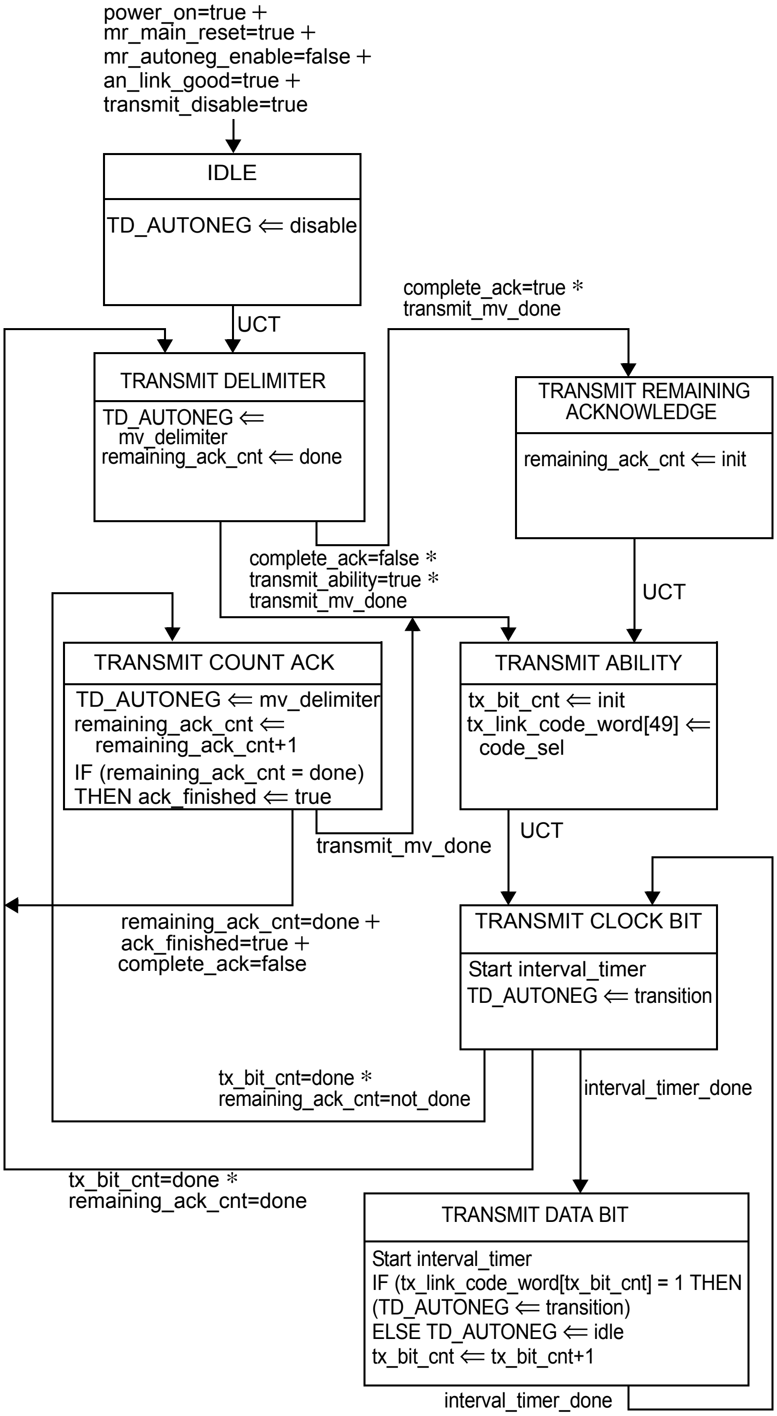


Figure 73–9—Transmit state diagram

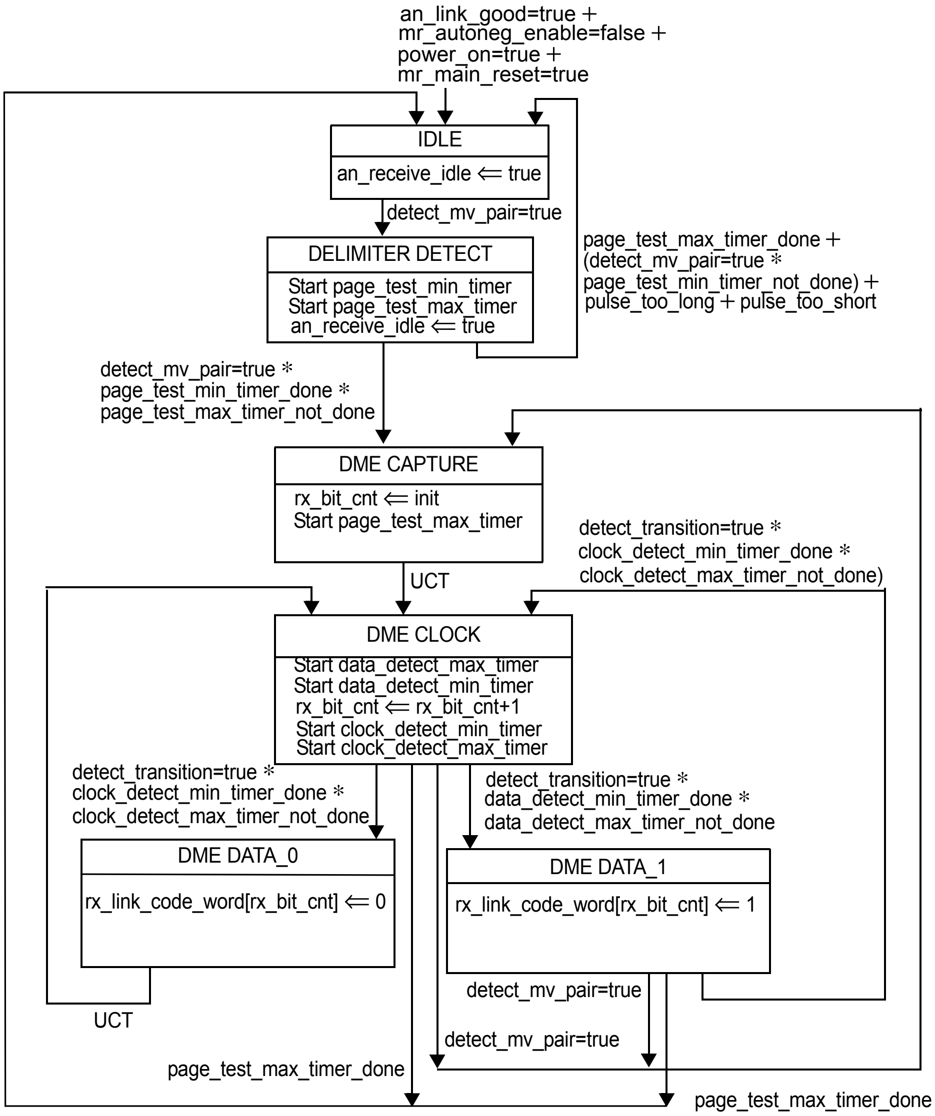


Figure 73–10—Receive state diagram

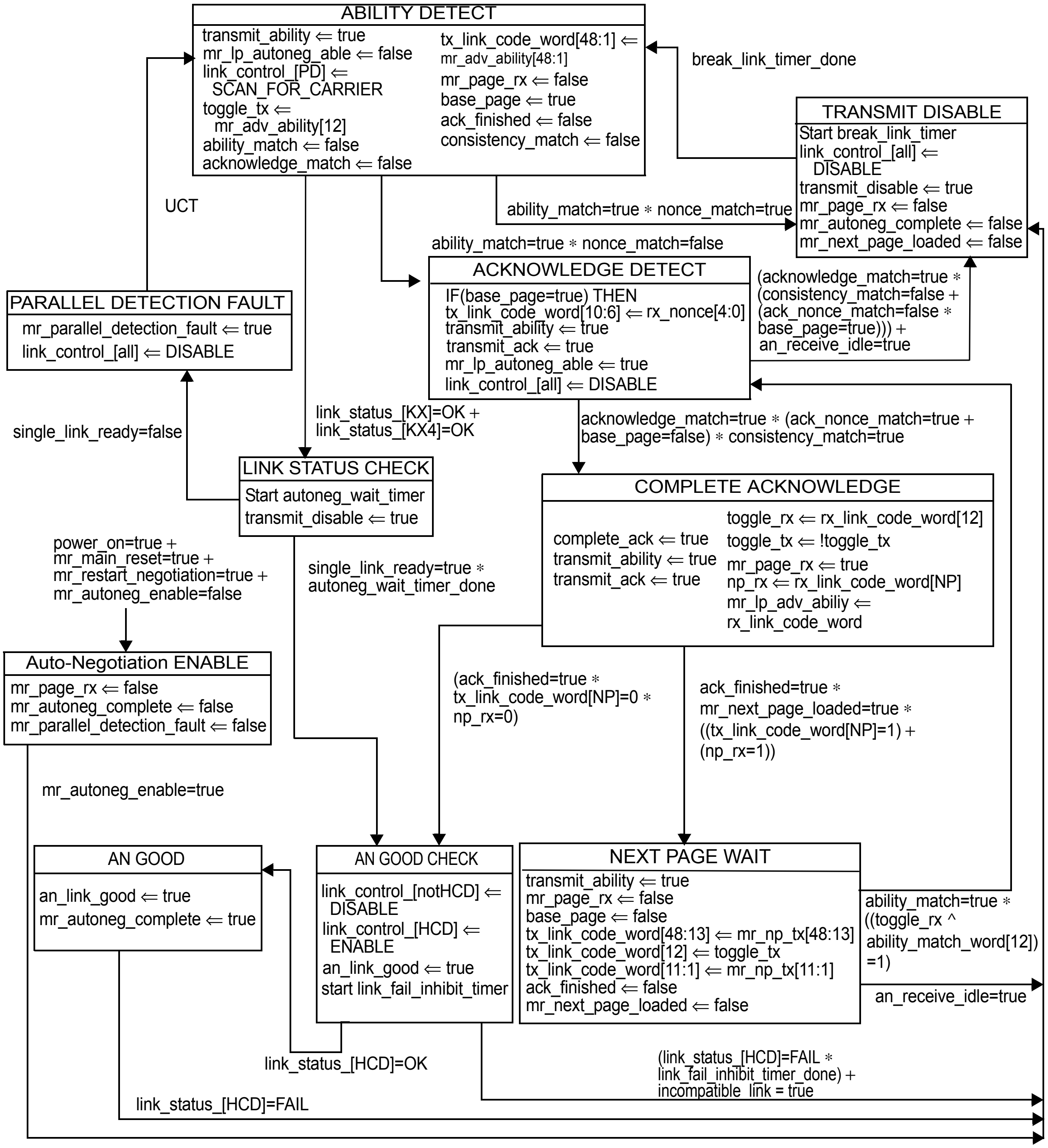


Figure 73–11—Arbitration state diagram

73.11 Protocol implementation conformance statement (PICS) proforma for Clause 73, Auto-Negotiation for backplane and copper cable assembly[30]

73.11.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3, Clause 73, Auto-Negotiation for backplane and copper cable assembly, shall complete the following protocol implementation conformance statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

73.11.2 Identification

73.11.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

73.11.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 73, Auto-Negotiation for backplane and copper cable assembly
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[30] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

73.11.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
ANG	Auto-Negotiation	73.1		M	Yes [ ]
PLD	Parallel detection	73.1		M	Yes [ ]
NP	Next page support	73.6.9		M	Yes [ ]

73.11.4 PICS proforma tables for Auto-Negotiation for backplane and copper cable assembly

73.11.4.1 Functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	Clause 37 Auto-Negotiation	73.1	Clause 37 Auto-Negotiation to be disabled	O	Yes [ ] No [ ]
FS2	Device intends to enable Clause 37 Auto-Negotiation after Clause 73 Auto-Negotiation	73.1	Ensure that link partner intends to enable Clause 37 Auto-Negotiation	FS1:M	Yes [ ]
FS3	Advertised abilities for Clause 37 Auto-Negotiation	73.1	Shall match those advertised in Clause 73 Auto-Negotiation	FS1:M	Yes [ ]
FS4	Auto-Negotiation functions	73.3	Auto-Negotiation function shall provide transmit, receive, and arbitration	M	Yes [ ]
FS5	Compliance with state diagrams	73.3	Figure 73–9 through Figure 73–11	M	Yes [ ]
FS6	Interaction with PHYs	73.3	Auto-Negotiation shall interact with technology-dependent PHYs through Technology -Dependent interface.	M	Yes [ ]

73.11.4.2 DME transmission

Item	Feature	Subclause	Value/Comment	Status	Support
DT1	Transmission of DME pages	73.5	DME pages shall not be transmitted when Auto-Negotiation is complete and HCD PHY has been enabled	M	Yes [ ]
DT2	Multi-lane DME pages	73.5.1	Multi-lane DME pages shall be transmitted on Lane 0	M	Yes [ ]
DT3	DME electrical characteristics	73.5.1	Meet requirements of Table 73–1	M	Yes [ ]
DT4	Transitions in odd numbered positions	73.5.2	Remaining 49 odd-numbered positions shall contain a transition	M	Yes [ ]
DT5	Transitions in even numbered positions	73.5.2	Remaining 49 even-numbered positions shall represent data	M	Yes [ ]
DT6	First 48 even numbered positions	73.5.2	First 48 even numbered positions shall carry data of Auto-Negotiation page	M	Yes [ ]
DT7	Pseudo-random bit value	73.5.2	Value shall be derived from source as defined in 48.2.4.2	M	Yes [ ]
DT8	Pseudo-random counter	73.5.2	Counter shall increment once per DME page	M	Yes [ ]
DT9	DME page timing parameters	73.5.3	Meet requirements of Table 73–2	M	Yes [ ]

73.11.4.3 Link codeword encoding

Item	Feature	Subclause	Value/Comment	Status	Support
LE1	Link codeword encoding	73.6	As shown in Figure 73–6	M	Yes [ ]
LE2	First bit transmitted	73.6	D0	M	Yes [ ]
LE3	RF, ACK, NP bits	73.6	As specified in 28.2.1.1	M	Yes [ ]
LE4	Reserved Selector Field	73.6.1	Shall not be transmitted	M	Yes [ ]
LE5	Echoed Nonce Field with Acknowledge set to zero	73.6.2	Contains logical zeros	M	Yes [ ]
LE6	Echoed Nonce Field with Acknowledge set to one	73.6.2	Values received in Transmitted Nonce Field from Link Partner	M	Yes [ ]
LE7	Transmitted Nonce Field	73.6.3	New value generated for each entry into Ability Detect	M	Yes [ ]
LE8	Support of multiple technologies	73.6.4	Shall support all technologies advertised	M	Yes [ ]
LE9	Technology ability reserved fields	73.6.4	Sent as zero and ignored by the receiver	M	Yes [ ]
LE10	FEC capability resolution	73.6.5	Resolve enabling of FEC capability based on F0 and F1 bits	M	Yes [ ]
LE11	Acknowledge with no Next Page	73.6.8	Set to 1 after three DME pages	M	Yes [ ]
LE12	Acknowledge with Next Page	73.6.8	Set to 1 after three DME pages	M	Yes [ ]
LE13	Device has no Next Pages to send	73.6.9	Next Page bit set to 0	M	Yes [ ]
LE14	Device has Next Pages to send	73.6.9	Next Page bit set to 1	M	Yes [ ]
LE15	Transmit switch function upon entry into the AN_GOOD_CHECK state	73.6.10	Connect the transmit path of HCD PHY to the MDI	M	Yes [ ]
LE16	Transmit switch function during Auto-Negotiation and prior to entry into the AN_GOOD_CHECK state	73.6.10	Connect only DME page generator to MDI	M	Yes [ ]
LE17	PHY connection to MDI	73.6.10	Signals at MDI conform to all PHY specifications within 20 ms	M	Yes [ ]
LE18	Incompatible abilities	73.6.4	PHYs for operation over electrical backplane are not simultaneously advertised with PHYs for operation over copper cable	M	Yes [ ]

73.11.4.4 Receive function requirements

Item	Feature	Subclause	Value/Comment	Status	Support
RF1	Receive switch function upon entry into the AN_GOOD_CHECK state	73.7.2	Connect the receive path of HCD PHY to the MDI	M	Yes [ ]
RF2	Receive switch function during Auto-Negotiation and prior to entry into the AN_GOOD_CHECK state	73.7.2	Connect DME page receiver to MDI	M	Yes [ ]
RF3	Receive switch function during Auto-Negotiation and prior to entry into the AN_GOOD_CHECK state	73.7.2	Connect receive path of the 1000BASE-KX and 10GBASE-KX4 PHY when present	M	Yes [ ]
RF4	Receive function variables	73.7.3	As defined in Figure 73–11	M	Yes [ ]
RF5	Parallel detection for 1000BASE-KX and 10GBASE-KX4	73.7.4.1	Device provides parallel detection if it supports those PHYs	M	Yes [ ]
RF6	Parallel detection	73.7.4.1	Direct MDI receive activity to PHYs prior to DME detection	M	Yes [ ]
RF7	Enable one link after parallel detection	73.7.4.1	Enable link if signaling is present	M	Yes [ ]
RF8	Disable all other links after parallel detection	73.7.4.1	Disable all other PHYs	M	Yes [ ]
RF9	Parallel detection register settings	73.7.4.1	Set bit corresponding to technology detected	M	Yes [ ]
RF10	Detection of link_status=OK	73.7.4.1	autoneg_wait_timer starts	M	Yes [ ]
RF11	Renegotiation request	73.7.5	Disable PHYs and halt transmissions for break_link_-timer	M	Yes [ ]
RF12	Resumption of Auto-Negotiation	73.7.5	Resume Auto-Negotiation after expiration of break_link_-timer	M	Yes [ ]
RF13	Priority resolution	73.7.6	PHY with highest priority connected to MDI	M	Yes [ ]
RF14	Reception of reserved technology ability field bits	73.7.6	Ignore reserved technology ability field bits	M	Yes [ ]
RF15	Priority resolution through parallel detection	73.7.6	PHY chose through parallel detection is HCD	M	Yes [ ]
RF16	Priority resolution with no common technology	73.7.6	HCD takes on value of NULL and link_status=FAIL	M	Yes [ ]

73.11.4.5 Next Page function

Item	Feature	Subclause	Value/Comment	Status	Support
NP1	Message codes	73.7.7	Each series of Next Pages has Message code	M	Yes [ ]
NP2	Next Page transmission while link partner not done	73.7.7	Device transmits Null Message code and sets NP bit to 0	M	Yes [ ]
NP3	Reception of Null message codes	73.7.7	Recognized as end of link partner’s Next Pages	M	Yes [ ]
NP4	Next page encoding	73.7.7.1	As shown in Figure 73–7 and Figure 73–8	M	Yes [ ]
NP5	NP, Ack, MP, Ack2, T bits	73.7.7.1	As specified in 28.2.3.4	M	Yes [ ]
NP6	MP bit for message Next Pages	73.7.7.1	Set to logical one	M	Yes [ ]
NP7	Message Code Field in message Next Page	73.7.7.1	Encoded in D[10:0]	M	Yes [ ]
NP8	Unformatted Code Field in message Next Page	73.7.7.1	Encoded in D[47:16]	M	Yes [ ]
NP9	MP bit for Unformatted Next Pages	73.7.7.1	Set to logical zero	M	Yes [ ]
NP10	Unformatted Code Field in Unformatted Next Pages	73.7.7.1	Encoded in D[15:0] and D[47:16]	M	Yes [ ]
NP11	Continuation of Next Page exchange	73.7.7.2	Exchange continues until NP bit is zero on both devices	M	Yes [ ]
NP12	Transmission of Null Message Code field	73.7.7.2	Sent if device has no other information to transmit	M	Yes [ ]

73.11.4.6 Management register requirements

Item	Feature	Subclause	Value/Comment	Status	Support
MR1	MMD 7 of Clause 45 MDIO	73.8	Logical interface for access to device registers	M	Yes [ ]
MR2	Clause 45 electrical interface	73.8	Electrical interface for access to device registers	O	Yes [ ] No [ ]

73.11.4.7 State diagrams and variable definitions

Item	Feature	Subclause	Value/Comment	Status	Support
SD1	Support of state diagrams	73.10	Transmit, Receive, Arbitration	M	Yes [ ]
SD2	Support of options	73.10	Options are allowed	M	Yes [ ]
SD3	Ambiguity between state diagrams and text	73.10	State diagrams take precedence	M	Yes [ ]
SD4	Pulse too short	73.10.1	Transitions separated by less than 1.6 ns	M	Yes [ ]
SD5	Pulse too short with valid transitions	73.10.1	Valid transitions not to cause this to be true	M	Yes [ ]
SD6	Pulse too long	73.10.1	Transitions separated by more than 20 ns	M	Yes [ ]
SD7	Pulse too long with valid violation delimiters	73.10.1	Valid Manchester violation delimiters not to set this	M	Yes [ ]
SD8	autoneg_wait_timer	73.10.2	25 ms to 50 ms	M	Yes [ ]
SD9	break_link_timer	73.10.2	60 ms to 75 ms	M	Yes [ ]
SD10	clock_detect_min_timer	73.10.2	4.8 ns to 6.2 ns	M	Yes [ ]
SD11	clock_detect_max_timer	73.10.2	6.6 ns to 8.0 ns	M	Yes [ ]
SD12	data_detect_max_timer	73.10.2	4.0 ns to 4.8 ns	M	Yes [ ]
SD13	data_detect_min_timer	73.10.2	1.6 ns to 2.4 ns	M	Yes [ ]
SD14	interval_timer	73.10.2	3.2 ns ± 0.01%	M	Yes [ ]
SD15	link_fail_inhibit_timer	73.10.2	500 to 510 ms when the link is not 1000BASE-KX or 10GBASE-KX4 and 40 ms to 50 ms otherwise	M	Yes [ ]
SD16	page_test_max_timer	73.10.2	350 ns to 375 ns	M	Yes [ ]
SD17	page_test_min_timer	73.10.2	305 ns to 330 ns	M	Yes [ ]

73.11.4.8 Service primitives

Item	Feature	Subclause	Value/Comment	Status	Support
SP1	link_status parameter	73.9.1.1	OK, FAIL	M	Yes [ ]
SP2	Generation of link_status primitive	73.9.1.2	Generated by technology dependent PCS	M	Yes [ ]
SP3	Receipt of link_status primitive	73.9.1.3	Governed by Figure 73–10	M	Yes [ ]

73.11.4.9 Auto-Negotiation annexes

Item	Feature	Subclause	Value/Comment	Status	Support
AN1	Null Message code	73A.1	Transmitted during Next Page exchange when local device has no information to transmit and link partner has additional pages to transmit	M	Yes [ ]
AN2	OUI message code	73A.2	0000 0000 0101	M	Yes [ ]
AN3	OUI first user code	73A.2	OUI or CID (bits 23:13)	M	Yes [ ]
AN4	OUI second user code	73A.2	OUI or CID (bits 12:2)	M	Yes [ ]
AN5	OUI third user code	73A.2	OUI or CID (bits 1:0)	M	Yes [ ]
AN6	OUI fourth user code	73A.2	User-defined code value	M	Yes [ ]
AN7	AN device identifier Message code	73A.3	0000 0000 0110	M	Yes [ ]
AN8	AN device identifier first user code	73A.3	AN device identifier (7.2.15:5)	M	Yes [ ]
AN9	AN device identifier second user code	73A.3	AN device identifier (7.2.4:0 to 7.3.15:10)	M	Yes [ ]
AN10	AN device identifier third user code	73A.3	AN device identifier (7.3.9:0)	M	Yes [ ]
AN11	AN device identifier third user code bit 0	73A.3	User-defined code value	M	Yes [ ]
AN12	AN device identifier fourth user code	73A.3	User-defined code value	M	Yes [ ]
AN13	AN message code 10	73A.4	EEE technology message code	M	Yes [ ]

74. Forward Error Correction (FEC) sublayer for BASE-R PHYs

74.1 Overview

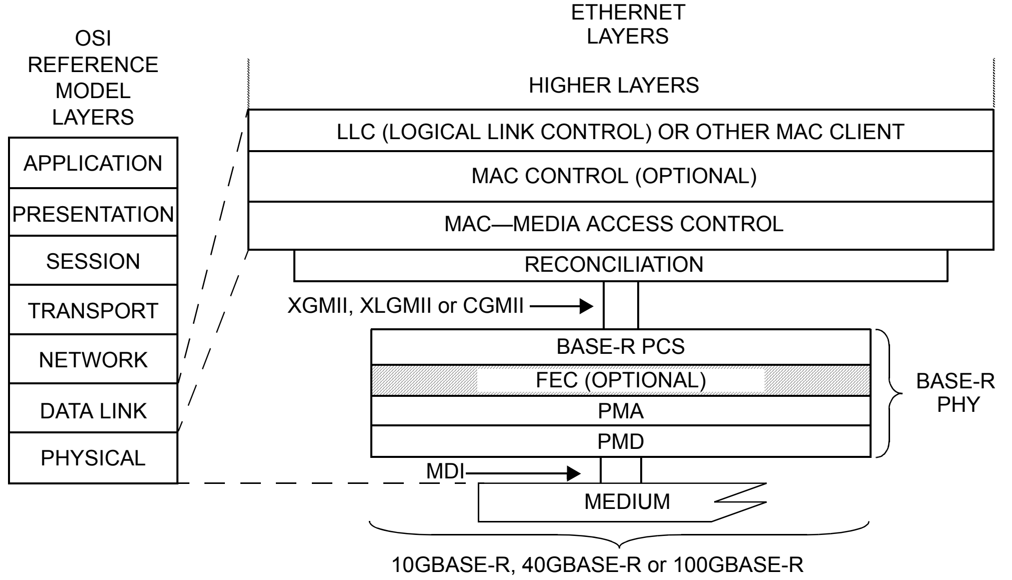
This clause specifies an optional Forward Error Correction (FEC) sublayer for 10GBASE-R and other BASE-R PHYs. The FEC sublayer can be placed in between the PCS and PMA sublayers of the 10GBASE-R and other BASE-R Physical Layer implementations as shown in Figure 74–2, Figure 74–3, and Figure 74–4. For a PHY with a multi-lane BASE-R PCS, the FEC sublayer is instantiated for each PCS lane and operates autonomously on a per PCS lane basis. The FEC provides coding gain to increase the link budget and BER performance. The 10GBASE-KR and 40GBASE-KR4 PHYs described in Clause 72 and Clause 84 optionally use the FEC sublayer to increase the performance on a broader set of backplane channels than are defined in Clause 69. The FEC sublayer provides additional margin to account for variations in manufacturing and environmental conditions. The 40GBASE-CR4 and 100GBASE-CR10 PHYs described in Clause 85 optionally use the FEC sublayer to improve the BER performance beyond 10^{-12}.

74.2 Objectives

NOTE—The contents of this subclause have been deleted.

74.3 Relationship to other sublayers

Figure 74–1 depicts the relationships among the BASE-R FEC (shown shaded), the MAC and Reconciliation Sublayers, the BASE-R PCS, PMA and PMD, the ISO/IEC 8802-2 LLC, and the ISO/IEC Open System Interconnection (OSI) reference model.



CGMII = 100 Gb/s MEDIA INDEPENDENT INTERFACE
FEC = FORWARD ERROR CORRECTION
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
XGMII = 10 Gb/s MEDIA INDEPENDENT INTERFACE
XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE

Figure 74–1—BASE-R FEC relationship to ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

74.4 Inter-sublayer interfaces

An FEC service interface is provided to allow the FEC sublayer to transfer information to and from the PCS. An abstract service model is used to define the operation of this interface. For 10GBASE-R, the FEC service interface directly maps to the PMA service interface of the PCS defined in Clause 49 and the lower FEC sublayer interface maps to the service interface provided by the serial PMA sublayer defined in Clause 51. For 40GBASE-R and 100GBASE-R, the FEC service interface is an instance of the inter-sublayer service interface defined in 80.3 as is the PMA service interface defined in 83.2.

For 40GBASE-R and 100GBASE-R the FEC service interface can either connect to the PCS as illustrated in Figure 74–1 or the PMA as illustrated in Figure 83–2 where the FEC and PCS are in separate devices connected by XLAUI/CAUI-n.

This standard defines these interfaces in terms of bits, octets, data-group, data units, and signals; however, implementers may choose other data-path widths and other control mechanisms for implementation convenience, provided that the implementation adheres to the logical model of the service interface.

74.4.1 Functional Block Diagram for 10GBASE-R PHYs

Figure 74–2 shows the functional block diagram of FEC for 10GBASE-R PHY and the relationship between the PCS and PMA sublayers.

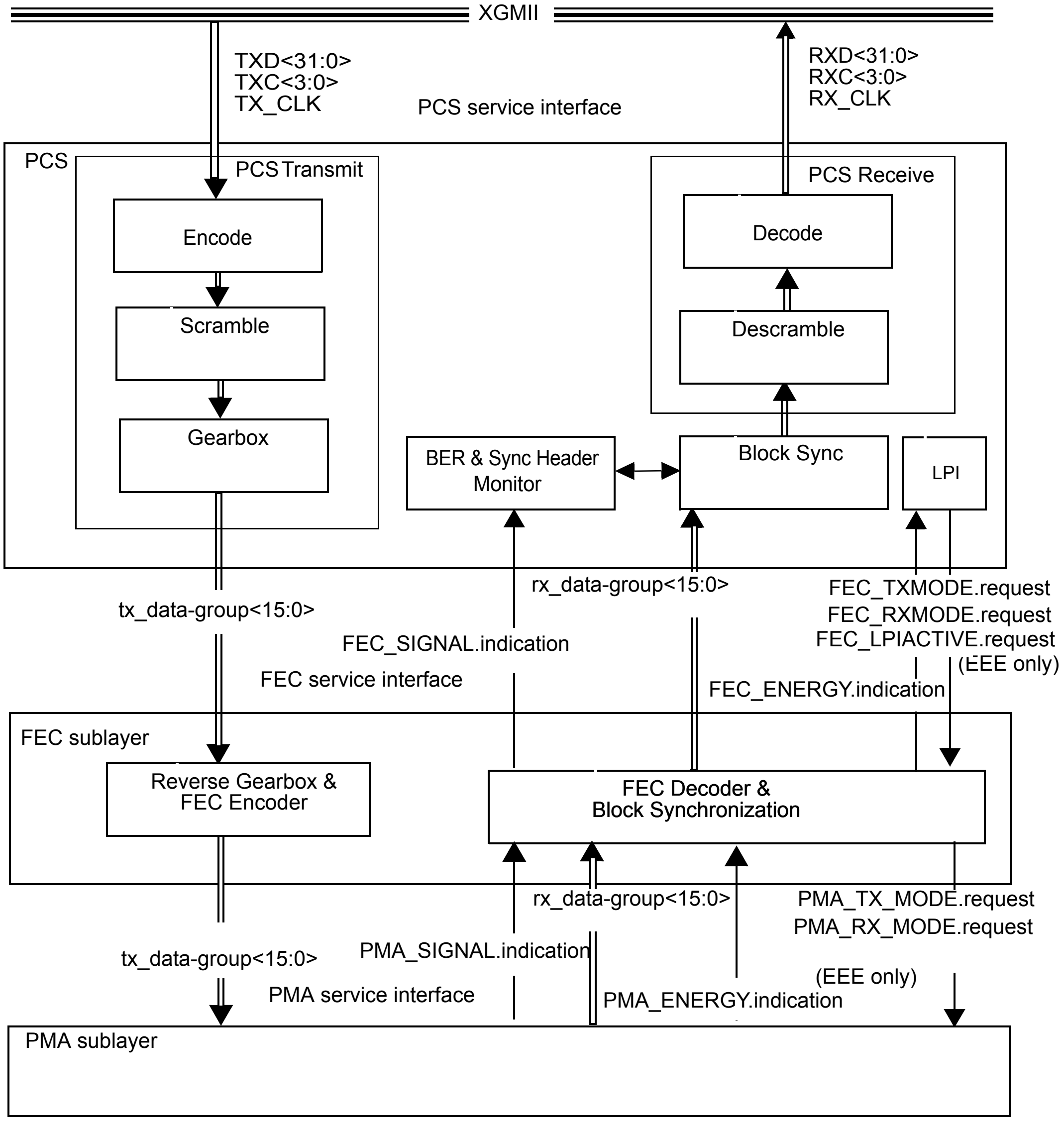


Figure 74–2—Functional block diagram for 10GBASE-R PHYs

74.4.2 Functional block diagram for 40GBASE-R PHYs

Figure 74–3 shows the functional block diagram of FEC for 40GBASE-R PHYs and the relationship between the PCS and PMA sublayers.

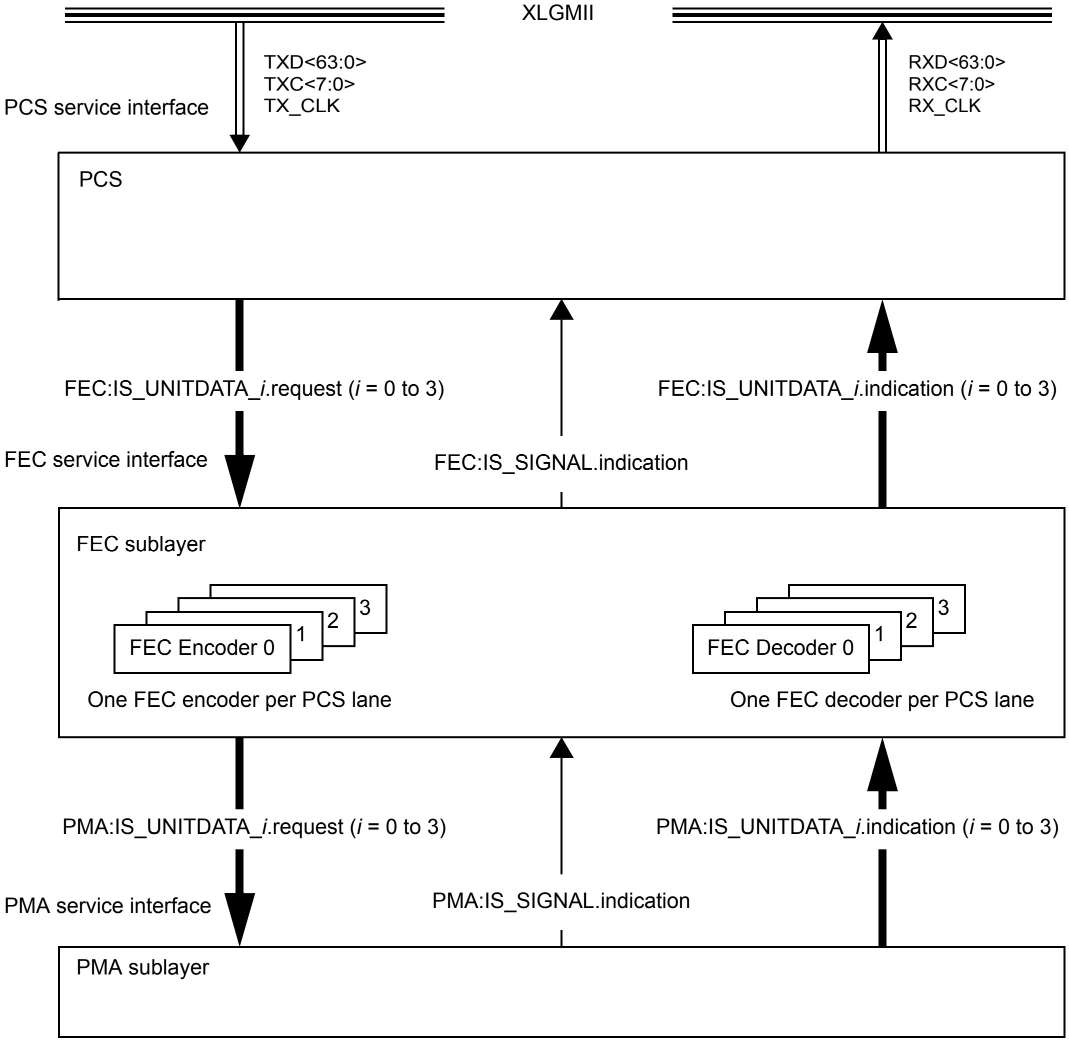


Figure 74–3—Functional block diagram for 40GBASE-R PHY

74.4.3 Functional block diagram for 100GBASE-R PHYs

Figure 74–4 shows the functional block diagram of FEC for 100GBASE-R PHYs and the relationship between the PCS and PMA sublayers.

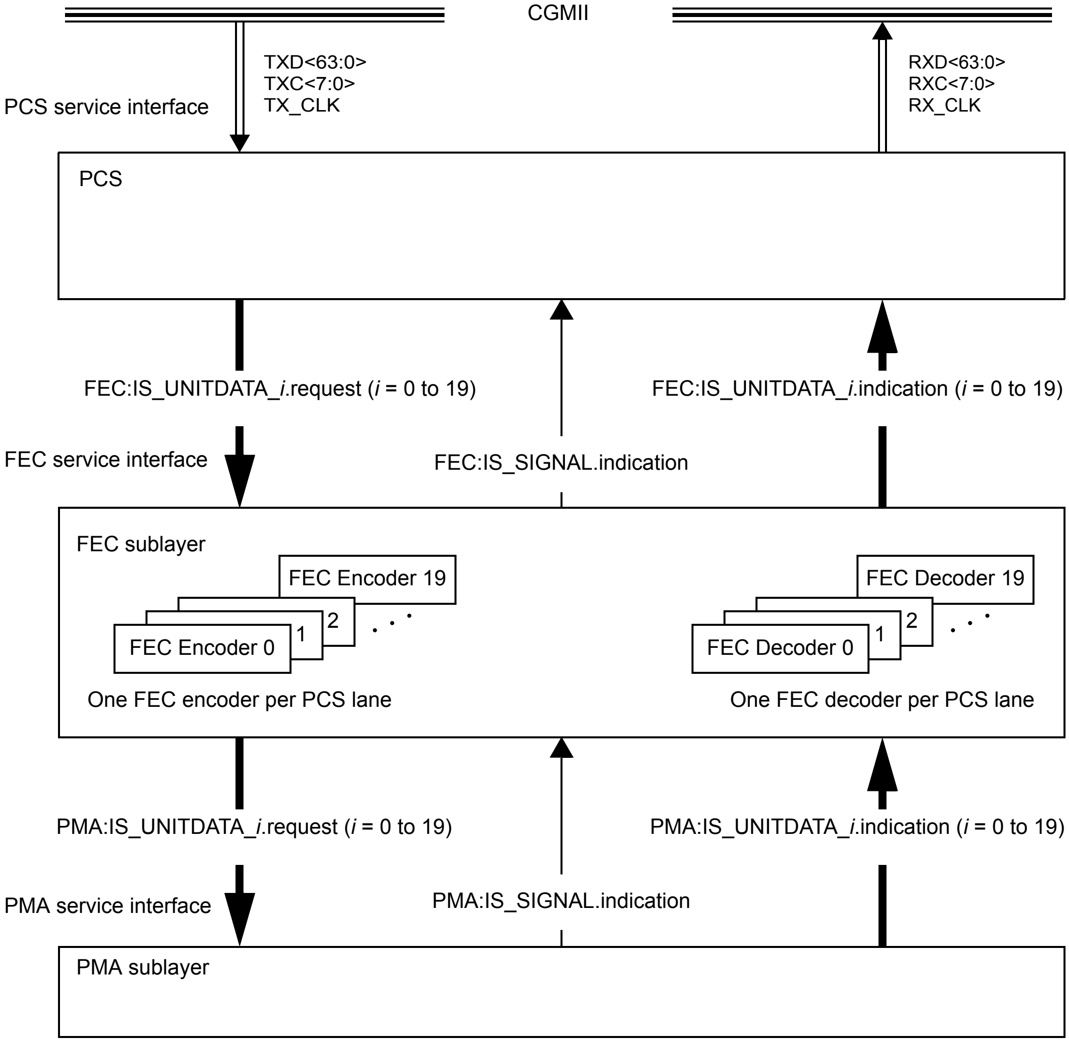


Figure 74–4—Functional block diagram for 100GBASE-R PHY

74.5 FEC service interface

The FEC service interface is provided to allow the PCS to transfer information to and from the FEC. The FEC service interface is equivalent to the PMA service interface for 10GBASE-R and an instance of the inter-sublayer service interface defined in 80.3 for 40GBASE-R and 100GBASE-R. These services are defined in an abstract manner and do not imply any particular implementation. The FEC service interface supports exchange of data units between PCS entities on either side of a link using request and indication primitives. Data units are mapped into FEC blocks by the FEC and passed to the PMA, and vice versa.

The service primitives are defined differently for 10GBASE-R and for 40GBASE-R and 100GBASE-R.

Optional physical instantiations of the PMA service interface have been defined (see Clause 51, Annex 83A, Annex 83B, Annex 83D, and Annex 83E). There is XSBI (10 Gigabit Sixteen-Bit Interface) for 10GBASE-R, XLAUI for 40GBASE-R and CAUI-n for 100GBASE-R. These physical instantiations, with a PMA if required, may also be used for the FEC service interface.

74.5.1 10GBASE-R service primitives

The following primitives are defined within the FEC service interface:

a) FEC_UNITDATA.request(tx_data-group<15:0>)
b) FEC_UNITDATA.indication(rx_data-group<15:0>)
c) FEC_SIGNAL.indication(SIGNAL_OK)
d) FEC_TX_MODE.request(tx_mode)
e) FEC_RX_MODE.request(rx_mode)
f) FEC_ENERGY.indication(energy_detect)
g) FEC_LPI_ACTIVE.request(rx_lpi_active)

Items d), e), f), and g) are only required for the optional EEE capability.

The FEC service interface directly maps to the PMA service interface of the 10GBASE-R PCS defined in Clause 49. The FEC_UNITDATA.request maps to the PMA_UNITDATA.request primitive, the FEC_UNITDATA.indication maps to the PMA_UNITDATA.indication primitive, and the FEC_SIGNAL.indication maps to the PMA_SIGNAL.indication primitive of the 10GBASE-R PCS.

If the optional Energy-Efficient Ethernet (EEE) capability is supported (see Clause 78) then the interface with the PMA sublayer (or FEC sublayer) includes rx_mode and tx_mode to control power states in lower sublayers and energy_detect that indicates whether the PMD sublayer has detected a signal at the receiver.

74.5.1.1 FEC_UNITDATA.request

This primitive defines the transfer of data in the form of constant-width data units from the PCS to the FEC. The data supplied via FEC_UNITDATA.request is mapped by the FEC Transmit process into the payload capacity of the outgoing FEC block stream.

74.5.1.1.1 Semantics of the service primitive

FEC_UNITDATA.request(tx_data-group<15:0>)

The data conveyed by FEC_UNITDATA.request is a 16-bit vector representing a single data unit that has been prepared for transmission by the 10GBASE-R PCS Transmit process.

74.5.1.1.2 When generated

The 10GBASE-R PCS sends tx_data-group<15:0> to the FEC at a nominal rate of 644.53125 MHz, corresponding to the 10GBASE-R signaling rate of 10.3125 GBd.

74.5.1.1.3 Effect of receipt

Upon receipt of this primitive, the FEC Transmit process maps the data conveyed by the tx_data unit<15:0> parameter into the payload of the transmitted FEC block stream, adds FEC overhead as required, scrambles the data, and transfers the result to the PMA via the PMA_UNITDATA.request primitives.

74.5.1.2 FEC_UNITDATA.indication

This primitive defines the transfer of received data in the form of constant-width data units from the FEC to the PCS. FEC_UNITDATA.indication is generated by the FEC Receive process in response to FEC block data received from the PMA.

74.5.1.2.1 Semantics of the service primitive

FEC_UNITDATA.indication(rx_data-group<15:0>)

The rx_data-group<15:0> parameter is a 16-bit vector that represents the data unit transferred by the FEC to the 10GBASE-R PCS.

74.5.1.2.2 When generated

The FEC sends one rx_data-group<15:0> to the 10GBASE-R PCS for each 16 bits received from the PMA sublayer. The nominal rate of generation of the FEC_UNITDATA.indication primitive is 644.53125 Mtransfers/s.

74.5.1.2.3 Effect of receipt

The effect of receipt of this primitive by the FEC client is unspecified by the FEC sublayer.

74.5.1.3 FEC_SIGNAL.indication

This primitive is sent by the FEC to the PCS to indicate the status of the Receive process. FEC_SIGNAL.indication is generated by the FEC Receive process in order to propagate the detection of severe error conditions (e.g., no valid signal being received from the PMA sublayer) to the PCS.

74.5.1.3.1 Semantics of the service primitive

FEC_SIGNAL.indication(SIGNAL_OK)

The SIGNAL_OK parameter can take one of two values: OK or FAIL. A value of OK denotes that the FEC Receive process is successfully delineating valid payload information from the incoming data stream received from the PMA sublayer indicated by the fec_signal_ok variable equal to true, and this payload information is being presented to the PCS via the FEC_UNITDATA.indication primitive. A value of FAIL denotes that errors have been detected by the Receive process indicated by the fec_signal_ok variable equal to false, that prevent valid data from being presented to the PCS, in this case the FEC_UNITDATA.indication primitive and its associated rx_data-group<15:0> parameter are meaningless.

74.5.1.3.2 When generated

The FEC generates the FEC_SIGNAL.indication primitive to the 10GBASE-R PCS whenever there is a change in the value of the SIGNAL_OK parameter and FEC block synchronization is achieved.

74.5.1.3.3 Effect of receipt

The effect of receipt of this primitive by the FEC client is unspecified by the FEC sublayer.

74.5.1.4 FEC_ENERGY.indication (optional)

FEC_ENERGY.indication(energy_detect)

A Boolean variable that reflects the value of the energy detection primitive PMA_ENERGY.indication.

74.5.1.4.1 Effect of receipt

The effect of receipt of this primitive by the FEC client is unspecified by the FEC sublayer.

74.5.1.5 FEC_LPI_ACTIVE.request (optional)

FEC_LPI_ACTIVE.request(rx_lpi_active)

The rx_lpi_active parameter is a Boolean variable sent from the PCS that is set to TRUE when LPI mode is active at the receiver and set to FALSE otherwise.

74.5.1.5.1 When generated

The generation of this primitive by the FEC client is unspecified by the FEC sublayer.

74.5.1.5.2 Effect of receipt

When rx_lpi_active is TRUE, rapid block lock as specified in 74.7.4.8 will be used to quickly determine the start of the FEC block during EEE REFRESH or WAKE. When rx_lpi_active is FALSE, rapid block lock will not be used.

74.5.1.6 FEC_RX_MODE.request (optional)

FEC_RX_MODE.request(rx_mode)

The rx_mode parameter is a variable sent from the PCS. It is set to QUIET while the receiver is in the RX_QUIET state and is set to DATA otherwise.

74.5.1.6.1 When generated

The generation of this primitive by the FEC client is unspecified by the FEC sublayer.

74.5.1.6.2 Effect of receipt

When rx_mode is QUIET, the FEC decoder logic may deactivate functional blocks to conserve energy. When rx_mode is DATA, the FEC decoder logic operates normally. The value rx_mode is passed to the client layer through PMA_RX_MODE(rx_mode).request.

74.5.1.7 FEC_TX_MODE.request (optional)

FEC_TX_MODE.request(tx_mode)

The tx_mode parameter is a variable sent from the PCS. It is set to QUIET while the transmitter is in the TX_QUIET state, it is set to ALERT while the transmitter is in the TX_ALERT state and is set to DATA otherwise.

74.5.1.7.1 When generated

The generation of this primitive by the FEC client is unspecified by the FEC sublayer.

74.5.1.7.2 Effect of receipt

When tx_mode is QUIET or ALERT, the FEC encoder logic may deactivate functional blocks to conserve energy. When tx_mode is DATA, the FEC encoder logic operates normally. The value tx_mode is passed to the client layer through PMA_TX_MODE(tx_mode).request.

74.5.2 40GBASE-R and 100GBASE-R service primitives

The FEC service interface for 40GBASE-R and 100GBASE-R is an instance of the inter-sublayer service interface defined in 80.3. The FEC service interface primitives are summarized as follows:

a) FEC:IS_UNITDATA_*i*.request
b) FEC:IS_UNITDATA_*i*.indication
c) FEC:IS_SIGNAL.indication
d) FEC_TX_MODE.request(tx_mode)
e) FEC_RX_MODE.request(rx_mode)
f) FEC_RX_TX_MODE.indication(rx_tx_mode)
g) FEC_LPI_ACTIVE.request(rx_lpi_active)
h) FEC_ENERGY.indication(energy_detect)

Items d), e), f), g), and h) are only required for the optional EEE capability.

The 40GBASE-R FEC has four parallel bit streams, hence $i = 0$ to 3 for 40GBASE-R and the 100GBASE-R FEC has twenty parallel bit streams, hence $i = 0$ to 19 for 100GBASE-R.

The PCS (or PMA) continuously sends four or twenty parallel bit streams to the FEC, one per PCS lane, each at a nominal signaling rate of 10.3125 GBd for 40GBASE-R and 5.15625 GBd for 100GBASE-R.

This FEC:IS_SIGNAL.indication primitive is sent by the FEC to the PCS (or PMA) to indicate the status of the Receive process. FEC:IS_SIGNAL.indication is generated by the FEC Receive process in order to propagate the detection of severe error conditions (e.g., no valid signal being received from the PMA sublayer) to the PCS (or PMA).

The SIGNAL_OK parameter in FEC:IS_SIGNAL.indication can take one of two values: OK or FAIL. A value of OK denotes that the FEC Receive process is successfully delineating valid payload information from all of the incoming data streams received from the PMA sublayer indicated by the fec_signal_ok variable equal to true, for all data streams, and this payload information is being presented to the PCS (or PMA) via the FEC:IS_UNITDATA_*i*.indication primitive. A value of FAIL denotes that errors have been detected by the Receive process indicated by the fec_signal_ok variable equal to false, in any of the data streams, that prevent valid data from being presented to the PCS (or PMA), in this case the FEC:IS_UNITDATA_*i*.indication primitive is a direct pass through of the PMA:IS_UNITDATA_*i*.indication from the PMA.

If the optional Energy-Efficient Ethernet (EEE) capability is supported (see Clause 78) then the interface with the PMA sublayer (or FEC sublayer) includes rx_mode and tx_mode to control power states in lower sublayers and energy_detect that indicates whether the PMD sublayer has detected a signal at the receiver. If the optional EEE deep sleep capability is supported, rx_tx_mode is passed through the FEC but is not used by it.

The tx_mode parameter in FEC_TX_MODE.request is sent from the PCS. It is set to QUIET while the transmitter is in the TX_QUIET state, it is set to ALERT while the transmitter is in the TX_ALERT state, and is set to DATA otherwise.

The rx_mode parameter in FEC_RX_MODE.request is sent from the PCS. It is set to QUIET while the receiver is in the RX_QUIET state and is set to DATA otherwise.

The FEC_RX_TX_MODE.indication primitive communicates the rx_tx_mode parameter. This parameter indicates the value of tx_mode that the PMA sublayer has inferred from the received signal. Without EEE deep sleep capability, the primitive is never generated and the sublayer behaves as if rx_tx_mode=DATA. The parameter rx_tx_mode is assigned one of the following values: DATA, QUIET, or ALERT.

The rx_lpi_active parameter in FEC_LPI_ACTIVE.request is a Boolean variable sent from the PCS that is set to TRUE when LPI mode is active at the receiver and set to FALSE otherwise.

The energy_detect parameter in FEC_ENERGY.indication is a Boolean variable that indicates to the PCS that energy has been detected at the PMD.

74.6 Delay constraints

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers must conform to certain delay maxima, and that network planners and administrators conform to constraints regarding the cable topology and concatenation of devices.

The maximum delay contributed by the 10GBASE-R FEC (sum of transmit and receive delays at one end of the link) shall be no more than 6144 BT (or 12 pause_quanta or 614.4 ns).

The maximum delay contributed by the 40GBASE-R FEC (sum of transmit and receive delays at one end of the link) shall be no more than 24576 BT (or 48 pause_quanta or 614.4 ns).

The maximum delay contributed by the 100GBASE-R FEC (sum of transmit and receive delays at one end of the link) shall be no more than 122880 BT (or 240 pause_quanta or 1228.8 ns).

A description of overall system delay constraints and the definitions for bit-times and pause_quanta can be found in 80.4 and its references.

74.7 FEC principle of operation

On transmission, the FEC sublayer receives data from the PCS, transcodes 64B/66B words, performs the FEC coding/framing, scrambles and sends the data to the PMA. On reception, the FEC sublayer receives data from the PMA, performs descrambling, achieves FEC framing synchronization, decodes the FEC code, correcting data where necessary and possible, re-codes 64B/66B words, and sends the data to the PCS.

74.7.1 FEC code

The FEC code used is a shortened cyclic code (2112, 2080) for error checking and forward error correction. The FEC block length is 2112 bits. The code encodes 2080 bits of payload (or information symbols) and adds 32 bits of overhead (or parity symbols). The code is systematic—meaning that the information symbols are not disturbed in anyway in the encoder and the parity symbols are added separately to the end of each block.

The (2112,2080) code is constructed by shortening the cyclic code (42987, 42955). The shortened cyclic code (2112,2080) is guaranteed to correct an error burst of up to 11 bits per block. It is a systematic code that is well suited for correction of the burst errors typical in a backplane channel (see 69.3) resulting from error propagation in the receive equalizer.

See Blahut [B22] and Lin and Costello [B52] for additional information on cyclic codes and shortened cyclic codes for correcting burst errors.

74.7.2 FEC block format

The format of the FEC block is shown in Table 74–1. The length of the FEC block is 2112 bits. Each FEC block contains 32 rows of 65 bits each; 64 bits of payload and 1 bit transcoding overhead (T bits). At the end of each block there is 32-bit overhead or parity check bits. Transmission is from left to right within each row and from top to bottom between rows. The payload bits carry the information symbols from the PCS layer.

Table 74–1—FEC block format

T_0	64 bit payload Word 0	T_1	64 bit payload Word 1	T_2	64 bit payload Word 2	T_3	64 bit payload Word 3
T_4	64 bit payload Word 4	T_5	64 bit payload Word 5	T_6	64 bit payload Word 6	T_7	64 bit payload Word 7
T_8	64 bit payload Word 8	T_9	64 bit payload Word 9	T_{10}	64 bit payload Word 10	T_{11}	64 bit payload Word 11
T_{12}	64 bit payload Word 12	T_{13}	64 bit payload Word 13	T_{14}	64 bit payload Word 14	T_{15}	64 bit payload Word 15
T_{16}	64 bit payload Word 16	T_{17}	64 bit payload Word 17	T_{18}	64 bit payload Word 18	T_{19}	64 bit payload Word 19
T_{20}	64 bit payload Word 20	T_{21}	64 bit payload Word 21	T_{22}	64 bit payload Word 22	T_{23}	64 bit payload Word 23
T_{24}	64 bit payload Word 24	T_{25}	64 bit payload Word 25	T_{26}	64 bit payload Word 26	T_{27}	64 bit payload Word 27
T_{28}	64 bit payload Word 28	T_{29}	64 bit payload Word 29	T_{30}	64 bit payload Word 30	T_{31}	64 bit payload Word 31
32 parity bits							

Total FEC block length = $(32 \times 65) + 32 = 2112$ bits

74.7.3 Composition of the FEC block

The FEC sublayer does not decrease the symbol rate of the PCS, nor does it increase the signaling rate of the PMD sublayer. Instead, the FEC sublayer compresses the sync bits from the 64B/66B encoded data provided by the PCS to accommodate the addition of 32 parity check bits for every block of 2080 bits.

The BASE-R 64B/66B PCS maps 64 bits of scrambled payload and 2 bits of unscrambled sync header into 66-bit encoded blocks. The 2-bit sync header allows establishment of 64B/66B block boundaries by the PCS sync process. The sync header is 01 for data blocks and 10 for control blocks; the sync header is the only position in the PCS block that always contain a transition and this feature of the code is used to establish 64B/66B block boundaries.

The FEC sublayer compresses the 2 bits of the sync header to 1 transcode bit. The transcode bit carries the state of BASE-R sync bits for the associated payload. This is achieved by eliminating the first bit in 64B/66B block, which is also the first sync bit, and preserving the second bit. The value of the second bit defines the value of the removed first bit uniquely, since it is always an inversion of the first bit. The transcode bits are further scrambled (as explained in 74.7.4.2) to ensure DC balance.

The 32 sequential 64B/66B blocks are transcoded in this fashion, and then 32 bits of FEC parity are computed for them. The 32 transcoded words and the 32 FEC parity bits constitute an FEC block.

The error detection property of the FEC cyclic code is used to establish block synchronization at FEC block boundaries at the receiver. If decoding passes successfully, the FEC decoder produces 32 65-bit words, the first decoded bit of each word being the transcode bit. Then the first sync bit in 64B/66B code is constructed by the inversion of the transcode bit, and the value of the second sync bit is equal to the transcode bit.

74.7.4 Functions within FEC sublayer

The FEC sublayer comprises four functional blocks; FEC Encoder, Reverse Gearbox function, FEC decoder, and FEC block synchronization.

74.7.4.1 Reverse gearbox function

74.7.4.1.1 Reverse gearbox function for 10GBASE-R

The reverse gearbox function adapts between the 66-bit width of the 64B/66B blocks and the 16-bit width of the PCS interface. It receives the 16-bit stream from the PCS interface and converts them back to 66-bit encoded blocks for the FEC Encoder to process. The reverse gearbox function operates in the same manner as the block sync function defined in 49.2.9.

The reverse gearbox function receives data via 16-bit FEC_UNITDATA.request primitive. It will form a bit stream from the primitives by concatenating requests with the bits of each primitive in order to form tx_data-group<0> to tx_data-group<15> (see Figure 49–6). It obtains lock to the 66-bit blocks in the bit stream using the sync headers and outputs 66-bit blocks. Lock is obtained as specified in the block lock state diagram shown in Figure 49–14.

The reverse gearbox functionality is necessary only when the optional PMA compatibility interface named XSBI is implemented between the PCS and FEC functions, since that interface passes data via a 16-bit wide path. When the XSBI is not implemented, the internal data-path width between the PCS and FEC is an implementation choice. Depending on the path width, the reverse gearbox function may not be necessary.

74.7.4.1.2 Reverse gearbox function for 40GBASE-R and 100GBASE-R

The reverse gearbox function adapts between the 66-bit width of the 64B/66B blocks and the 1-bit wide lane of the 40GBASE-R or 100GBASE-R PCS to FEC interface (or PMA to FEC interface). It receives the 1-bit stream from the FEC service interface (or PMA service interface) and converts it back to 66-bit encoded blocks for the FEC Encoder to process. The reverse gearbox function, if implemented, shall operate in the same manner as the lane block sync function defined in 82.2.12.

The reverse gearbox function receives data via the 40GBASE-R and 100GBASE-R FEC:IS_UNITDATA_*i*.request primitive see 74.5.2 (or via the PMA:IS_UNITDATA_*i*.request primitive). It obtains lock to the 66-bit blocks in each bit stream using the sync headers and outputs 66-bit blocks to the FEC encoder function (see 74.7.4.4). PCS lane lock is obtained as specified in the PCS lane lock state diagram shown in Figure 82–12.

The internal data-path width from the PCS or PMA is an implementation choice. Depending on the path width, the reverse gearbox function may not be necessary.

74.7.4.2 FEC Encoder

The FEC encoder connects to the reverse gearbox function using the 66-bit wide data path. The FEC encoder takes 32 × 64B/66B blocks from the reverse gearbox and encodes it into a single FEC block of 2112 bits. The FEC Encoder compresses the two sync bits to one transcode bit as explained in 74.7.3. The transcode bit is then XOR'ed with data bit 8 of the corresponding 64B/66B block. The resulting 32 × 65b = 2080 bits with the block format as shown in Table 74–1 are fed to the (2112,2080) encoder, which produces 32 parity-check bits. The parity check bits are appended to the end of the FEC block. The FEC block is scrambled using the PN-2112 pseudo-noise sequence as described in 74.7.4.4.1. and sent to the PMA interface.

74.7.4.3 FEC transmission bit ordering

The format of the FEC block and the transmit bit ordering is shown in Figure 74–5.

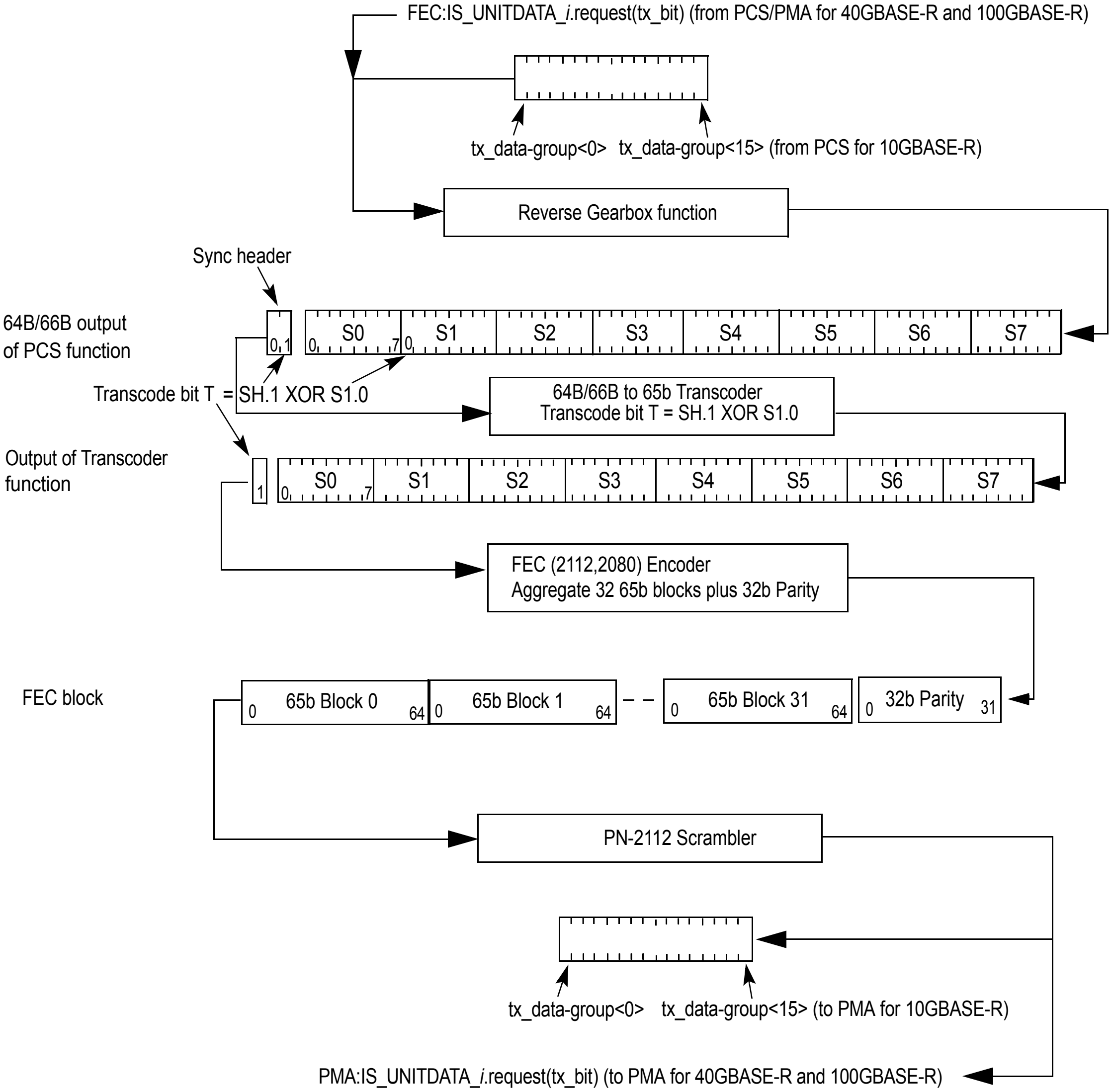


Figure 74–5—FEC Transmit bit ordering

74.7.4.4 FEC (2112,2080) encoder

The block diagram of the FEC Encoder is illustrated in Figure 74–6. The 32 × 65-bit payload blocks are encoded by the (2112, 2080) code. This code is a shortened cyclic code that can be encoded by generator polynomial *g(x)*. The FEC block is scrambled using the PN-2112 pseudo-noise sequence as described in 74.7.4.4.1.

The generator polynomial *g(x)* for the (2112, 2080) parity-check bits is defined as given in Equation (74–1).

$$g(x) = x^{32} + x^{23} + x^{21} + x^{11} + x^2 + 1 \qquad (74–1)$$

If the polynomial representation of information bits is *m(x)*, the codeword *c(x)* can be calculated in systematic form as given in Equation (74–2) and Equation (74–3).

$$p(x) = x^{32}m(x) \bmod g(x) \qquad (74–2)$$

$$c(x) = p(x) + x^{32}m(x) \qquad (74–3)$$

(Multiplication by x^{32} is performed using shifts).

Systematic form of the codeword means that first 2080 bits of the codeword are information bits that can be extracted directly.

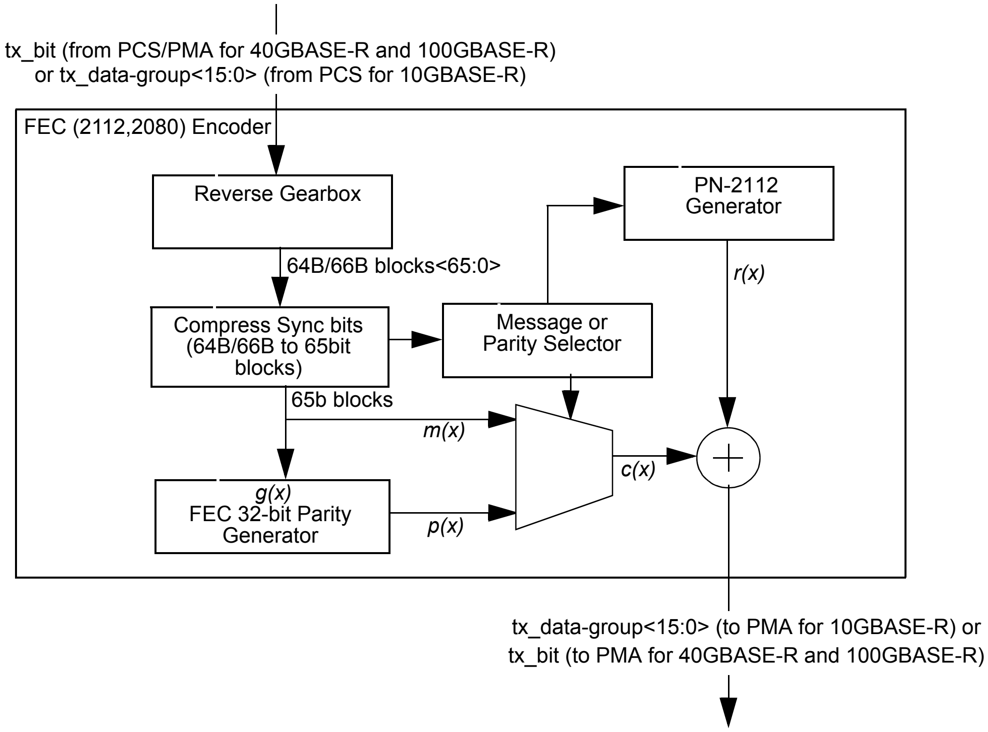


Figure 74–6—FEC (2112,2080) encoding

74.7.4.4.1 PN-2112 pseudo-noise sequence generator

PN-2112 is a pseudo-noise sequence of length 2112 generated by the polynomial *r(x)*, which is equal to the scrambler polynomial defined in 49.2.6 with initial state S57 = 1, Si–1 = Si XOR 1 or simply the binary sequence of 101010…. . Before each FEC block processing (encoding or decoding) the PN-2112 generator is initialized with this state. The PN-2112 generator shall produce the same result as the implementation shown in Figure 74–7. This implements the PN-2112 generator polynomial given in Equation (74–4).

$$r(x) = 1 + x^{39} + x^{58} \qquad (74–4)$$

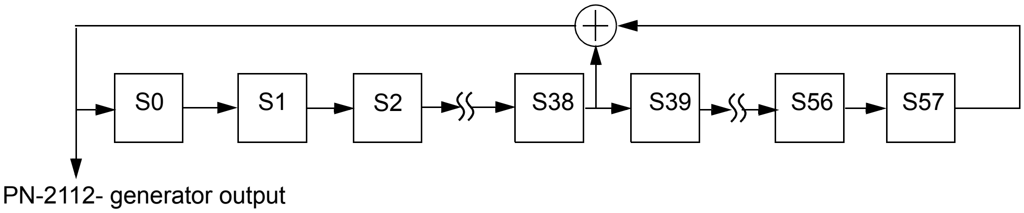


Figure 74–7—PN-2112 generator

Scrambling with the PN-2112 sequence at the FEC codeword boundary is necessary for establishing FEC block synchronization (to ensure that any shifted input bit sequence is not equal to another FEC codeword) and to ensure DC balance.

74.7.4.5 FEC decoder

The FEC decoder establishes FEC block synchronization based on repeated decoding of the received sequence. Decoding and error correction is performed after FEC synchronization is achieved. There is an option for the FEC decoder to indicate any decoding errors to the upper layer.

The FEC decoder recovers and extracts the information bits using the parity-check data. In case of successful decoding the decoder restores the sync bits in each of the 64B/66B blocks sent to the PCS function, by first performing an XOR operation of the received transcode bit with the associated data bit 8 and then generating the two sync bits.

When the decoder for 10GBASE-R is configured to indicate decoding error, the decoder indicates error to the PCS by means of setting both sync bits to the value 11 in the 1st, 9th, 17th, 25th, and 32nd of the 32 decoded 64B/66B blocks from the corresponding errored FEC block, thus forcing the PCS sublayer to consider this block as invalid.

When the decoder for 40GBASE-R or 100GBASE-R is configured to indicate decoding error, the decoder needs to mark errors in more of the 64B/66B blocks to ensure that detected errors are signaled to the MAC for every frame containing an error. The FEC sublayers for 40GBASE-R and 100GBASE-R set both sync bits to the value 11 in all thirty-two 64B/66B blocks to indicate error to the PCS.

The FEC Synchronization process continuously monitors PMA_SIGNAL.indication(SIGNAL_OK) or PMA:IS_SIGNAL.indication(SIGNAL_OK). When SIGNAL_OK indicates OK, the FEC Synchronization process accepts data units via the PMA_UNITDATA.indication primitive or the PMA:IS_UNITDATA_*i*.indication primitives. It attains block synchronization based on the decoding of FEC blocks and conveys received 64B/66B blocks to the PCS Receive process. The FEC Synchronization process sets the sync_status flag to the PCS function to indicate whether the FEC has obtained synchronization.

74.7.4.5.1 FEC (2112,2080) decoding

The FEC decoding function block diagram is shown in Figure 74–8. The decoder processes the 16-bit rx_data-group stream received from the PMA sublayer and descrambles the data using the PN-2112 pseudo-noise sequence as described in 74.7.4.4.1.

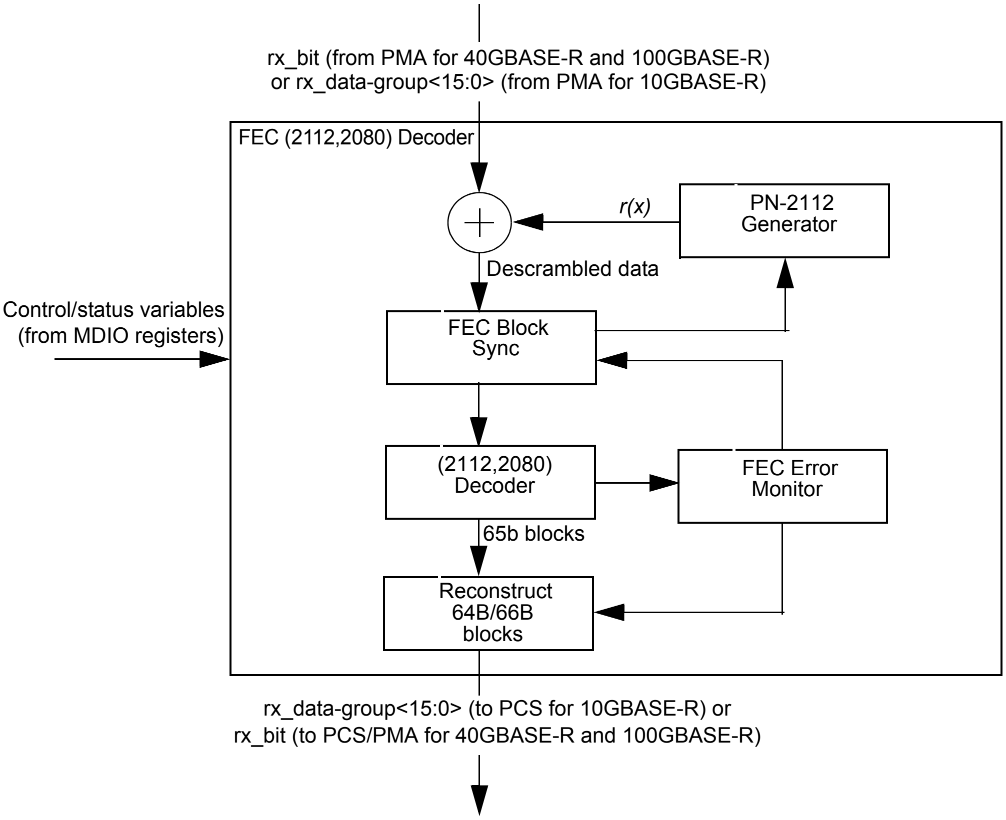


Figure 74–8—FEC (2112,2080) decoding

The synchronization of the 2112 bit FEC block is established using FEC decoding as described in 74.7.4.7. Each of the 32 65-bit data words is extracted from the recovered FEC block and the 2-bit sync is reconstructed for the 64B/66B codes from the transcode bit as shown in Figure 74–9. The FEC decoder provides an option to indicate decoding errors in the reconstructed sync bits. The sync bits {SH.0, SH.1} take the value as described in the following:

a) If decoding is successful (by either the parity match or the FEC block is correctable) and the descrambled received transcode bit (T) is 1 then the sync bits take a value of {SH.0,SH.1} = 01 or if the descrambled received transcode bit (T) is 0 then the sync bits take a value of {SH.0,SH.1} = 10.
b) If the variable FEC_Enable_Error_to_PCS is set to 1 to indicate error to PCS layer and the received FEC block has uncorrectable errors then the sync bits for the 1st, 9th, 17th, 25th, and 32nd of the 32 decoded 64B/66B blocks take a value of {SH.0,SH.1} = 11 for the 10GBASE-R PHY. For the 40GBASE-R and 100GBASE-R PHYs, sync bits in all thirty-two 64B/66B decoded 64B/66B blocks take a value of {SH.0,SH.1} = 11. The sync bits for all other 64B/66B blocks take a value as described in item a) above.
c) If the variable FEC_Enable_Error_to_PCS is set to 0 and the received FEC block has uncorrectable errors then the sync bits take a value as described in item a) above.

This information corresponds to one complete (2112,2080) FEC block that is equal to 32 64B/66B code blocks.

The FEC code (2112, 2080) and its performance is specified in 74.7.1. The FEC (2112,2080) decoder implementations shall be able to correct up to a minimum of 11-bit burst errors per FEC block.

74.7.4.6 FEC receive bit ordering

The format of the FEC block and the receive bit ordering is shown in Figure 74–9.

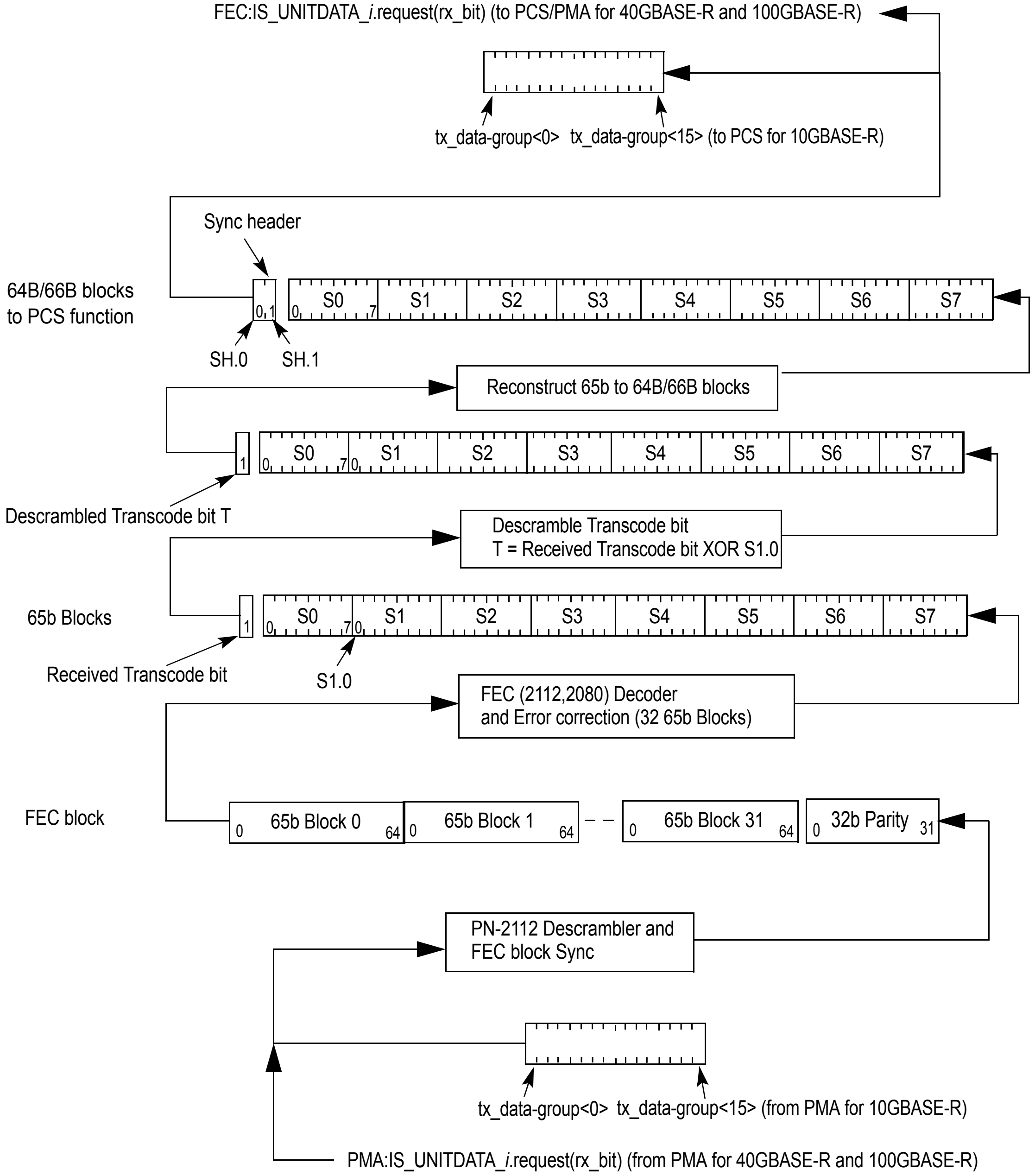


Figure 74–9—FEC Receive bit ordering

74.7.4.7 FEC block synchronization

The receive synchronization of FEC blocks is illustrated by FEC Lock state diagram in Figure 74–10.

Receive FEC block synchronization is achieved using conventional n/m serial locking techniques as described as follows:

a) Test a potential candidate block start position
    1) Descramble block using PN-2112 Generator per 74.7.4.4.1
    2) Evaluate parity for the potential block
        i) If the parity does not match (i.e., the received parity does not match the computed parity), shift candidate start by one bit position and try again.
b) Validate potential block start position has good parity for “n” consecutive blocks
    1) If any of them fail shift candidate start one bit position and start again
    2) If “n” consecutive blocks are received with good parity, report Block Sync
c) Block Sync is established.
d) If “m” consecutive blocks are received with bad parity, drop Block Sync and restart again at item a).

The procedure is repeated at most 2111 times for all bits positions in the 2112 codeword. The values for m and n are as follows: m = 8 and n = 4.

74.7.4.8 FEC rapid block synchronization for EEE (optional)

If the optional EEE capability is supported then during the wake and refresh states the FEC decoder receives one of the two types of deterministic blocks to achieve rapid block synchronization. During these states the reverse gearbox of the remote FEC encoder is receiving unscrambled data from the PCS sublayer via 16-bit FEC_UNITDATA.request primitive. A Clause 49 PCS sublayer encodes /I/ during the wake state and /LI/ during the refresh state, which produces the two types of deterministic FEC blocks. If the optional EEE deep sleep capability is supported, then a Clause 82 PCS sublayer also encodes /I/ during the wake state and /LI/ during the refresh state, but in addition inserts Rapid Alignment Markers into each of the PCS Lanes (see 82.2.9). This causes the two types of deterministic FEC blocks to have a number of 65-bit words within the deterministic FEC block replaced with Rapid Alignment Markers, thus not matching the two deterministic patterns as shown in Table 74A–5 and Table 74A–6. The locations of the Rapid Alignment Markers within the Rapid FEC block are consistent for a given entry into the wake or refresh states, but the locations can vary for subsequent entries. This modification to the two deterministic patterns needs to be taken into account by the Rapid FEC Lock implementation.

When rx_lpi_active is TRUE and rx_mode (or rx_tx_mode if appropriate) transitions to DATA, start a hold-off timer whose duration is greater than or equal to 13.7 µs and enable the FEC Rapid block lock mechanism, which attempts to determine the FEC start of block location based on the deterministic pattern. When the rapid block lock is locked, the determined start of block location is used as the FEC lock state diagram candidate start of block location until the rapid block lock loses lock. Assuming the rapid block lock determined the correct start of block location, the FEC lock state diagram achieves lock without requiring subsequent slips. The rapid block lock mechanism is implementation dependent and outside the scope of this standard. The FEC sublayer shall hold off asserting SIGNAL_OK until one of the following two events occurs:

1) Two 65b payload blocks after the transition from deterministic FEC block to normal scrambled FEC block
2) Expiration of the hold-off timer

74.8 FEC MDIO function mapping

The optional MDIO capability described in Clause 45 defines several variables that provide control, status, abilities/capabilities, error indication information for and about the PHY. If MDIO is implemented, it shall map MDIO variables to FEC variables as shown in Table 74–1.

Table 74–1—MDIO/FEC variable mapping

MDIO variable	PMA/PMD register name	Register/ bit number	FEC variable
BASE-R FEC ability	BASE-R FEC ability register	1.170.0	FEC_ability
BASE-R FEC Error Indication ability	BASE-R FEC ability register	1.170.1	FEC_Error_Indication_ability
FEC Enable	BASE-R FEC control register	1.171.0	FEC_Enable
FEC Enable Error Indication	BASE-R FEC control register	1.171.1	FEC_Enable_Error_to_PCS
FEC corrected blocks	10GBASE-R FEC corrected blocks counter register	1.172, 1.173	FEC_corrected_blocks_counter
FEC uncorrected blocks	10GBASE-R FEC uncorrected blocks counter register	1.174, 1.175	FEC_uncorrected_blocks_counter
FEC corrected blocks, lanes 0 through 19	BASE-R FEC corrected blocks counter register, lanes 0 through 19	1.300 through 1.339	FEC_corrected_blocks_counter_*i*
FEC uncorrected blocks, lanes 0 through 19	BASE-R FEC uncorrected blocks counter register, lanes 0 through 19	1.700 through 1.739	FEC_uncorrected_blocks_counter_*i*

74.8.1 FEC capability

Since the FEC is an optional sublayer, the FEC ability is indicated by the variable FEC_ability for each of the BASE-R PHY types. An MDIO interface or an equivalent management interface shall be provided to access the variable FEC_ability for the BASE-R PHY type. The FEC_ability variable bit is set to a one to indicate that the PHY supports FEC sublayer, it defaults to zero otherwise.

The FEC_ability variable for the BASE-R PHY is mapped to register bit 1.170.0 (refer to 45.2.1.92.1).

The FEC capability between the link partners can be negotiated using the Clause 73 Auto-Negotiation as defined in 73.6.5. The FEC function is enabled on the link only if both the link partners advertise they have FEC ability and either one of them requests to enable FEC through the Auto-Negotiation function.

74.8.2 FEC Enable

The FEC sublayer shall have capability to enable or disable the FEC function. An MDIO interface or an equivalent management interface shall be provided to access the variable FEC_Enable for the BASE-R PHY (refer to 45.2.1.93 register bit 1.171.0). When FEC_Enable variable bit is set to a one, this enables the FEC for the BASE-R PHY. When the variable is set to zero, the FEC is disabled in the BASE-R PHY. This variable shall be set to zero upon execution of PHY reset. When the FEC function is disabled, the PHY shall have a mechanism to bypass the FEC Encode and Decode functions so as not to cause additional latency associated with encoding or decoding functions.

74.8.3 FEC Enable Error Indication

The FEC sublayer may have the option to enable the BASE-R FEC decoder to indicate decoding errors to the upper layers (PCS) through the sync bits for the BASE-R PHY as defined in 74.7.4.5, if this ability is supported. An MDIO interface or an equivalent management interface shall be provided to access the variable FEC_Enable_Error_to_PCS. When the variable is set to one, this enables indication of decoding errors through the sync bits to the PCS layer. When set to zero, the error indication function is disabled.

74.8.3.1 FEC Error Indication ability

The FEC error indication ability shall be indicated by the variable FEC_Error_Indication_ability. The variable is set to one to indicate that the BASE-R FEC has the ability to indicate decoding errors to the PCS layer. The variable is set to zero if this ability is not supported by the BASE-R FEC. An MDIO interface or an equivalent management interface shall be provided to access the variable FEC_Error_Indication_ability.

74.8.4 FEC Error monitoring capability

The following counters apply to FEC sublayer management and error monitoring. If an MDIO interface is provided (see Clause 45), it is accessed via that interface. If not, it is recommended that an equivalent access be provided. These counters are reset to zero upon read or upon reset of the FEC sublayer. When a counter reaches all ones, it stops counting. The counters' purpose is to help monitor the quality of the link.

These counters shall be disabled if FEC_LPI_ACTIVE.request(rx_lpi_active) is TRUE.

74.8.4.1 FEC_corrected_blocks_counter

A corrected block is an FEC block that has invalid parity, and has been corrected by the FEC decoder.

FEC_corrected_blocks_counter (for single-lane PHYs) or FEC_corrected_blocks_counter_*i* (for multi-PCS-lane PHYs, where $i = 0$ to 3 for 40 Gb/s and $i = 0$ to 19 for 100 Gb/s,) count once for each corrected FEC block processed when FEC_SIGNAL.indication or FEC:IS_SIGNAL.indication is OK. These are 32-bit counters. These variables are accessed through a management interface that may be mapped to the registers defined in 45.2.1.94 (1.172, 1.173) for single-lane PHYs and 45.2.1.116 (1.300 to 1.339) for multi-lane PHYs.

74.8.4.2 FEC_uncorrected_blocks_counter

An uncorrected block is an FEC block that has invalid parity, and has not been corrected by the FEC decoder.

FEC_uncorrected_blocks_counter (for single-lane PHYs) or FEC_uncorrected_blocks_counter_*i* (for multi-PCS-lane PHYs, where $i = 0$ to 3 for 40 Gb/s and $i = 0$ to 19 for 100 Gb/s,) count once for each uncorrected FEC block processed when FEC_SIGNAL.indication or FEC:IS_SIGNAL.indication is OK. These are 32-bit counters. These variables are accessed through a management interface that may be mapped to the registers defined in 45.2.1.95 (1.174, 1.175) for single-lane PHYs and 45.2.1.117 (1.700 to 1.739) for multi-lane PHYs.

74.9 BASE-R PHY test-pattern mode

The 10GBASE-R PCS provides test-pattern functionality and the PCS transmit channel and receive channel can each operate in normal mode or test-pattern mode (see 49.2.2). When the 10GBASE-R PHY is configured for test-pattern mode, the FEC function may be disabled by setting the FEC Enable variable to zero, so the test-pattern from the 10GBASE-R PCS can be sent to the PMA service interface, bypassing the FEC Encode and Decode functions.

The Clause 82 PCS can also operate in test pattern mode (see 82.2.11); however, the scrambled idle test pattern does not require bypassing FEC encode and decode.

74.10 Detailed functions and state diagrams

74.10.1 State diagram conventions

The body of this subclause is comprised of state diagrams, including the associated definitions of variables, constants, and functions. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

The notation used in the state diagrams follows the conventions of 21.5. State diagram timers follow the conventions of 14.2.3.2. The notation ++ after a counter or integer variable indicates that its value is to be incremented.

74.10.2 State variables

74.10.2.1 Constants

m
    Positive integer constant set to value 8.
n
    Positive integer constant set to value 4.

74.10.2.2 Variables

fec_block_lock
    Boolean variable that is set to true when receiver acquires FEC block delineation.
fec_block<2111:0>
    Vector containing 2112 bits of a new FEC block accumulated from the candidate start position received from the PMA and descrambled using PN-2112 as specified in 74.7.4.4.1. For each FEC block processing, the PN-2112 is returned to the initial state as described in 74.7.4.4.1.
fec_signal_ok
    Boolean variable that is set based on the most recently received value of PMA_UNITDATA.indication(SIGNAL_OK) or PMA:IS_SIGNAL.indication(SIGNAL_OK) and fec_block_lock. It is set to true if the fec_block_lock value is true and PMA_UNITDATA.indication(SIGNAL_OK) or PMA:IS_SIGNAL.indication(SIGNAL_OK) value was OK and set to false otherwise. The value is sent to the PCS layer through the primitive FEC_SIGNAL.indication or FEC:IS_SIGNAL.indication as specified in 74.5.1.3 or 74.5.2.
parity_good
    Boolean indication that is set to true if the FEC_PARITY_CHECK function returns "match" and false if the FEC_PARITY_CHECK function returns "no_match".
parity_invalid
    Boolean indication that is set to true if the FEC_PARITY_CHECK function returns "no_match" and false if the FEC_PARITY_CHECK function returns "match".
reset
    Boolean variable that controls the resetting of the FEC sublayer. It is true whenever a reset is necessary, including when reset is initiated from the MDIO during power on.
signal_ok
    Boolean variable that is set based on the most recently received value of PMA_UNITDATA.indication(SIGNAL_OK). It is true if the value was OK and false if the value was FAIL.
slip_done
    Boolean variable that is asserted true when the SLIP requested by the FEC Block Lock state diagram has been completed indicating that the next candidate block sync position can be tested.
test_fec_block
    Boolean variable that is set to true when a new FEC block is available for testing and false when

TEST_FEC_BLOCK state is entered. A new FEC block is available for testing when the FEC Block Sync process has accumulated one FEC block from the candidate start position (fec_block<2111:0>) from the PMA to evaluate the parity of the next block.

74.10.2.3 Functions

FEC_PARITY_CHECK(fec_block<2111:0>)

Computes parity based on the FEC generator polynomial *g(x)* on fec_block<2079:0> and compares it against the received 32-bit parity bits fec_block<2111:2080>. The FEC_PARIY_CHECK function returns “match” if the parity check matches, and returns “no_match” if the computed parity does not match the received parity.

SLIP

Causes the next candidate FEC block sync position to be tested. The precise method for determining the next candidate block sync position is not specified and is implementation dependent. However, an implementation shall ensure that all possible bit positions are evaluated.

74.10.2.4 Counters

parity_good_cnt

Count of the number of times the computed parity of received message bits matched the received parity.

parity_invalid_cnt

Count of the number of times the computed parity of received message bits did not match the received parity.

74.10.3 State diagrams

The FEC sublayer shall implement the FEC Lock state diagram shown in Figure 74–10, including compliance with the associated state variables as specified in 74.10.2. The FEC Lock state diagram determines when the receiver has obtained FEC block lock on the received data stream.

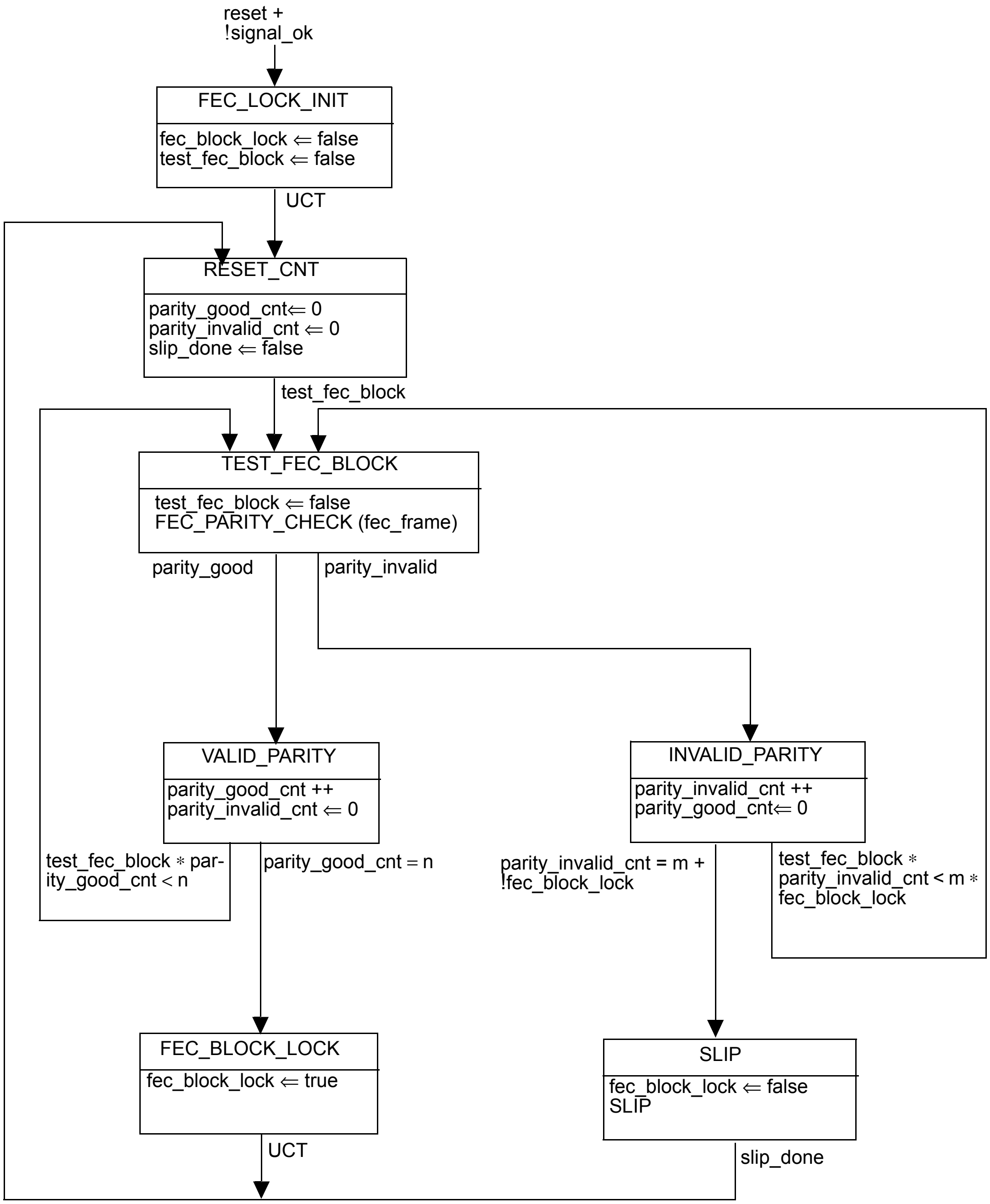


Figure 74–10—FEC Lock state diagram

74.11 Protocol implementation conformance statement (PICS) proforma for Clause 74, Forward Error Correction (FEC) sublayer for BASE-R PHYs[31]

74.11.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3, Clause 74 Forward Error Correction (FEC) sublayer for BASE-R PHYs, shall complete the following protocol implementation conformance statement (PICS) proforma. A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

74.11.2 Identification

74.11.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Names(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

74.11.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 74, Forward Error Correction (FEC) sublayer for BASE-R PHYs
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015)	
Date of Statement	

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[31] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

74.11.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
DC	FEC Delay Constraints	74.6	Sum of transmit and receive. No more than 12 pause_quanta for 10GBASE-R, 48 pause_quanta for 40GBASE-R, and 240 pause_quanta for 100GBASE-R	M	Yes [ ]
*MD	MDIO Interface	45, 74.8.2, 74.8.4	Device implements MDIO registers and interface	O	Yes [ ] No [ ]
EF	FEC_Enable	74.8.2	The device has the capability to enable/disable the FEC function	M	Yes [ ]
*EIA	FEC Error Indication ability	74.8.3, 74.8.3.1	The device has ability to indicate FEC decoding errors to the PCS layer as specified in 74.8.3	O	Yes [ ] No [ ]
BF	Bypass FEC function	74.8.2	The device has mechanism to bypass FEC encode/decode functions to reduce latency	M	Yes [ ]
EEE	Rapid Block Lock	74.7.4.8	Device implements Rapid block lock mechanism to support EEE	O	Yes[]/No []
*XSBI	PMA compatibility interface XSBI	51, 74.7.4.1	Optional PMA compatibility interface named XSBI is implemented between the PCS and FEC functions	O	Yes [ ] No [ ]

74.11.4 Management

Item	Feature	Subclause	Value/Comment	Status	Support
M1	Alternate access to FEC Management objects is provided	74.8.2, 74.8.4		M	Yes [ ]
M2	Default value for FEC_Enable	74.8.2	FEC_Enable variable is set to zero upon execution of PHY reset	M	Yes [ ]
M3	MDIO Register Mapping	74.8	If MDIO is implemented, the FEC variables and capabilities are mapped to the appropriate registers found in Table 74–1	MD:M	N/A [ ] Yes [ ]
M4	FEC_Error_Indication_ability variable access	74.8.3.1	An MDIO or equivalent managment interface is provided to access this variable	M	Yes [ ]
M5	FEC_Enable_Error_to_PCS variable access	74.8.3	An MDIO or equivalent managment interface is provided to access this variable	EIA:M	N/A [ ] Yes [ ]
M6	FEC_Enable variable access	74.8.2	An MDIO or equivalent managment interface is provided to access this variable	M	Yes [ ]
M7	FEC_ability variable access	74.8.1	An MDIO or equivalent managment interface is provided to access this variable	M	Yes [ ]

74.11.5 FEC Requirements

Item	Feature	Subclause	Value/Comment	Status	Support
FE1	FEC coding	74.7.1	The FEC code used is a shortened cyclic code (2112, 2080) for error checking and forward error correction	M	Yes [ ]
FE2	FEC block format	74.7.2	Meets the requirements of 74.7.2	M	Yes [ ]
FE3	Reverse gearbox function for 10GBASE-R	74.7.4.1.1	Reverse gearbox function implemented	XSBI:M	N/A[ ] Yes [ ]
FE4	Reverse gearbox function for 40GBASE-R and 100GBASE-R	74.7.4.1.2	Reverse gearbox function meets the requirements of 82.2.12	O	Yes [ ] No [ ]
FE5	FEC transmission bit ordering	74.7.4.3	Implements FEC transmission bit ordering as specified in 74.7.4.3	M	Yes [ ]
FE6	FEC encoder	74.7.4.4	Meets FEC encoder requirements of 74.7.4.4	M	Yes [ ]
FE7	PN-2112 generator	74.7.4.4.1	PN-2112 generator produces the same result as the implementation shown in Figure 74–7	M	Yes [ ]
FE8	PN-2112 Scrambler	74.7.4.4.1	Meets PN-2112 scrambler requirements of 74.7.4.4.1	M	Yes [ ]
FE9	PN-2112 descrambler	74.7.4.5.1	Meets PN-2112 descrambler requirements of 74.7.4.5.1	M	Yes [ ]
FE10	FEC decoding	74.7.4.5	Meets FEC decoder requirements of 74.7.4.5	M	Yes [ ]
FE11	FEC decoder error correction capability	74.7.4.5	The FEC decoder implementation is able to correct up to a minimum of 11 bit burst errors per FEC block as specified in 74.7.4.5.1	M	Yes [ ]
FE12	Indication of decoding errors	74.7.4.5, 74.7.4.5.1, 74.8.3	Device implements indication of decoding errors to PCS layer.	EIA:M	N/A[ ] Yes [ ]
FE13	FEC block sync	74.7.4.7	Meets FEC block sync requirements as specified in 74.7.4.7	M	Yes [ ]
FE14	FEC Enable Error Indication	74.8.3	Enable FEC decoder to indicate decoding errors to PCS layer	EIA:M	N/A[ ] Yes [ ]
FE15	SLIP function	74.10.2.3	All possible bit positions can be evaluated	M	Yes [ ]
FE16	FEC Lock function	74.10.3	The FEC lock function meets the requirements of the state diagram in 74.10.3	M	Yes [ ]

74.11.6 FEC Error Monitoring

Item	Feature	Subclause	Value/Comment	Status	Support
FEM1	FEC Error Monitoring	74.8.4	Meets FEC error monitoring capability requirements of 74.8.4	M	Yes [ ]
FEM2	FEC_corrected_blocks_counter	74.8.4.1	Meets 32-bit FEC corrected blocks counter requirements of 74.8.4.1	M	Yes [ ]
FEM3	FEC_uncorrected_blocks_counter	74.8.4.2	Meets 32-bit FEC uncorrected blocks counter requirements of 74.8.4.2	M	Yes [ ]
FEM4	FEC Error Monitoring during EEE	74.8.4	Disables FEC Error Monitoring during EEE as specified in 74.8.4	EEE:M	Yes[]

75. Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX

75.1 Overview

Clause 75 describes Physical Medium dependent (PMD) sublayer for Ethernet Passive Optical Networks operating at the line rate of 10.3125 GBd in either downstream or in both downstream and upstream directions.

75.1.1 Terminology and conventions

The following list contains references to terminology and conventions used in Clause 75:

Basic terminology and conventions, see 1.1 and 1.2.

Normative references, see 1.3.

Definitions, see 1.4

Abbreviations, see 1.5.

Informative references, see Annex A.

Introduction to 1000 Mb/s baseband networks, see Clause 34.

Introduction to 10 Gb/s baseband network, see Clause 44.

Introduction to Ethernet for subscriber access networks, see Clause 56.

EPONs operate over a point-to-multipoint (P2MP) topology, also called a tree or trunk-and-branch topology. The device connected at the root of the tree is called an Optical Line Terminal (OLT) and the devices connected as the leaves are referred to as Optical network Units (ONUs). The direction of transmission from the OLT to the ONUs is referred to as the *downstream* direction, while the direction of transmission from the ONUs to the OLT is referred to as the *upstream* direction.

75.1.2 Goals and objectives

The following are the PMD objectives fulfilled by Clause 75:

a) Support subscriber access networks using point-to-multipoint topologies on optical fiber.
b) Provide Physical Layer specifications:
    1) PHY for PON, 10 Gb/s downstream / 1 Gb/s upstream, on a single SMF
    2) PHY for PON, 10 Gb/s downstream / 10 Gb/s upstream, on a single SMF
c) PHY(s) to have a BER better than or equal to 10^{-12} at the PHY service interface.
d) Define up to four optical power budgets that support split ratios of at least 1:16, 1:32, and 1:64, and distances of at least 10 km and 20 km.

75.1.3 Power budget classes

To support the above-stated objectives, Clause 75 defines the following four power budget classes:

- *Low power budget class* supports P2MP media channel insertion loss of ≤ 20 dB e.g., a PON with the split ratio of at least 1:16 and the distance of at least 10 km.
- *Medium power budget class* supports P2MP media channel insertion loss of ≤ 24 dB e.g., a PON with the split ratio of at least 1:16 and the distance of at least 20 km or a PON with the split ratio of at least 1:32 and the distance of at least 10 km.

- *High power budget class* supports P2MP media channel insertion loss of ≤ 29 dB e.g., a PON with the split ratio of at least 1:32 and the distance of at least 20 km.
- *Extended power budget class* supports P2MP media channel insertion loss of ≤ 33 dB e.g., a PON with the split ratio of at least 1:64 and the distance of at least 20 km.

75.1.4 Power budgets

Each power budget class is represented by PRX-type power budget and PR-type power budget as follows:

- PRX–type power budget describes asymmetric-rate PHY for PON operating at 10 Gb/s downstream and 1 Gb/s upstream over a single SMF [see objective b 1) in 75.1.2].
- PR–type power budget describes symmetric-rate PHY for PON operating at 10 Gb/s downstream and 10 Gb/s upstream over a single SMF [see objective b 2) in 75.1.2].

Each power budget is further identified with a numeric representation of its class, where a value of 10 represents low power budget, a value of 20 represents medium power budget, and a value of 30 represents high power budget. Thus, the following power budgets are defined in Clause 75:

- PRX10: asymmetric-rate, low power budget, compatible with PX10 power budget defined in Clause 60.
- PRX20: asymmetric-rate, medium power budget, compatible with PX20 power budget defined in Clause 60.
- PRX30: asymmetric-rate, high power budget, compatible with PX30 power budget defined in Clause 60.
- PRX40: asymmetric-rate, extended power budget, compatible with PX40 power budget defined in Clause 60.
- PR10: symmetric-rate, high power budget, compatible with PX10 power budget defined in Clause 60
- PR20: symmetric-rate, high power budget, compatible with PX20 power budget defined in Clause 60
- PR30: symmetric-rate, high power budget, compatible with PX30 power budget defined in Clause 60.
- PR40: symmetric-rate, extended power budget, compatible with PX40 power budget defined in Clause 60.

Table 75–1 shows the primary attributes of all power budget types defined in Clause 75.

Table 75–1—Power budgets

Description	Low Power Budget		Medium Power Budget		High Power Budget		Extended Power Budget		Units
	PRX10	PR10	PRX20	PR20	PRX30	PR30	PRX40	PR40	
Number of fibers	1								–
Nominal downstream line rate	10.3125								GBd
Nominal upstream line rate	1.25	10.3125	1.25	10.3125	1.25	10.3125	1.25	10.3125	GBd
Nominal downstream wavelength	1577								nm
Downstream wavelength tolerance	–2, +3								nm
Nominal upstream wavelength	1310	1270	1310	1270	1310	1270	1310	1270	nm
Upstream wavelength tolerance	±50	±10	±50	±10	±50	±10	±20	±10	nm
Maximum reach[a]	≥10		≥20						km
Maximum channel insertion loss	20		24		29		33		dB
Minimum channel insertion loss	5		10		15		18		dB

[a] A compliant system may exceed the maximum reach designed for given power budget as long as optical power budget and other mandatory optical layer specifications are met.

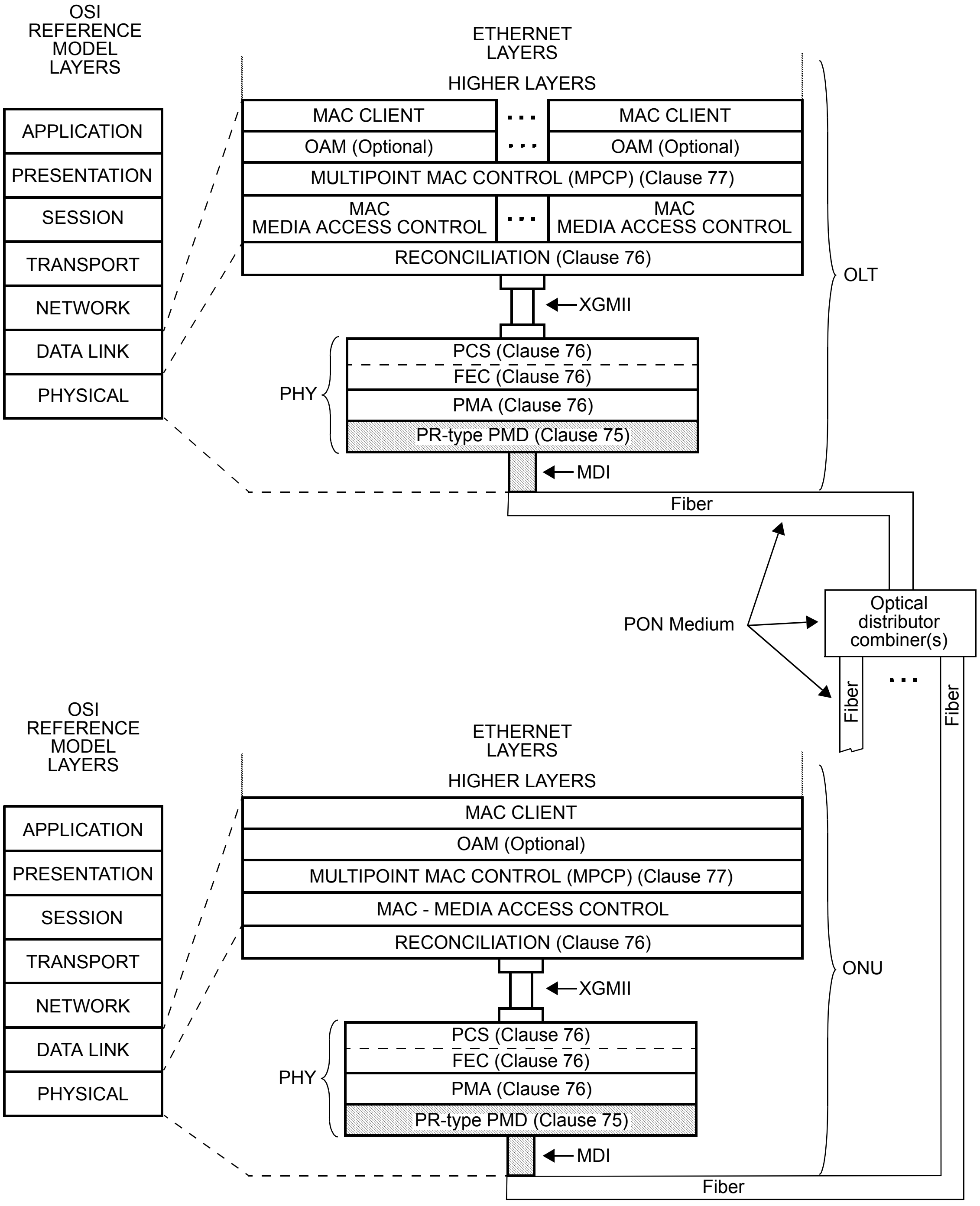
75.1.5 Positioning of PMD sublayer within the IEEE 802.3 architecture

Figure 75–1 and Figure 75–2 depict the relationships of the symmetric-rate (10/10G–EPON) and asymmetric-rate (10/1G–EPON) PMD sublayer (shown hatched) with other sublayers and the ISO/IEC Open System Interconnection (OSI) reference model.

75.2 PMD types

Similarly to power budget classes, asymmetric-rate and symmetric-rate PMDs are identified by PRX and PR designations, respectively.

The characteristics of the P2MP topology result in significantly different ONU and OLT PMDs. For example, the OLT PMD operates in a continuous mode in the transmit direction (downstream), but uses a burst mode in the receive direction (upstream). On the other hand, the ONU PMD receives data in a continuous mode, but transmits in a burst mode. To differentiate OLT PMDs from ONU PMDs, the OLT



▨ PMD and MDI described in this clause

XGMII= 10 GIGABIT MEDIA INDEPENDENT INTERFACE	ONU = OPTICAL NETWORK UNIT
MDI = MEDIUM DEPENDENT INTERFACE	PCS = PHYSICAL CODING SUBLAYER
OAM = OPERATIONS, ADMINISTRATION & MAINTENANCE	PHY = PHYSICAL LAYER DEVICE
OLT = OPTICAL LINE TERMINAL	PMA = PHYSICAL MEDIUM ATTACHMENT
	PMD = PHYSICAL MEDIUM DEPENDENT

Figure 75–1—Relationship of 10/10G–EPON P2MP PMD to the ISO/IEC OSI reference model and the IEEE 802.3 Ethernet model

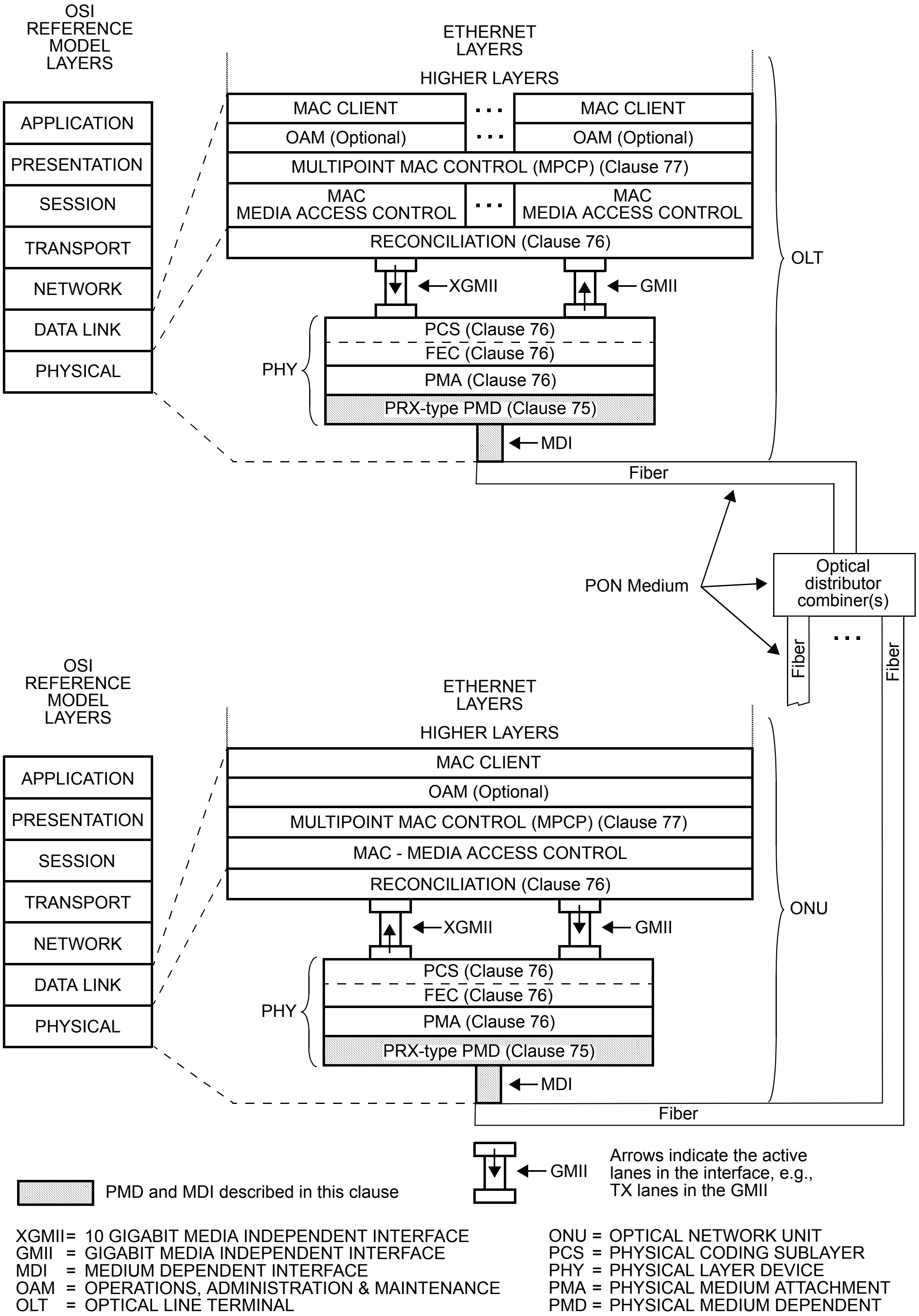


Figure 75–2—Relationship of 10/1G–EPON P2MP PMD to the ISO/IEC OSI reference model and the IEEE 802.3 Ethernet model

PMD name has a suffix “D” appended to it, where D stands for downstream–facing PMD, e.g., 10GBASE–PR–D1. ONU PMDs have suffix “U” for upstream–facing PMD, e.g., 10GBASE–PR–U1.

In the downstream direction, the signal transmitted by the D-type PMD is received by all U-type PMDs. In the upstream direction, the D-type PMD receives data bursts from each of the U-type PMDs.

Clause 75 defines several D-type and several U-type PMDs, that differ in their receive and/or transmit characteristics. Such PMDs are further distinguished by appending a digit after the suffix D or U, e.g., 10GBASE–PR–D1 or 10GBASE–PR–D2.

The following OLT PMDs (D-type) are defined in this subclause:

a) Asymmetric-rate D-type PMDs (collectively referred to as 10/1GBASE–PRX–D), transmitting at 10.3125 GBd continuous mode and receiving at 1.25 GBd burst mode:
    1) 10/1GBASE–PRX–D1
    2) 10/1GBASE–PRX–D2
    3) 10/1GBASE–PRX–D3
    4) 10/1GBASE–PRX–D4
b) Symmetric-rate D-type PMDs (collectively referred to as 10GBASE–PR–D), transmitting at 10.3125 GBd continuous mode and receiving at 10.3125 GBd burst mode:
    1) 10GBASE–PR–D1
    2) 10GBASE–PR–D2
    3) 10GBASE–PR–D3
    4) 10GBASE–PR–D4

The following ONU PMDs (U-type) are defined in this subclause:

c) Asymmetric-rate U-type PMDs (collectively referred to as 10/1GBASE–PRX–U), transmitting at 1.25 GBd burst mode and receiving at 10.3125 GBd continuous mode:
    1) 10/1GBASE–PRX–U1
    2) 10/1GBASE–PRX–U2
    3) 10/1GBASE–PRX–U3
    4) 10/1GBASE–PRX–U4
d) Symmetric-rate U-type PMDs (collectively referred to as 10GBASE–PR–U), transmitting at 10.3125 GBd burst mode and receiving at 10.3125 GBd continuous mode:
    1) 10GBASE–PR–U1
    2) 10GBASE–PR–U3
    3) 10GBASE-PR–U4

A specific power budget is achieved by combining an OLT PMD (D-type) with an ONU PMD (U-type) as shown in 75.2.1. Detailed PMD receive and transmit characteristics for D-type PMDs are given in 75.4 and characteristics for U-type PMDs are presented in 75.5. Every PMD has non-overlapping transmit and receive wavelength bands and operates over a single SMF (see 75B.2).

75.2.1 Mapping of PMDs to power budgets

The power budget is determined by the PMDs located at the ends of the physical media. This subclause describes how PMDs may be combined to achieve the power budgets listed in Table 75–1.

75.2.1.1 Asymmetric-rate, 10 Gb/s downstream and 1 Gb/s upstream power budgets (PRX type)

Table 75–2 illustrates recommended pairings of asymmetric-rate ONU PMDs with asymmetric-rate OLT PMDs to achieve the power budgets shown in Table 75–1.

Table 75–2—PMD – power budget mapping for asymmetric-rate PRX–type power budgets

		OLT PMDs			
		10/1GBASE–PRX–D1	**10/1GBASE–PRX–D2**	**10/1GBASE–PRX–D3**	**10/1GBASE–PRX–D4**
ONU PMDs	**10/1GBASE–PRX–U1**	PRX10	N/A	N/A	N/A
	10/1GBASE–PRX–U2	N/A	PRX20	N/A	N/A
	10/1GBASE–PRX–U3	N/A	N/A	PRX30	N/A
	10/1GBASE–PRX–U4	N/A	N/A	N/A	PRX40

75.2.1.2 Symmetric-rate, 10 Gb/s power budgets (PR type)

Table 75–3 illustrates recommended pairings of symmetric-rate ONU PMDs with symmetric-rate OLT PMDs to achieve the power budgets as shown in Table 75–1.

Table 75–3—PMD – power budget mapping for symmetric-rate PR–type power budgets

		OLT PMDs			
		10GBASE–PR–D1	**10GBASE–PR–D2**	**10GBASE–PR–D3**	**10GBASE–PR–D4**
ONU PMDs	**10GBASE–PR–U1**	PR10	PR20	N/A	N/A
	10GBASE–PR–U3	N/A	N/A	PR30	N/A
	10GBASE–PR–U4	N/A	N/A	N/A	PR40

75.3 PMD functional specifications

The 10GBASE–PR and 10/1GBASE–PRX type PMDs perform the transmit and receive functions that convey data between the PMD service interface and the MDI.

75.3.1 PMD service interface

The following specifies the services provided by Clause 75 PMDs. These PMD sublayer service interfaces are described in an abstract manner and do not imply any particular implementation.

The PMD Service Interface supports the exchange of a continuous stream of bits, representing either 64B/66B blocks (the transmit and receive paths in 10GBASE–PR PMDs, transmit path in 10/1GBASE–PRX–D PMDs) or 8B/10B blocks (transmit path in 10/1GBASE–PRX–U PMDs, receive path in 10/1GBASE–PRX–D PMDs), between the PMA and PMD entities. The PMD translates the serialized data received from the compatible PMA to and from signals suitable for the specified medium. The following primitives are defined:

- PMD_UNITDATA.request
- PMD_UNITDATA.indication
- PMD_SIGNAL.request
- PMD_SIGNAL.indication

75.3.1.1 Delay constraints

The PMD shall introduce a transmit delay of not more than 4 time_quanta with the variability of no more than 0.5 time_quanta, and a receive delay of not more than 4 time_quanta with the variability of no more than 0.5 time_quanta. A description of the overall system delay constraints can be found in 76.1.2 and the definition for the time_quantum can be found in 77.2.2.1.

75.3.1.2 PMD_UNITDATA.request

This primitive defines the transfer of a serial data stream from the Clause 65 or Clause 76 PMA to the PMD.

The semantics of the service primitive are PMD_UNITDATA.request(tx_bit). The data conveyed by PMD_UNITDATA.request is a continuous stream of bits. The tx_bit parameter can take one of two values: ONE or ZERO. The Clause 76 PMA continuously sends the appropriate stream of bits to the PMD for transmission on the medium, at a nominal signaling speed of 10.3125 GBd in the case of 10/10G–EPON OLT, 10/10G–EPON ONU, and 10/1G–EPON OLT PMDs. The Clause 65 PMA continuously sends the appropriate stream of bits to the PMD for transmission on the medium, at a nominal signaling speed of 1.25 GBd in the case of 10/1G–EPON ONU PMDs. Upon the receipt of this primitive, the PMD converts the specified stream of bits into the appropriate signals at the MDI.

75.3.1.3 PMD_UNITDATA.indication

This primitive defines the transfer of data from the PMD to the Clause 65 or Clause 76 PMA.

The semantics of the service primitive are PMD_UNITDATA.indication(rx_bit). The data conveyed by PMD_UNITDATA.indication is a continuous stream of bits. The rx_bit parameter can take one of two values: ONE or ZERO. The PMD continuously sends a stream of bits to the Clause 76 PMA corresponding to the signals received from the MDI, at the nominal signaling speed of 10.3125 GBd in the case of 10/10G–EPON OLT, 10/10G–EPON ONU, and 10/1G–EPON ONU PMDs or to the Clause 65 PMA at the nominal signaling speed of 1.25 GBd in the case of 10/1G–EPON OLT PMDs.

75.3.1.4 PMD_SIGNAL.request

In the upstream direction, this primitive is generated by the Clause 76 PMA to turn on and off the transmitter according to the granted time. A signal for laser control is generated as described in 76.4.1.1 for the Clause 76 PCS.

The semantics of the service primitive are PMD_SIGNAL.request(tx_enable). The tx_enable parameter can take on one of two values: ENABLE or DISABLE, determining whether the PMD transmitter is on (enabled) or off (disabled). The Clause 76 PMA generates this primitive to indicate a change in the value of tx_enable. Upon the receipt of this primitive, the PMD turns the transmitter on or off as appropriate.

75.3.1.5 PMD_SIGNAL.indication

This primitive is generated by the PMD to indicate the status of the signal being received from the MDI.

The semantics of the service primitive are PMD_SIGNAL.indication(SIGNAL_DETECT). The SIGNAL_DETECT parameter can take on one of two values: OK or FAIL, indicating whether the PMD is detecting light at the receiver (OK) or not (FAIL). When SIGNAL_DETECT = FAIL, PMD_UNITDATA.indication(rx_bit) is undefined. The PMD generates this primitive to indicate a change in the value of SIGNAL_DETECT. If the MDIO interface is implemented, then PMD_global_signal_detect shall be continuously set to the value of SIGNAL_DETECT.

NOTE—SIGNAL_DETECT = OK does not guarantee that PMD_UNITDATA.indication(rx_bit) is known good. It is possible for a poor quality link to provide sufficient light for a SIGNAL_DETECT = OK indication and still not meet the specified bit error ratio. PMD_SIGNAL.indication(SIGNAL_DETECT) has different characteristics for upstream and downstream links, see 75.3.5.

75.3.2 PMD block diagram

The PMD sublayer is defined at the eight reference points shown in Figure 75–3 for 10GBASE–PR and 10/1GBASE–PRX PMDs.

For 10GBASE–PR and 10/1GBASE–PRX PMDs, test points TP1 through TP4 refer to the downstream channel, while test points TP5 through TP8 refer to the upstream channel. In the downstream channel, TP2 and TP3 are compliance points, while in the upstream channel TP6 and TP7 are compliance points. TP1, TP4, TP5, and TP8 are reference points for use by implementers. The optical transmit signal is defined at the output end of a patch cord (TP2 for the downstream channel and TP6 for the upstream channel), between 2 m and 5 m in length, of a fiber type consistent with the link type connected to the transmitter. Unless specified otherwise, all transmitter measurements and tests defined in 75.7 are made at TP2 or TP6, while tests defined in 60.9 are made at TP6. The optical receive signal is defined at the output of the fiber optic cabling (TP3 for the downstream channel and TP7 for the upstream channel) connected to the receiver. Unless specified otherwise, all receiver measurements and tests defined in 75.7 are made at TP3 or TP7.

The electrical specifications of the PMD service interface (TP1 and TP4 for the downstream channel and TP5 and TP8 for the upstream channel) are not system compliance points (these are not readily testable in a system implementation).

75.3.3 PMD transmit function

The PMD Transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the optical specifications in Clause 75.

In the upstream direction, the flow of bits is interrupted according to PMD_SIGNAL.request(tx_enable). This implies three optical levels, 1, 0, and dark, the latter corresponding to the transmitter being in the OFF state. The higher optical power level shall correspond to tx_bit = ONE.

75.3.4 PMD receive function

The PMD Receive function shall convey the bits received from the MDI according to the optical specifications in Clause 75 to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). The higher optical power level shall correspond to rx_bit = ONE.

75.3.5 PMD signal detect function

75.3.5.1 ONU PMD signal detect

The PMD Signal Detect function for the continuous mode downstream signal shall report to the PMD service interface, using the message PMD_SIGNAL.indication(SIGNAL_DETECT), which is signaled continuously. PMD_SIGNAL.indication is intended to be an indicator of the presence of the optical signal.

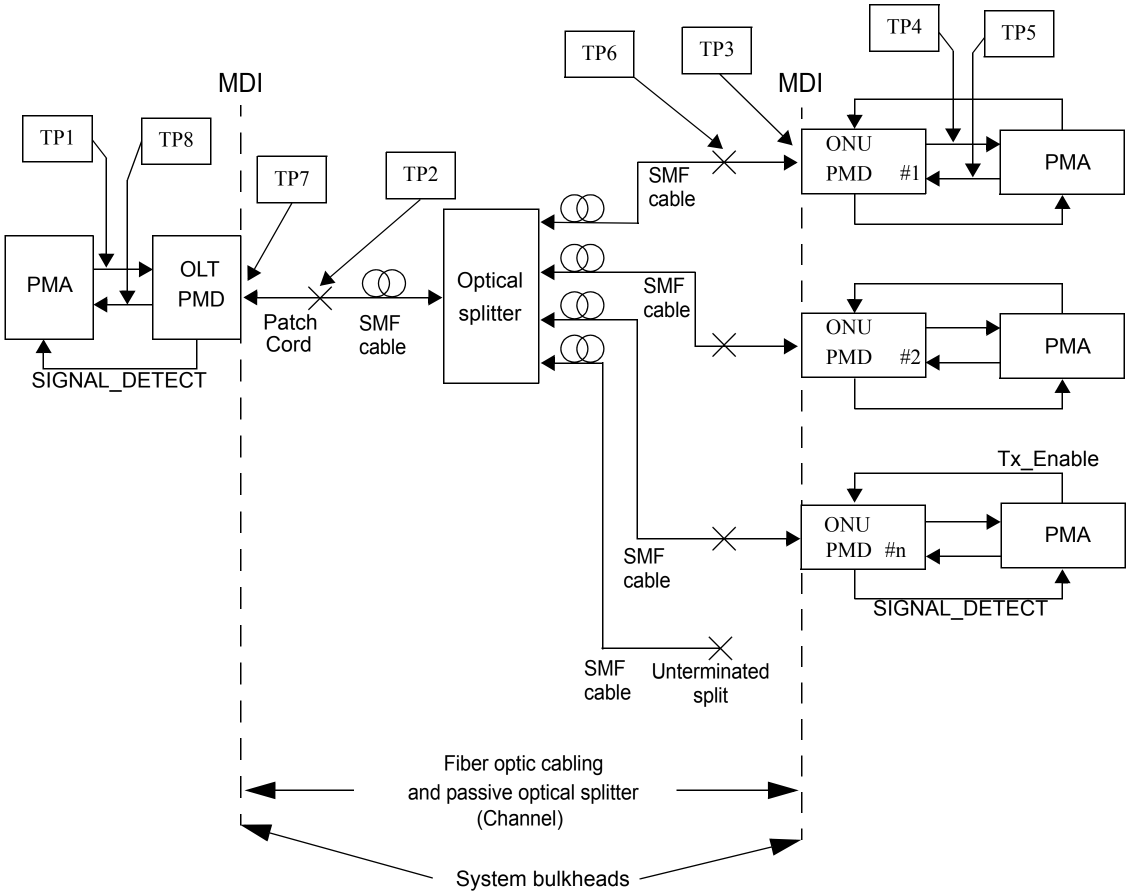


Figure 75–3—10GBASE–PR and 10/1GBASE–PRX block diagram

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 75–4 for 10GBASE–PR and 10/1GBASE–PRX type PMDs. The ONU PMD receiver is not required to verify whether a compliant 10GBASE–PR signal is being received.

75.3.5.2 OLT PMD signal detect

The response time for the PMD Signal Detect function for the burst mode upstream signal may be longer or shorter than a burst length; thus, it may not fulfill the traditional requirements placed on Signal Detect. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence. The signal detect function in the OLT may be realized in the PMD or the Clause 76 PMA sublayer.

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 75–4 for PMDs defined in Clause 75. The 10GBASE–PR–D PMD receiver is not required to verify whether a compliant 10GBASE–PR signal is being received. Similarly, the 10/1GBASE–PRX–D PMD receiver is not required to verify whether a compliant 1000BASE–PX signal is being received.

75.3.5.3 10GBASE–PR and 10/1GBASE–PRX Signal detect functions

The Signal Detect value definitions for Clause 75 PMDs are shown in Table 75–4.

Table 75–4—SIGNAL_DETECT value definitions for Clause 75 PMDs

PMD type	Receive conditions	SIGNAL_DETECT value
10GBASE–PR–D1, 10GBASE–PR–D2, 10GBASE–PR–D3, 10GBASE–PR–D4	Average input optical power ≤ Signal Detect Threshold (min) in Table 75–6 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 75–6 with a compliant 10GBASE–PR signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified
10GBASE–PR–U1, 10GBASE–PR–U3, 10GBASE–PR–U4 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2, 10/1GBASE–PRX–U3, 10/1GBASE–PRX–U4	Average input optical power ≤ Signal Detect Threshold (min) in Table 75–10 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 75–10 with a compliant 10GBASE–PR signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified
10/1GBASE–PRX–D1, 10/1GBASE–PRX–D2, 10/1GBASE–PRX–D3, 10/1GBASE–PRX–D4	Average input optical power ≤ Signal Detect Threshold (min) in Table 75–7 at the specified receiver wavelength	FAIL
	Average input optical power ≥ Receive sensitivity (max) in Table 75–7 with a compliant 1000BASE–PX signal input at the specified receiver wavelength	OK
	All other conditions	Unspecified

75.3.6 PMD transmit enable function for ONU

PMD_SIGNAL.request(tx_enable) is defined for all ONU PMDs specified in Clause 75. PMD_SIGNAL.request(tx_enable) is asserted prior to data transmission by the ONU PMDs.

75.4 PMD to MDI optical specifications for 10/10G–EPON and 10/1G–EPON OLT PMDs

This subclause details the PMD to MDI optical specifications for 10/10G–EPON and 10/1G–EPON OLT PMDs, as specified in 75.2. Specifically, 75.4.1 defines the OLT transmit parameters, while 75.4.2 defines the OLT receive parameters.

The operating ranges for PR and PRX power budget classes are defined in Table 75–1. A PR or PRX compliant transceiver operates over the media types listed in Table 75–14 according to the specifications described in 75.9. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

NOTE—The specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is defined in 58.7.6.

75.4.1 Transmitter optical specifications

The signaling speed, operating wavelength, side mode suppression ratio, average launch power, extinction ratio, return loss tolerance, OMA, eye, and Transmitter and Dispersion Penalty (TDP) for transmitters making part of the 10/10G–EPON and 10/1G–EPON OLT PMDs (as specified in 75.2) shall meet the specifications defined in Table 75–5 per measurement techniques described in 75.7. Their $RIN_{15}OMA$ should meet the value listed in Table 75–5 per measurement techniques described in 75.7.8. Note that there are only two groups of transmit parameters. The first group is shared by 10GBASE–PR–D1, 10/1GBASE–PRX–D1, 10GBASE–PR–D3, and 10/1GBASE–PRX–D3. The second group is shared by 10GBASE–PR–D2, 10GBASE–PR–D4, 10/1GBASE–PRX–D2, and 10/1GBASE-PRX-D4.

Table 75–5—PR and PRX type OLT PMD transmit characteristics

Description	10GBASE–PR–D1, 10GBASE–PR–D3, 10/1GBASE–PRX–D1, 10/1GBASE–PRX–D3	10GBASE–PR–D2, 10GBASE–PR–D4, 10/1GBASE–PRX–D2, 10/1GBASE-PRX-D4	Unit
Signaling speed (range)	10.3125 ± 100 ppm		GBd
Wavelength (range)	1575 to 1580		nm
Side Mode Suppression Ratio (min)[a]	30		dB
Average launch power (max)	5	9	dBm
Average launch power (min)[b]	2	5	dBm
Average launch power of OFF transmitter (max)	–39		dBm
Extinction ratio (min)	6		dB
$RIN_{15}OMA$ (max)	–128		dB/Hz
Launch OMA (min)[b]	3.91 (2.46)	6.91 (4.91)	dBm (mW)
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}[c]	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}		UI
Optical return loss tolerance (max)	15		dB
Transmitter reflectance (max)	–10		dB
Transmitter and dispersion penalty (max)	1.5		dB
Decision timing offset for transmitter and dispersion penalty	±0.05		UI

[a] Transmitter is a single longitudinal mode device. Chirp is allowed such that the total optical path penalty does not exceed that found in Table 75B–1 and Table 75B–2.
[b] Minimum average launch power and minimum launch OMA are valid for ER = 9 dB (see Figure 75–4 for details)
[c] As defined in Figure 75–6.

The relationship between OMA, extinction ratio, and average power is described in 58.7.6 and illustrated in Figure 75–4 for a compliant transmitter. Note that the OMA_{min} and AVP_{min} are calculated for ER = 9 dB, where AVP_{min} represents the Average launch power (min) as presented in Table 75–5. The transmitter specifications are further relaxed by allowing lower ER = 6 dB while maintaining the OMA_{min} and AVP_{min} constant. The shaded area indicates a compliant part.

75.4.2 Receiver optical specifications

The signaling speed, operating wavelength, overload, stressed sensitivity, reflectance, and signal detect for receivers forming part of the 10/10G–EPON and 10/1G–EPON OLT PMDs (as specified in 75.2) shall meet the specifications defined in Table 75–6 for 10/10G–EPON OLT PMDs and in Table 75–7 for 10/1G–EPON OLT PMDs, per measurement techniques defined in 75.7. Their unstressed receive characteristics should meet the values listed in Table 75–6 and Table 75–7 per measurement techniques described in 75.7.11. Either the damage threshold included in Table 75–6 or Table 75–7 shall be met, or the receiver shall be labeled to indicate the maximum optical input power level to which it can be continuously exposed without damage.

The damage threshold included in Table 75–6 and Table 75–7 does not guarantee direct ONU–OLT connection, which may result in damage of the receiver. If direct ONU–OLT connection is necessary, optical attenuators and/or equivalent loss components should be inserted to decrease receive power below the damage threshold.

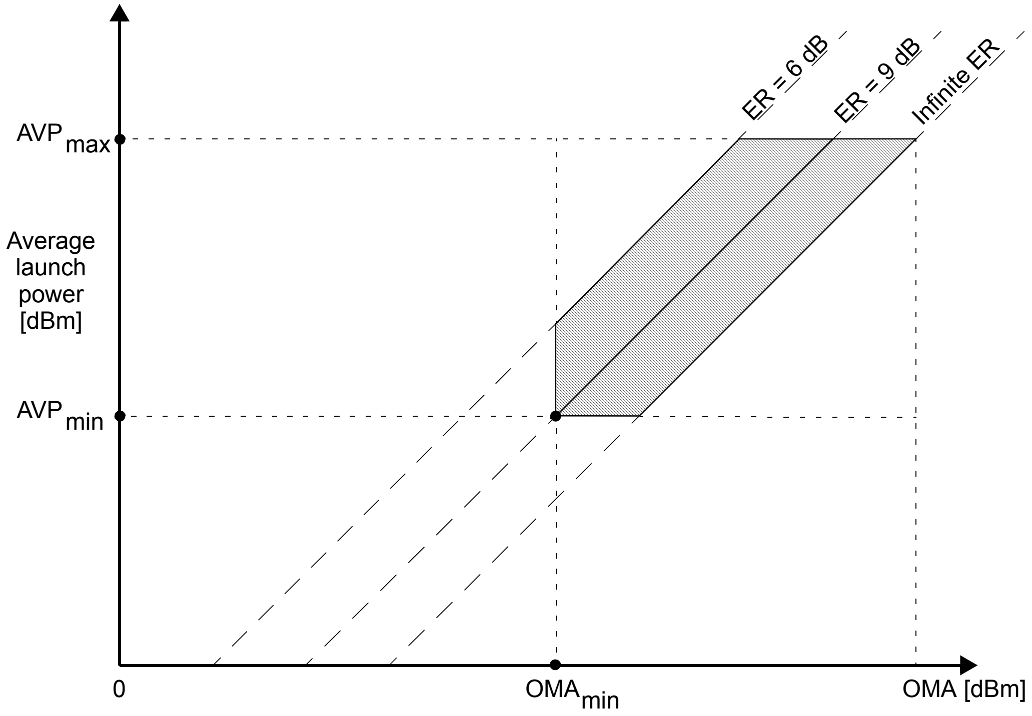


Figure 75–4—Graphical representation of region of PR–D type transmitter compliance

Table 75–6—PR type OLT PMD receive characteristics

Description	10GBASE–PR–D1	10GBASE–PR–D2, 10GBASE–PR–D3	10GBASE–PR–D4	Unit
Signaling speed (range)	10.3125 ± 100 ppm			GBd
Wavelength (range)	1260 to 1280			nm
Bit error ratio (max)[a]	10^{-3}			–
Average receive power (max)	–1	–6	–9	dBm
Damage threshold (max)[b]	0	–5	–8	dBm
Receiver sensitivity (max)	–24	–28	–29	dBm
Receiver sensitivity OMA (max)	–23.22 (4.77)	–27.22 (1.9)	–28.22 (1.51)	dBm (μW)
Signal detect threshold (min)	–45			dBm
Receiver reflectance (max)	–12			dB
Stressed receive sensitivity (max)[c]	–21	–25	–27	dBm

Table 75–6—PR type OLT PMD receive characteristics *(continued)*

Description	10GBASE–PR–D1	10GBASE–PR–D2, 10GBASE–PR–D3	10GBASE–PR–D4	Unit
Stressed receive sensitivity OMA (max)	–20.22 (9.51)	–24.22 (3.79)	–26.22 (2.39)	dBm (µW)
Vertical eye–closure penalty[d]	2.99			dB
$T_{receiver\_settling}$ (max)[e]	800			ns
Stressed eye jitter	0.3			UI pk-pk
Jitter corner frequency for a sinusoidal jitter	4			MHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	(0.05, 0.15)			UI

[a] The BER of 10^{-12} is achieved by the utilization of FEC as described in 76.3.
[b] Direct ONU–OLT connection may result in damage of the receiver.
[c] The stressed receiver sensitivity is mandatory.
[d] Vertical eye closure penalty and the jitter specifications are test conditions for measuring stressed receiver sensitivity. They are not required characteristics of the receiver.
[e] $T_{receiver\_settling}$ represents an upper bound. Optics with better performance may be used in compliant implementations, since the OLT notifies the ONUs of its requirements in terms of the $T_{receiver\_settling}$ time via the syncTime parameter (see 77.3.3.2).

Table 75–7—PRX type OLT PMD receive characteristics

PMD type	Receive parameters	Reference
10/1GBASE–PRX–D1	same as 1000BASE–PX10–D receive parameters	see Table 60–5
10/1GBASE–PRX–D2	same as 1000BASE–PX20–D receive parameters	see Table 60–8
10/1GBASE–PRX–D3	same as 1000BASE–PX30–D receive parameters[a]	see Table 60–11
10/1GBASE–PRX–D4	same as 1000BASE–PX40–D receive parameters[a]	see Table 60–13

[a] Stressed receive sensitivity (max) is mandatory for 10/1GBASE–PRX–D3 and 10/1GBASE–PRX–D4 PMDs.

75.5 PMD to MDI optical specifications for 10/10G–EPON and 10/1G–EPON ONU PMDs

This subclause details the PMD to MDI optical specifications for 10/10G–EPON and 10/1G–EPON ONU PMDs, as specified in 75.2. Specifically, 75.5.1 defines the ONU transmit parameters, while 75.5.2 defines the ONU receive parameters.

The operating ranges for PR and PRX power budget classes are defined in Table 75–1. A PR or PRX compliant transceiver operates over the media types listed in Table 75–14 according to the specifications described in 75.9. A transceiver which exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

NOTE—The specifications for OMA have been derived from extinction ratio and average launch power (minimum) or receiver sensitivity (maximum). The calculation is defined in 58.7.6.

75.5.1 Transmitter optical specifications

The signaling speed, operating wavelength, spectral width (for 10/1G–EPON ONU PMDs) or side mode suppression ratio (for 10/10G–EPON ONU PMDs), average launch power, extinction ratio, return loss tolerance, OMA, eye and TDP for transmitters forming part of the 10/10G–EPON and 10/1G–EPON ONU PMDs (as specified in 75.2) shall meet the specifications defined in Table 75–8 for 10/10G–EPON ONU PMDs and in Table 75–9 for 10/1G–EPON ONU PMDs, per measurement techniques described in 75.7. Their $\mathrm{RIN}_{15}\mathrm{OMA}$ should meet the value listed in Table 75–8 or Table 75–9, as appropriate, per measurement techniques described in 75.7.8.

Table 75–8—PR type ONU PMD transmit characteristics

Description	10GBASE –PR–U1	10GBASE –PR–U3	10GBASE –PR–U4	Unit
Signaling speed (range)	10.3125 ± 100 ppm			GBd
Wavelength (range)	1260 to 1280			nm
Side Mode Suppression Ratio (min)[a]	30			dB
Average launch power (max)	4	9	9	dBm
Average launch power (min)[b]	–1	4	6	dBm
Average launch power of OFF transmitter (max)	–45			dBm
Extinction ratio (min)	6			dB
$\mathrm{RIN}_{15}\mathrm{OMA}$ (max)	–128			dB/Hz
Launch OMA (min)[b]	–0.22 (0.95)	4.78 (3.01)	6.78 (4.77)	dBm (mW)
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}[c]	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}			UI
T_{on} (max)	512			ns
T_{off} (max)	512			ns
Optical return loss tolerance (max)	15			dB
Transmitter reflectance (max)	–10			dB
Transmitter and dispersion penalty (max)[d]	3	3	2	dB
Decision timing offset for transmitter and dispersion penalty	±0.0625			UI

[a] Transmitter is a single longitudinal mode device. Chirp is allowed such that the total optical path penalty does not exceed that found in Table 75B–2.

[b] Minimum average launch power and minimum launch OMA are valid for ER = 6 dB (see Figure 75–5 for details).

[c] As defined in Figure 75–6.

[d] If a transmitter has a lower TDP, the minimum transmitter launch OMA (OMA_{min}) and average minimum launch power (AVP_{min}) may be relaxed by the amount 3 dB – TDP for 10GBASE-PR-U1 and 10GBASE-PR-U3 and 2 dB – TDP for 10G-BASE-PR-U4.

The relationship between OMA, extinction ratio and average power is described in 58.7.6 and illustrated in Figure 75–5 for a compliant transmitter. Note that the OMA_{min} and AVP_{min} are calculated for ER = 6 dB. The transmitter average launch power specifications are further relaxed by allowing ER higher than 6 dB while maintaining the OMA_{min} constant. The shaded area indicates a compliant part.

Table 75–9—PRX type ONU PMD transmit characteristics

PMD type	Transmit parameters[a]	Reference
10/1GBASE–PRX–U1	same as 1000BASE–PX10–U transmit parameters	see Table 60–3
10/1GBASE–PRX–U2	same as 1000BASE–PX20–U transmit parameters	see Table 60–6
10/1GBASE–PRX–U3	same as 1000BASE–PX30–U transmit parameters	see Table 60–9
10/1GBASE–PRX–U4	same as 1000BASE–PX40–U transmit parameters	see Table 60–12

[a] Optical return loss of ODN (min) is informative for 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2, 10/1GBASE–PRX–U3, and 10/1GBASE–PRX–U4 PMDs.

The maximum RMS spectral width vs. wavelength for 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2 and 10/1GBASE–PRX–U3 PMDs are shown, respectively, in Table 60–4, Table 60–7, and Table 75–10. The equation used to generate these values is included in 60.9.2.

75.5.2 Receiver optical specifications

The signaling speed, operating wavelength, overload, stressed sensitivity, reflectance, and signal detect for receivers forming part of the 10/10G–EPON ONU and 10/1G–EPON ONU PMDs (as specified in 75.2) shall meet the specifications defined in Table 75–10 for Clause 75 ONU PMDs, per measurement techniques defined in 75.7. Their unstressed receive characteristics should meet the values listed in Table 75–10 per measurement techniques described in 75.7.11. Either the damage threshold included in Table 75–10 shall be met, or the receiver shall be labeled to indicate the maximum optical input power level to which it can be continuously exposed without damage.

The damage threshold included in Table 75–10 does not guarantee direct ONU–OLT connection, which may result in damage of the receiver. If direct ONU–OLT connection is necessary, optical attenuators and/or equivalent loss components should be inserted to decrease receive power below damage threshold.

Table 75–10—PR and PRX type ONU PMD receive characteristics

Description	10GBASE–PR–U1, 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2	10GBASE–PR–U3, 10/1GBASE–PRX–U3	10GBASE–PR–U4, 10/1GBASE–PRX–U4	Unit
Signaling speed (range)	10.3125 ± 100 ppm			GBd
Wavelength (range)	1575 to 1580			nm
Bit error ratio (max)[a]	10^{-3}			—
Average receive power (max)	0	–10	–9	dBm
Damage threshold (max)[b]	1	–9	–8	dBm
Receiver sensitivity (max)	–20.5	–28.5	–29.5	dBm
Receiver sensitivity OMA (max)	–18.59 (13.84)	–26.59 (2.19)	–27.59 (1.74)	dBm (μW)

Table 75–10—PR and PRX type ONU PMD receive characteristics *(continued)*

Description	10GBASE–PR–U1, 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2	10GBASE–PR–U3, 10/1GBASE–PRX–U3	10GBASE–PR–U4, 10/1GBASE–PRX–U4	Unit
Signal detect threshold (min)	–44			dBm
Receiver reflectance (max)	–12			dB
Stressed receive sensitivity (max)[c]	–19	–27	–28	dBm
Stressed receive sensitivity OMA (max)	–17.09 (19.55)	–25.09 (3.1)	–26.09 (2.46)	dBm (µW)
Vertical eye–closure penalty[d]	1.5			dB
Stressed eye jitter (min)	0.3			UI pk-pk
Jitter corner frequency for a sinusoidal jitter	4			MHz
Sinusoidal jitter limits for stressed receiver conformance test (min, max)	(0.05, 0.15)			UI

[a] The BER of 10^{-12} is achieved by the utilization of FEC as described in 76.3.
[b] Direct ONU–OLT connection may result in damage of the receiver.
[c] The stressed receiver sensitivity is mandatory over the entire PR–D transmitter compliance region, as illustrated in Figure 75–4.
[d] Vertical eye closure penalty and the jitter specifications are test conditions for measuring stressed receiver sensitivity. They are not required characteristics of the receiver.

75.6 Dual-rate (coexistence) mode

To support coexistence of 10G–EPON and 1G–EPON ONUs on the same outside plant, the OLT may be configured to use a dual-rate mode. Dual-rate mode supports transmission and/or reception of both 10 Gb/s and 1 Gb/s data rates, and can be introduced as options for 10G–EPON OLTs, functionally combining PMDs supporting 10 Gb/s and 1 Gb/s data rates.

Table 75–11 depicts PMD coexistence mapping for dual-rate mode options.

Table 75–11—PMD coexistence mapping for dual-rate mode option[a]

Direction of dual-rate operation	OLT PMD combination	ONU PMDs coexisting on the same ODN
Downstream	1000BASE–PX–D 10/1GBASE–PRX–D	(1) 1000BASE–PX–U (2) 10/1GBASE–PRX–U
Upstream	10GBASE–PR–D 10/1GBASE–PRX–D	(1) 10GBASE–PR–U (2) 10/1GBASE–PRX–U
Downstream and upstream	1000BASE–PX–D 10GBASE–PR–D	(1) 1000BASE–PX–U (2) 10/1GBASE–PRX–U (3) 10GBASE–PR–U

[a] Only PMDs with compatible power budgets can be connected to the same ODN.

75.6.1 Downstream dual-rate operation

When the downstream dual-rate operation is enabled, the OLT transmits both 10 Gb/s and 1 Gb/s downstream signals in a WDM manner. The OLT should meet both 10 Gb/s and 1 Gb/s specifications defined in Table 75–5 (10GBASE–PR–D transmit characteristics) and in Table 60–3, Table 60–6, Table 60–9, or Table 60–12 (1000BASE–PX–D transmit characteristics).

75.6.2 Upstream dual-rate operation

When the upstream dual-rate operation is enabled, the OLT receives both 10 Gb/s and 1 Gb/s upstream signals in a TDMA manner. Further implementation details are described in Annex 75A. The OLT should meet both 10 Gb/s and 1 Gb/s specifications defined in Table 75–6 (10GBASE–PR–D receive characteristics), and in Table 60–5, Table 60–8, Table 60–11, and Table 60–13 (1000BASE–PX–D receive characteristics).

NOTE—The damage threshold values in Table 60–5, Table 60–8, Table 60–11, and Table 60–13 are considerably higher than those in Table 75–6; the dual-rate PMD should be labeled appropriately.

75.7 Definitions of optical parameters and measurement methods

When measuring jitter at TP1 and TP5, it is recommended that jitter contributions at frequencies below receiver corner frequencies (i.e., 4 MHz for 10.3125 GBd receiver and 637 kHz for 1.25 GBd receiver) are filtered at the measurement unit. The following subclauses describe definitive patterns and test procedures for certain PMDs of this standard. Implementers using alternative verification methods should ensure adequate correlation and allow adequate margin such that specifications are met by reference to the definitive methods. All optical measurements, except TDP and $RIN_{15}OMA$ shall be made through a short patch cable between 2 m and 5 m in length.

75.7.1 Insertion loss

Insertion loss for SMF fiber optic cabling (channel) is defined at 1270 nm, 1310 nm, or 1577 nm, depending on the particular PMD. A suitable test method is described in ITU–T G.650.1.

75.7.2 Allocation for penalties in 10G–EPON PMDs

All the receiver types specified in Clause 75 are required to tolerate a path penalty not exceeding 1 dB to account for total degradations due to reflections, intersymbol interference, mode partition noise, laser chirp and detuning of the central wavelength, including chromatic dispersion penalty. All the transmitter types specified in Clause 75 introduce less than 1 dB of optical path penalty over the channel. The path penalty is a component of transmitter and dispersion penalty (TDP), which is specified in Table 75–5, Table 75–8, and Table 75–9 and described in 58.7.9.

75.7.3 Test patterns

Two types of test patterns are used for testing of 10 Gb/s optical PMDs: square wave (52.9.1.2) and patterns 1, 2, or 3 (52.9.1.1). These 10 Gb/s test patterns for 10GBASE–PR and 10/1GBASE–PRX are in Table 75–12. Two types of test frames [random and jitter (59.7.1)] are used for 1 Gb/s tests relevant to the 10/1GBASE–PRX PHY. All test patterns are listed in Table 75–12.

Table 75–12—Test patterns

Test	10 Gb/s pattern[a]	1 Gb/s pattern	Related subclause
Average optical power	1 or 3	Valid 8B/10B	75.7.5
OMA (modulated optical power)	Square	Idles	75.7.7
Extinction ratio	1 or 3	Idles	75.7.6
Transmit eye	1 or 3	Valid 8B/10B	75.7.7
$\mathrm{RIN}_{15}\mathrm{OMA}$	Square	Idles	75.7.8
Wavelength, spectral width	1 or 3	Valid 8B/10B	75.7.4
Side mode suppression ratio	1 or 3	Valid 8B/10B	—
VECP calibration	2 or 3	Jitter frame	75.7.12
Receiver sensitivity	1 or 3	Random frame	75.7.11
Receiver overload	1 or 3	Valid 8B/10B	—
Stressed receive sensitivity	2 or 3	Random frame	75.7.12
Transmitter and dispersion penalty	2 or 3	Random frame	75.7.10
Jitter	2 or 3	Jitter frame	75.7.13
Laser On/Off	1 or 3	Valid 8B/10B	75.7.14
Receiver settling	1 or 3	Valid 8B/10B	75.7.15

[a] Individual 10 Gb/s test patterns are described in 52.9.1.2 for a square wave and 52.9.1.1 for test patterns represented by numbers.

75.7.4 Wavelength and spectral width measurement

The center wavelength and spectral width (RMS) shall meet the specifications when measured according to TIA-455-127-A under modulated conditions using an appropriate PRBS or a valid 10GBASE–PR signal, 1000BASE–X signal, or another representative test pattern.

NOTE—The allowable range of central wavelengths is narrower than the operating wavelength range by the actual RMS spectral width at each extreme.

75.7.5 Optical power measurements

Optical power shall meet specifications according to the methods specified in ANSI/EIA-455-95. A measurement may be made with the port transmitting any valid encoded 8B/10B or 64B/66B data stream.

75.7.6 Extinction ratio measurements

The extinction ratio shall meet the specifications when measured according to IEC 61820-2-2 with the port transmitting a repeating idle pattern /I2/ ordered set (see 36.2.4.12) or valid 10GBASE–PR signal, and with minimal back reflections into the transmitter, lower than –20 dB. The test receiver has the frequency response as specified for the transmitter optical waveform measurement.

75.7.7 Optical modulation amplitude (OMA) test procedure

A description of OMA measurements for 1 Gb/s PHYs is found in 58.7.5. The OMA measurements for 10 Gb/s PHYs shall be compliant with the description found in 52.9.5.

75.7.8 Relative intensity noise optical modulation amplitude (RIN_xOMA) measuring procedure

This procedure describes a component test that may not be appropriate for a system level test depending on the implementation. If used, the procedure shall be performed as described in 52.9.6 for 10 Gb/s PHYs and in 58.7.7 for 1 Gb/s PHYs.

75.7.9 Transmit optical waveform (transmit eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 75–5 for upstream direction of 10/1GBASE–PRX PMD and Figure 75–6 for downstream direction of 10/1GBASE–PRX PMD and both directions of 10GBASE–PR PMD.

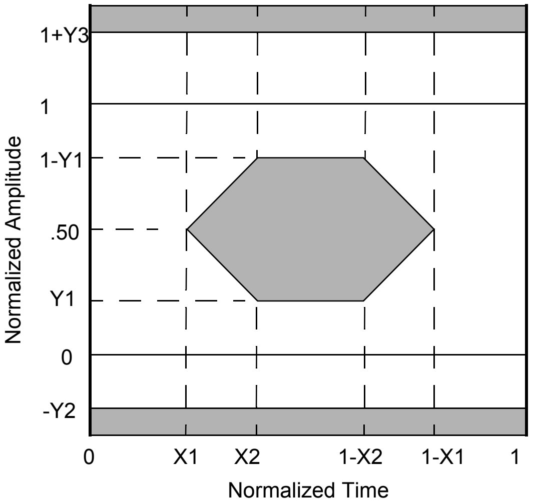


Figure 75–5—Transmitter eye mask definition for upstream direction of 10/1GBASE–PRX PMD

The measurement procedure is described in 58.7.8 for 1 Gb/s PHYs and 52.9.7 for 10 Gb/s PHYs and references therein. The eye shall comply to the mask of the eye using a fourth-order Bessel-Thomson receiver response as defined in 60.9.8 for 1 Gb/s PMD transmitters and 52.9.7 for 10 Gb/s PMD transmitters.

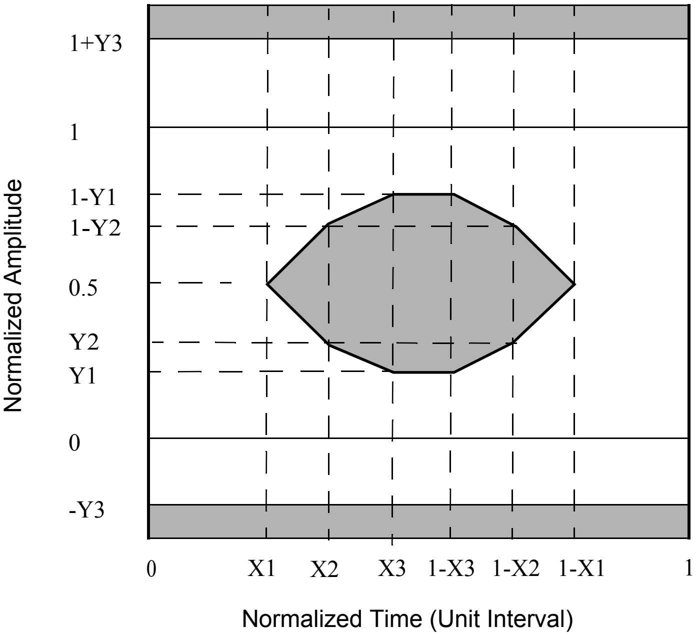


Figure 75–6—Transmitter eye mask definition for downstream direction of 10/1GBASE–PRX PMD and both directions of 10GBASE–PR PMD

75.7.10 Transmitter and dispersion penalty (TDP)

TDP measurement tests transmitter impairments, including chromatic dispersion effects, due to signal propagation in SMF used in PON. Possible causes of impairment include intersymbol interference, jitter, and RIN. Meeting the separate requirements (e.g., eye mask, spectral characteristics) does not in itself guarantee the TDP. The TDP limit shall be met. See 58.7.9 for details of the measurement for 1 Gb/s PHYs. For 10 Gb/s PHYs, TDP is measured as defined in 52.9.10 with an optical channel that meets the requirements listed in Table 75–13.

A 10 Gb/s transmitter is to be compliant with a total dispersion at least as negative as the “minimum dispersion” and at least as positive as the “maximum dispersion” columns specified in Table 75–13 for the wavelength of the device under test. This may be achieved with channels consisting of fibers with lengths chosen to meet the dispersion requirements.

75.7.11 Receive sensitivity

Receiver sensitivity is defined for the random pattern test frame, or test pattern 1, or test pattern 3, and an ideal input signal quality with the specified extinction ratio. The measurement procedure is described in 58.7.10 for 1 Gb/s PHYs and 52.9.8 for 10 Gb/s PHYs. The sensitivity shall be met for the bit error ratio defined in Table 75–6, Table 75–7, or Table 75–10 as appropriate.

75.7.12 Stressed receiver conformance test

Compliance with stressed receiver sensitivity is mandatory for the following PMDs: 10GBASE–PR–D1, 10GBASE–PR–D2, 10GBASE–PR–D3, 10GBASE–PR–D4, 10GBASE–PR–U1, 10GBASE–PR–U3, 10GBASE–PR–U4, 10/1GBASE–PRX–D3, 10/1GBASE–PRX–D4, 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2, 10/1GBASE–PRX–U3, and 10/1GBASE–PRX–U4. The stressed receiver conformance test is intended to screen against receivers with poor frequency response or timing characteristics that could cause errors when combined with a distorted but compliant signal. To be compliant with stressed receiver

Table 75–13—10 Gb/s transmitter compliance channel specifications

PMD type	Max reach L (km)	Dispersion[a] (ps/nm)		Insertion loss	Optical return loss (dB)
		Minimum	Maximum		
10GBASE–PR–D1 10/1GBASE–PRX–D1	10	0	$0.2325\,L\lambda[1-(1300/\lambda)^4]$	Minimum[b]	15
10GBASE–PR–D2 10GBASE–PR–D3 10GBASE–PR–D4 10/1GBASE–PRX–D2 10/1GBASE–PRX–D3 10/1GBASE–PRX–D4	20				
10GBASE–PR–U1	10	$0.2325\,L\lambda[1-(1324/\lambda)^4]$	0		
10GBASE–PR–U3 10GBASE–PR–U4	20				

[a] The dispersion is measured for the wavelength of the device under test (λ in nm).
[b] There is no intent to stress the sensitivity of the BERT's optical receiver.

sensitivity, the receiver shall meet the specified bit error ratio at the power level and signal quality defined in Table 75–6, Table 75–7, or Table 75–10 as appropriate, according to the measurement procedures of 58.7.11 for 1 Gb/s PHYs and 52.9.9 for 10 Gb/s PHYs.

75.7.13 Jitter measurements

Jitter measurements for 1 Gb/s are described in 58.7.12. Jitter measurements for 10 Gb/s are described in 52.8.1.

75.7.14 Laser on/off timing measurement

The laser on/off timing measurement procedure is described in 60.9.13.1 with the following changes:

a) T_{on} is defined in 60.9.13.1.1, and its value is less than 512 ns (defined in Table 75–8 and Table 75–9).
b) $T_{receiver\_settling}$ is defined in 60.9.13.2.1, and its value is defined in Table 75–6 and Table 75–7.
c) T_{CDR} is defined in 76.4.2.1, and its value is less than 400 ns.
d) $T_{code\_group\_align}$ is defined in 36.3.2.4, and its value is less than 4 ten bit code–groups for 1 Gb/s PHYs, and is defined as 0 for 10 Gb/s PHYs.
e) T_{off} is defined in 60.9.13.1.1, and its value is less than 512 ns (defined in Table 75–8 and Table 75–9).

75.7.15 Receiver settling timing measurement

75.7.15.1 Definitions

$T_{receiver\_settling}$ is denoted as the time beginning from the time that the optical power in the receiver at TP7 reaches the conditions specified in 75.7.12 and ending at the time that the electrical signal after the PMD at TP8 reaches within 15 % of its steady state parameter (average power, jitter) (see Table 75–6 for 10GBASE–PR–D1, 10GBASE–PR–D2, 10GBASE–PR–D3, and 10GBASE–PR–D4, and Table 75–7 for 10/1GBASE–PRX–D1, 10/1GBASE–PRX–D2, 10/1GBASE–PRX–D3, and 10/1GBASE–PRX–D4).

$T_{receiver\_settling}$ is presented in Figure 75–7. The data transmitted may be any valid 64B/66B symbols (or a specific power synchronization sequence). The optical signal at TP7, at the beginning of the locking, may have any valid 64B/66B pattern, optical power level, jitter, or frequency shift matching the standard specifications.

75.7.15.2 Test specification

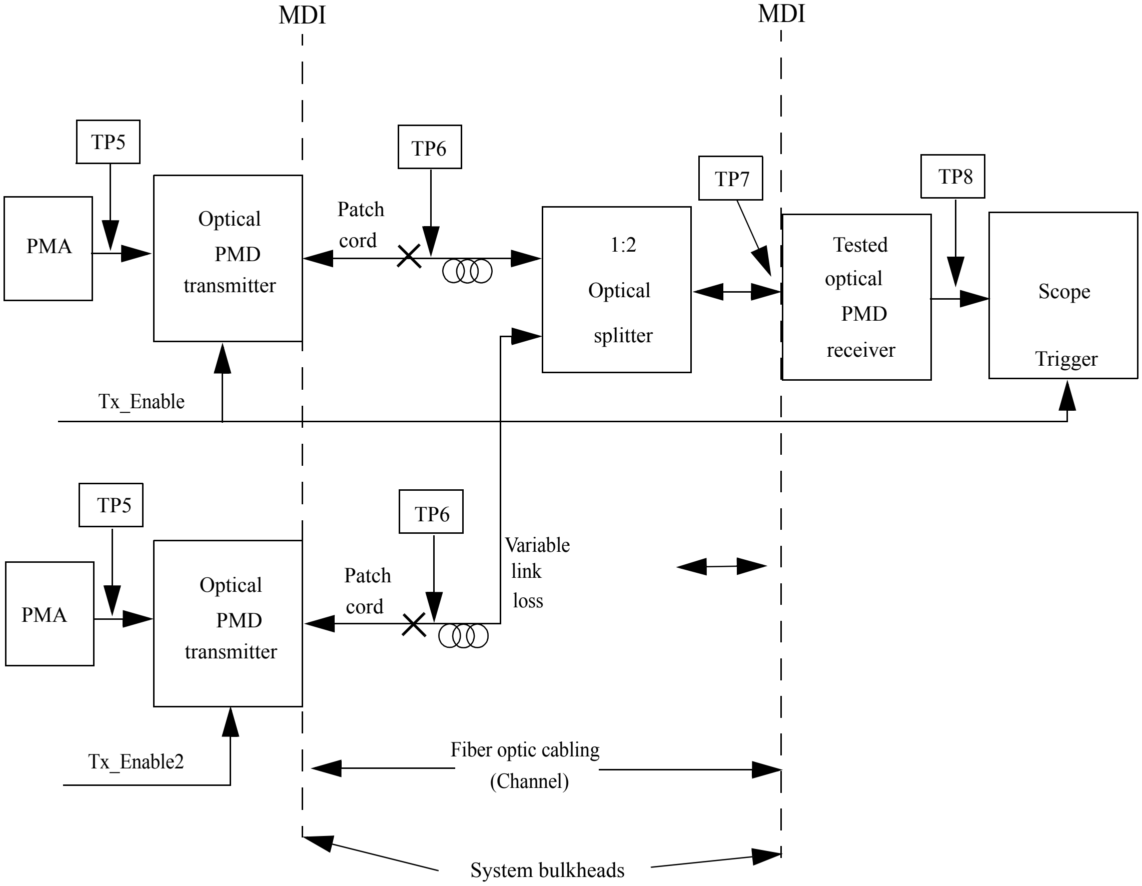


Figure 75–7—Receiver settling time measurement setup

Figure 75–7 illustrates the test setup for the OLT PMD receiver (upstream) $T_{receiver\_settling}$ time. The optical PMD transmitter has well–known parameters, with a fixed known T_{on} time. After T_{on} time the parameters of the reference transmitter, at TP6 and therefore at TP7, reach within 15% of its steady state values as specified in Table 75–8 for 10GBASE–PR–U1, 10GBASE–PR–U3, and 10GBASE–PR–U4 and Table 75–9 for 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2, 10/1GBASE–PRX–U3, and 10/1GBASE–PRX–U4.

Define $T_{receiver\_settling}$ time as the time from the Tx_Enable assertion, minus the known T_{on} time, to the time the electrical signal at TP8 reaches within 15% of its steady state conditions.

Conformance should be assured for an optical signal at TP7 with any level of its specified parameters before the Tx_Enable assertion. Especially the $T_{receiver\_settling}$ time must be met in the following scenarios:

— Switching from a 'weak' (minimal received power at TP7) ONU to a 'strong' (maximal received power at TP7) ONU, with minimal guard band between.
— Switching from a 'strong' ONU to a 'weak' ONU, with minimal guard band between.
— Switching from noise level, with maximal duration interval, to 'strong' ONU power level.

A non-rigorous way to describe this test setup would be (using a transmitter with a known T_{on}).

For a tested PMD receiver with a declared $T_{receiver\_settling}$ time, measure all PMD receiver electrical parameters at TP8 after $T_{receiver\_settling}$ from the TX_ENABLE trigger minus the reference transmitter T_{on}, reassuring conformance to within 15% of its specified steady state values.

75.8 Environmental, safety, and labeling

75.8.1 General safety

All equipment subject to this clause shall conform to IEC 60950–1.

75.8.2 Laser safety

10GBASE–PR and 10/1GBASE–PRX optical transceivers shall conform to Hazard Level 1 laser requirements as defined in IEC 60825–1 and IEC 60825–2, under any condition of operation. This includes single fault conditions whether coupled into a fiber or out of an open bore.

Conformance to additional laser safety standards may be required for operation within specific geographic regions.

Laser safety standards and regulations require that the manufacturer of a laser product provide information about the product’s laser, safety features, labeling, use, maintenance, and service. This documentation explicitly defines requirements and usage restrictions on the host system necessary to meet these safety certifications.

75.8.3 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulation, be followed in every instance in which such practices are applicable.

75.8.4 Environment

The 10GBASE–PR and 10/1GBASE–PRX operating environment specifications are as defined in 52.11, as defined in 52.11.1 for electromagnetic emission, and as defined in 52.11.2 for temperature, humidity, and handling.

See Annex 67A for additional environmental information. Two optional temperature ranges are defined in Table 60–18. Implementations shall be declared as compliant over one or both complete ranges, or not so declared (compliant over parts of these ranges or another temperature range).

75.8.5 PMD labeling

The 10GBASE–PR and 10/1GBASE–PRX labeling recommendations and requirements are as defined in 52.12.

Defined PMDs are as follows:

- 10/1GBASE–PRX–D1
- 10/1GBASE–PRX–D2
- 10/1GBASE–PRX–D3
- 10/1GBASE–PRX–D4
- 10GBASE–PR–D1
- 10GBASE–PR–D2

- — 10GBASE–PR–D3
- — 10GBASE–PR–D4
- — 10/1GBASE–PRX–U1
- — 10/1GBASE–PRX–U2
- — 10/1GBASE–PRX–U3
- — 10/1GBASE–PRX–U4
- — 10GBASE–PR–U1
- — 10GBASE–PR–U3
- — 10GBASE–PR–U4

Each field-pluggable component shall be clearly labeled with its operating temperature range over which compliance is ensured.

75.9 Characteristics of the fiber optic cabling

The 10GBASE–PR and 10/1GBASE–PRX fiber optic cabling shall meet the dispersion specifications defined in IEC 60793–2 and ITU–T G.652, or the requirements of Table 75–14 where they differ. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together. It also includes a connector plug at each end to connect to the MDI. The fiber optic cabling spans from one MDI to another MDI, as shown in Figure 75–3.

75.9.1 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 75–3.

NOTE—The optical splitter presented in Figure 75–3 may be replaced by a number of smaller 1:n splitters such that a different topology may be implemented while preserving the link characteristics and power budget as defined in Table 75B–1 and Table 75B–2.

The maximum channel insertion losses shall meet the requirements specified in Table 75–1. Insertion loss measurements of installed fiber cables are made in accordance with IEC 61280–4–2:2000. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term *channel* is used here for consistency with generic cabling standards.

75.9.2 Optical fiber and cable

The fiber optic cable requirements are satisfied by the fibers specified in IEC 60793–2 Type B1.1 (dispersion un–shifted SMF) and Type B1.3 (low water peak SMF), ITU–T G.652 and ITU–T G.657 (bend–insensitive SMF), or by the requirements of Table 75–14 where they differ.

75.9.3 Optical fiber connection

Table 75–14—Optical fiber and cable characteristics

Description[a]	IEC 60793–2 B1.1, B1.3 SMF, ITU–T G.652, G.657 SMF[b]				Unit
Nominal wavelength[c]	1270	1310	1550	1577	nm
Cable attenuation (max)[d]	0.44	0.4	0.35	0.35	dB/km
Zero dispersion wavelength[e]	$1300 \leq \lambda_0 \leq 1324$				nm
Dispersion slope (max)	0.093				$ps/nm^2 \cdot km$

[a] The fiber dispersion values are normative, all other values in the table are informative.
[b] Other fiber types are acceptable if the resulting ODN meets channel insertion loss and dispersion requirements.
[c] Wavelength specified is the nominal wavelength and typical measurement wavelength. Power penalties at other wavelengths are accounted for.
[d] Attenuation for single-mode optical fiber cables for 1310 nm and 1550 nm is defined in ITU–T G.652. The attenuation values in the 1270 nm and 1577 nm windows were calculated using spectral attenuation modelling method (5.4.4) included in G.650.1 and the matrix coefficients included in Appendix III therein. 1310 nm (0.4 dB/km), 1380 nm (0.5 dB/km) and 1550 nm (0.35 dB/km) attenuation values were used as the input for the predictor model.
[e] See IEC 60793 or ITU–T G.652.

An optical fiber connection as shown in Figure 75–3 consists of a mated pair of optical connectors. The 10GBASE–PR or 10/1GBASE–PRX PMD is coupled to the fiber optic cabling through an optical connection and any optical splitters into the MDI optical receiver, as shown in Figure 75–3. The channel insertion loss includes the loss for connectors, splices and other passive components such as splitters, see Table 75B–1 and Table 75B–2.

The channel insertion loss was calculated under the assumption of 14.5 dB loss for a 1:16 splitter/18.1 dB loss for a 1:32 splitter (ITU–T G.671 am 1). Unitary fiber attenuation for particular transmission wavelength is provided in Table 75–14. The number of splices/connectors is not predefined; the number of individual fiber sections between the OLT MDI and the ONU MDI is not defined. The only requirements are that the resulting channel insertion loss is within the limits specified in Table 75–1 and the maximum reach in Table 75–1 is not exceeded. Other fiber arrangements (e.g., increasing the split ratio while decreasing the fiber length) are supported as long as the limits for the channel insertion loss specified in Table 75–1 are observed.

The maximum discrete reflectance for single-mode connections shall be less than –26 dB.

75.9.4 Medium Dependent Interface (MDI)

The 10GBASE–PR or 10/1GBASE–PRX PMD is coupled to the fiber cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” as shown in Figure 75–3. Examples of an MDI include the following:

a) Connectorized fiber pigtail
b) PMD receptacle

When the MDI is a remateable connection, it shall meet the interface performance specifications of IEC 61753–1. The MDI carries the signal in both directions for 10GBASE–PR or 10/1GBASE–PRX PMD and couples to a single fiber.

NOTE—Compliance testing is performed at TP2 and TP3 as defined in 75.3.2, not at the MDI.

75.10 Protocol implementation conformance statement (PICS) proforma for Clause 75, Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX[32]

75.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 75, Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

75.10.2 Identification

75.10.2.1 Implementation identification

Supplier[1]	
Contact point for inquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1,3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

75.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 75, Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required?	No [ ] Yes [ ]
(See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[32] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

75.10.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
DTX	Transmit delay	75.3.1.1	Delay of 4 TQ (max) with variability 0.5 TQ (max)	M	Yes [ ]
DRX	Receive delay	75.3.1.1	Delay of 4 TQ (max) with variability 0.5 TQ (max)	M	Yes [ ]
HT	High temperature operation	75.8.4	–5 ºC to 85 ºC	O	Yes [ ] No [ ]
LT	Low temperature operation	75.8.4	–40 ºC to 60 ºC	O	Yes [ ] No [ ]
*PR10U	10GBASE–PR–U1 PHY or 10GBASE–PR–U1 PMD	75.5	Maximum channel insertion loss of 20 dB	O/1	Yes [ ] No [ ]
*PR10D	10GBASE–PR–D1 PHY or 10GBASE–PR–D1 PMD	75.4	Maximum channel insertion loss of 20 dB	O/1	Yes [ ] No [ ]
*PR20D	10GBASE–PR–D2 PHY or 10GBASE–PR–D2 PMD	75.4	Maximum channel insertion loss of 24 dB	O/1	Yes [ ] No [ ]
*PR30U	10GBASE–PR–U3 PHY or 10GBASE–PR–U3 PMD	75.5	Maximum channel insertion loss of 29 dB	O/1	Yes [ ] No [ ]
*PR30D	10GBASE–PR–D3 PHY or 10GBASE–PR–D3 PMD	75.4	Maximum channel insertion loss of 29 dB	O/1	Yes [ ] No [ ]
*PR40U	10GBASE–PR–U4 PHY or 10GBASE–PR–U4 PMD	75.5	Maximum channel insertion loss of 33 dB	O/1	Yes [ ] No [ ]
*PR40D	10GBASE–PR–D4 PHY or 10GBASE–PR–D4 PMD	75.4	Maximum channel insertion loss of 33 dB	O/1	Yes [ ] No [ ]
*PRX10U	10/1GBASE–PRX–U1 PHY or 10/1GBASE–PRX–U1 PMD	75.5	Maximum channel insertion loss of 20 dB	O/1	Yes [ ] No [ ]
*PRX10D	10/1GBASE–PRX–D1 PHY or 10/1GBASE–PRX–D1 PMD	75.4	Maximum channel insertion loss of 20 dB	O/1	Yes [ ] No [ ]
*PRX20U	10/1GBASE–PRX–U2 PHY or 10/1GBASE–PRX–U2 PMD	75.5	Maximum channel insertion loss of 24 dB	O/1	Yes [ ] No [ ]
*PRX20D	10/1GBASE–PRX–D2 PHY or 10/1GBASE–PRX–D2 PMD	75.4	Maximum channel insertion loss of 24 dB	O/1	Yes [ ] No [ ]
*PRX30U	10/1GBASE–PRX–U3 PHY or 10/1GBASE–PRX–U3 PMD	75.5	Maximum channel insertion loss of 29 dB	O/1	Yes [ ] No [ ]
*PRX30D	10/1GBASE–PRX–D3 PHY or 10/1GBASE–PRX–D3 PMD	75.4	Maximum channel insertion loss of 29 dB	O/1	Yes [ ] No [ ]
*PRX40U	10/1GBASE–PRX–U4 PHY or 10/1GBASE–PRX–U4 PMD	75.5	Maximum channel insertion loss of 33 dB	O/1	Yes [ ] No [ ]
*PRX40D	10/1GBASE–PRX–D4 PHY or 10/1GBASE–PRX–D4 PMD	75.4	Maximum channel insertion loss of 33 dB	O/1	Yes [ ] No [ ]
*INS	Installation/Cable	75.4.1	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer	O	Yes [ ] No [ ]

75.10.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX

75.10.4.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FN1	Transmit function	75.3.3	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FN2	Transmitter optical signal	75.3.3	Higher optical power transmitted is a logic 1	M	Yes [ ]
FN3	Receive function	75.3.4	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FN4	Receiver optical signal	75.3.4	Higher optical power received is a logic 1	M	Yes [ ]
FN5	ONU signal detect function	75.3.5.1	Mapping to PMD service interface	M	Yes [ ]
FN6	ONU signal detect parameter	75.3.5.1	Generated according to Table 75–4	M	Yes [ ]
FN7	OLT signal detect function	75.3.5.2	Mapping to PMD service interface	O/2	Yes [ ]
FN8	OLT signal detect function	75.3.5.2	Provided by higher layer	O/2	Yes [ ]
FN9	OLT signal detect parameter	75.3.5.1	Generated according to Table 75–4	O	Yes [ ]

75.10.4.2 PMD to MDI optical specifications for 10GBASE–PR–D1

Item	Feature	Subclause	Value/Comment	Status	Support
PRD1F1	10GBASE–PR–D1 transmitter	75.4.1	Meets specifications in Table 75–5	PR10D:M	Yes [ ] N/A [ ]
PRD1F2	10GBASE–PR–D1 receiver	75.4.2	Meets specifications in Table 75–6	PR10D:M	Yes [ ] N/A [ ]
PRD1F3	10GBASE–PR–D1 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–6 then label accordingly	PR10D:M	Yes [ ] N/A [ ]

75.10.4.3 PMD to MDI optical specifications for 10GBASE–PR–D2

Item	Feature	Subclause	Value/Comment	Status	Support
PRD2F1	10GBASE–PR–D2 transmitter	75.4.1	Meets specifications in Table 75–5	PR20D:M	Yes [ ] N/A [ ]
PRD2F2	10GBASE–PR–D2 receiver	75.4.2	Meets specifications in Table 75–6	PR20D:M	Yes [ ] N/A [ ]
PRD2F3	10GBASE–PR–D2 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–6 then label accordingly	PR20D:M	Yes [ ] N/A [ ]

75.10.4.4 PMD to MDI optical specifications for 10GBASE–PR–D3

Item	Feature	Subclause	Value/Comment	Status	Support
PRD3F1	10GBASE–PR–D3 transmitter	75.4.1	Meets specifications in Table 75–5	PR30D:M	Yes [ ] N/A [ ]
PRD3F2	10GBASE–PR–D3 receiver	75.4.2	Meets specifications in Table 75–6	PR30D:M	Yes [ ] N/A [ ]
PRD3F3	10GBASE–PR–D3 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–6 then label accordingly	PR30D:M	Yes [ ] N/A [ ]

75.10.4.5 PMD to MDI optical specifications for 10GBASE–PR–D4

Item	Feature	Subclause	Value/Comment	Status	Support
PRD4F1	10GBASE–PR–D4 transmitter	75.4.1	Meets specifications in Table 75–5	PR40D:M	Yes [ ] N/A [ ]
PRD4F2	10GBASE–PR–D4 receiver	75.4.2	Meets specifications in Table 75–6	PR40D:M	Yes [ ] N/A [ ]
PRD4F3	10GBASE–PR–D4 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–6 then label accordingly	PR40D:M	Yes [ ] N/A [ ]

75.10.4.6 PMD to MDI optical specifications for 10/1GBASE–PRX–D1

Item	Feature	Subclause	Value/Comment	Status	Support
PRXD1F1	10/1GBASE–PRX–D1 transmitter	75.4.1	Meets specifications in Table 75–5	PRX10D:M	Yes [ ] N/A [ ]
PRXD1F2	10/1GBASE–PRX–D1 receiver	75.4.2	Meets specifications in Table 75–7	PRX10D:M	Yes [ ] N/A [ ]
PRXD1F3	10/1GBASE–PRX–D1 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–7 then label accordingly	PRX10D:M	Yes [ ] N/A [ ]

75.10.4.7 PMD to MDI optical specifications for 10/1GBASE–PRX–D2

Item	Feature	Subclause	Value/Comment	Status	Support
PRXD2F1	10/1GBASE–PRX–D2 transmitter	75.4.1	Meets specifications in Table 75–5	PRX20D:M	Yes [ ] N/A [ ]
PRXD2F2	10/1GBASE–PRX–D2 receiver	75.4.2	Meets specifications in Table 75–7	PRX20D:M	Yes [ ] N/A [ ]
PRXD2F3	10/1GBASE–PRX–D2 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–7 then label accordingly	PRX20D:M	Yes [ ] N/A [ ]

75.10.4.8 PMD to MDI optical specifications for 10/1GBASE–PRX–D3

Item	Feature	Subclause	Value/Comment	Status	Support
PRXD3F1	10/1GBASE–PRX–D3 transmitter	75.4.1	Meets specifications in Table 75–5	PRX30D:M	Yes [ ] N/A [ ]
PRXD3F2	10/1GBASE–PRX–D3 receiver	75.4.2	Meets specifications in Table 75–7	PRX30D:M	Yes [ ] N/A [ ]
PRXD3F3	10/1GBASE–PRX–D3 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–7 then label accordingly	PRXD3F4:M	Yes [ ] N/A [ ]

75.10.4.9 PMD to MDI optical specifications for 10/1GBASE–PRX–D4

Item	Feature	Subclause	Value/Comment	Status	Support
PRXD4F1	10/1GBASE–PRX–D4 transmitter	75.4.1	Meets specifications in Table 75–5	PRX40D:M	Yes [ ] N/A [ ]
PRXD4F2	10/1GBASE–PRX–D4 receiver	75.4.2	Meets specifications in Table 75–7	PRX40D:M	Yes [ ] N/A [ ]
PRXD4F3	10/1GBASE–PRX–D4 receiver damage threshold	75.4.2	If the receiver does not meet the damage requirements in Table 75–7 then label accordingly	PRX40D:M	Yes [ ] N/A [ ]

75.10.4.10 PMD to MDI optical specifications for 10GBASE–PR–U1

Item	Feature	Subclause	Value/Comment	Status	Support
PRU1F1	10GBASE–PR–U1 transmitter	75.5.1	Meets specifications in Table 75–8	PR10U:M	Yes [ ] N/A [ ]
PRU1F2	10GBASE–PR–U1 receiver	75.5.2	Meets specifications in Table 75–10	PR10U:M	Yes [ ] N/A [ ]
PRU1F3	10GBASE–PR–U1 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PR10U:M	Yes [ ] N/A [ ]

75.10.4.11 PMD to MDI optical specifications for 10GBASE–PR–U3

Item	Feature	Subclause	Value/Comment	Status	Support
PRU3F1	10GBASE–PR–U3 transmitter	75.5.1	Meets specifications in Table 75–8	PR30U:M	Yes [ ] N/A [ ]
PRU3F2	10GBASE–PR–U3 receiver	75.5.2	Meets specifications in Table 75–10	PR30U:M	Yes [ ] N/A [ ]
PRU3F3	10GBASE–PR–U3 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PR30U:M	Yes [ ] N/A [ ]

75.10.4.12 PMD to MDI optical specifications for 10GBASE–PR–U4

Item	Feature	Subclause	Value/Comment	Status	Support
PRU4F1	10GBASE–PR–U4 transmitter	75.5.1	Meets specifications in Table 75–8	PR40U:M	Yes [ ] N/A [ ]
PRU4F2	10GBASE–PR–U4 receiver	75.5.2	Meets specifications in Table 75–10	PR40U:M	Yes [ ] N/A [ ]
PRU4F3	10GBASE–PR–U4 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PR40U:M	Yes [ ] N/A [ ]

75.10.4.13 PMD to MDI optical specifications for 10/1GBASE–PRX–U1

Item	Feature	Subclause	Value/Comment	Status	Support
PRXU1F1	10/1GBASE–PRX–U1 transmitter	75.5.1	Meets specifications in Table 75–9	PRX10U:M	Yes [ ] N/A [ ]
PRXU1F2	10/1GBASE–PRX–U1 receiver	75.5.2	Meets specifications in Table 75–10	PRX10U:M	Yes [ ] N/A [ ]
PRXU1F3	10/1GBASE–PRX–U1 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PRX10U:M	Yes [ ] N/A [ ]

75.10.4.14 PMD to MDI optical specifications for 10/1GBASE–PRX–U2

Item	Feature	Subclause	Value/Comment	Status	Support
PRXU2F1	10/1GBASE–PRX–U2 transmitter	75.5.1	Meets specifications in Table 75–9	PRX20U:M	Yes [ ] N/A [ ]
PRXU2F2	10/1GBASE–PRX–U2 receiver	75.5.2	Meets specifications in Table 75–10	PRX20U:M	Yes [ ] N/A [ ]
PRXU2F3	10/1GBASE–PRX–U2 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PRX20U:M	Yes [ ] N/A [ ]

75.10.4.15 PMD to MDI optical specifications for 10/1GBASE–PRX–U3

Item	Feature	Subclause	Value/Comment	Status	Support
PRXU3F1	10/1GBASE–PRX–U3 transmitter	75.5.1	Meets specifications in Table 75–9	PRX30U:M	Yes [ ] N/A [ ]
PRXU3F2	10/1GBASE–PRX–U3 receiver	75.5.2	Meets specifications in Table 75–10	PRX30U:M	Yes [ ] N/A [ ]
PRXU3F3	10/1GBASE–PRX–U3 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PRX30U:M	Yes [ ] N/A [ ]

75.10.4.16 PMD to MDI optical specifications for 10/1GBASE–PRX–U4

Item	Feature	Subclause	Value/Comment	Status	Support
PRXU4F1	10/1GBASE–PRX–U4 transmitter	75.5.1	Meets specifications in Table 75–9	PRX40U:M	Yes [ ] N/A [ ]
PRXU4F2	10/1GBASE–PRX–U4 receiver	75.5.2	Meets specifications in Table 75–10	PRX40U:M	Yes [ ] N/A [ ]
PRXU4F3	10/1GBASE–PRX–U4 receiver damage threshold	75.5.2	If the receiver does not meet the damage requirements in Table 75–10 then label accordingly	PRX40U:M	Yes [ ] N/A [ ]

75.10.4.17 Definitions of optical parameters and measurement methods

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Measurement cable	75.7.1	2 m to 5 m in length	M	Yes [ ]
OM2	Wavelength and spectral width	75.7.4	Per TIA–455–127–A under modulated conditions.	M	Yes [ ]
OM3	Average optical power	75.7.5	Per TIA/EIA–455–95.	M	Yes [ ]
OM4	Extinction ratio	75.7.6	Per ANSI/TIA/EIA–526–4A with minimal back reflections and fourth-order Bessel–Thomson receiver.	M	Yes [ ]
OM5	Optical modulation amplitude (OMA) test procedure	75.7.7	As described in 58.7.5 for 1 Gb/s PHY and in 52.9.5 for 10 Gb/s PHY.	M	Yes [ ]
OM6	$\mathrm{RIN_xOMA}$	75.7.8	As described in 58.7.7for 1 Gb/s PHY and in 52.9.6 for 10 Gb/s PHY	M	Yes [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
OM7	Transmit optical waveform (transmit eye)	75.7.9	Per ANSI/TIA/EIA–526–4A with test pattern and fourth-order Bessel–Thomson receiver.	M	Yes [ ]
OM8	Transmitter and dispersion penalty	75.7.10	As described in 58.7.7 for 1 Gb/s PHY and in 52.9.6 for 10 Gb/s PHY.	M	Yes [ ]
OM9	Receive sensitivity	75.7.11	As described in 58.7.10 for 1 Gb/s PHY and in 52.9.8 for 10 Gb/s PHY. Values defined in Table 75–6, Table 75–7, or Table 75–10 as appropriate.	M	Yes [ ]
*OM10	Stressed receiver conformance test	75.7.12	As described in 58.7.11 for 1 Gb/s PHY and in 52.9.9 for 10 Gb/s PHY. Values defined in Table 75–6, Table 75–7, or Table 75–10 as appropriate.	O	Yes[ ] N/A[ ]
OM11	Jitter measurements	75.7.13	As described in 58.7.12 for 1 Gb/s PHY and in 52.8.1 for 10 Gb/s PHY.	M	Yes [ ]
OM12	Laser On/Off timing measurement	75.7.14	As described in 60.9.13.1 for 1 Gb/s PHY and in 60.9.13.1 with modifications defined in 75.7.14 for 10 Gb/s PHY.	M	Yes [ ]
OM13	Receiver settling timing measurement	75.7.15	As described in 60.9.13.2 for 1 Gb/s and 10 Gb/s PHY.	O	Yes [ ] No [ ]

75.10.4.18 Characteristics of the fiber optic cabling and MDI

Item	Feature	Subclause	Value/Comment	Status	Support
FO1	Fiber optic cabling	75.9	Specified in Table 75–14	INS:M	Yes [ ] N/A[ ]
F02	End –to–end channel loss	75.9	Meeting the requirements of Table 75B–1 and Table 75B–2	INS:M	Yes [ ] N/A[ ]
FO3	Maximum discrete reflectance – single-mode fiber	75.9.3	Less than –26 dB	INS:M	Yes [ ] N/A [ ]
FO4	MDI requirements	75.9.4	Meet the interface performance specifications of IEC 61753–1, if remateable	INS:O	Yes [ ] No [ ] N/A [ ]

75.10.4.19 Environmental specifications

Item	Feature	Subclause	Value/Comment	Status	Support
ES1	General safety	75.8.1	Conforms to IEC–60950–1	M	Yes [ ]
ES2	Laser safety —IEC Hazard Level 1	75.8.1	Conform to Hazard Level 1 laser requirements defined in IEC 60825–1 and IEC 60825–2	M	Yes [ ]
ES3	Documentation	75.8.1	Explicitly defines requirements and usage restrictions to meet safety certifications	M	Yes [ ]
ES4	Operating temperature range labeling	75.8.5	If required	M	Yes [ ] N/A[ ]

76. Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for 10G-EPON

76.1 Overview

This clause describes the Reconciliation Sublayer (RS), Physical Coding Sublayer (PCS) with FEC, and Physical Medium Attachment (PMA) used with 10GBASE-PR and 10/1GBASE-PRX point-to-multipoint (P2MP) networks. These are passive optical multipoint networks (PONs) that connect multiple DTEs using a single shared fiber. The architecture is asymmetric, based on a tree and branch topology utilizing passive optical splitters. This type of network requires that the Multipoint MAC Control sublayer exists above the MACs, as described in Clause 77.

76.1.1 Conventions

The notation used in the state diagrams in this clause follows the conventions in 21.5. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation ++ after a counter indicates it is to be incremented by 1. The notation – – after a counter indicates it is to be decremented by 1. The notation –= after a counter indicates that the counter value is to be decremented by the following value. The notation += after a counter indicates that the counter value is to be incremented by the following value. Code examples given in this clause adhere to the style of the “C” programming language.

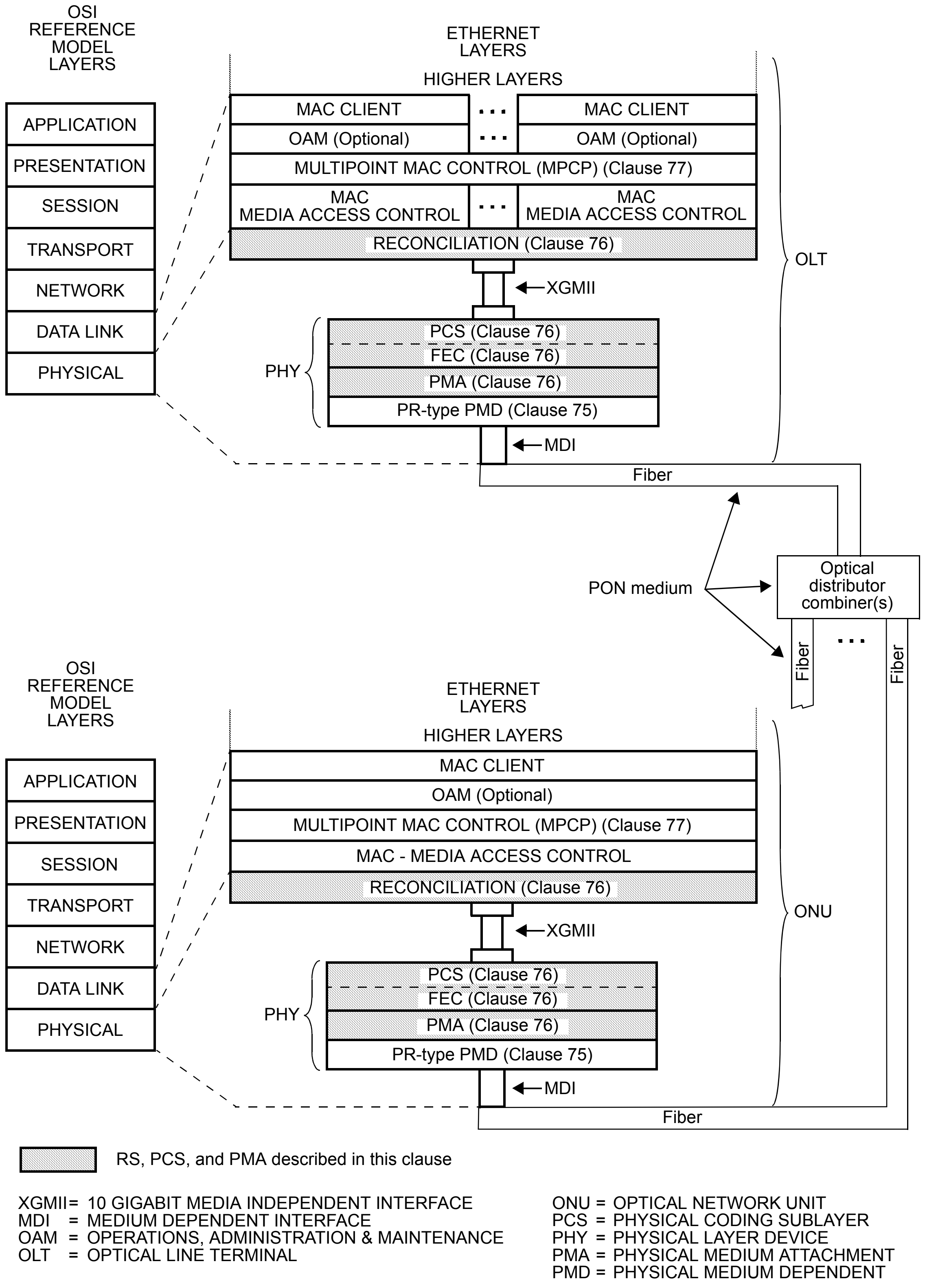
76.1.2 Delay constraints

The MPCP relies on strict timing based on the distribution of timestamps. The actual delay is implementation dependent but an implementation shall maintain a combined delay variation through RS, PCS, and PMA sublayers of no more than 1 time_quantum (see 77.2.2.1) so as not to interfere with the MPCP timing.

76.2 Reconciliation Sublayer (RS) for 10G-EPON

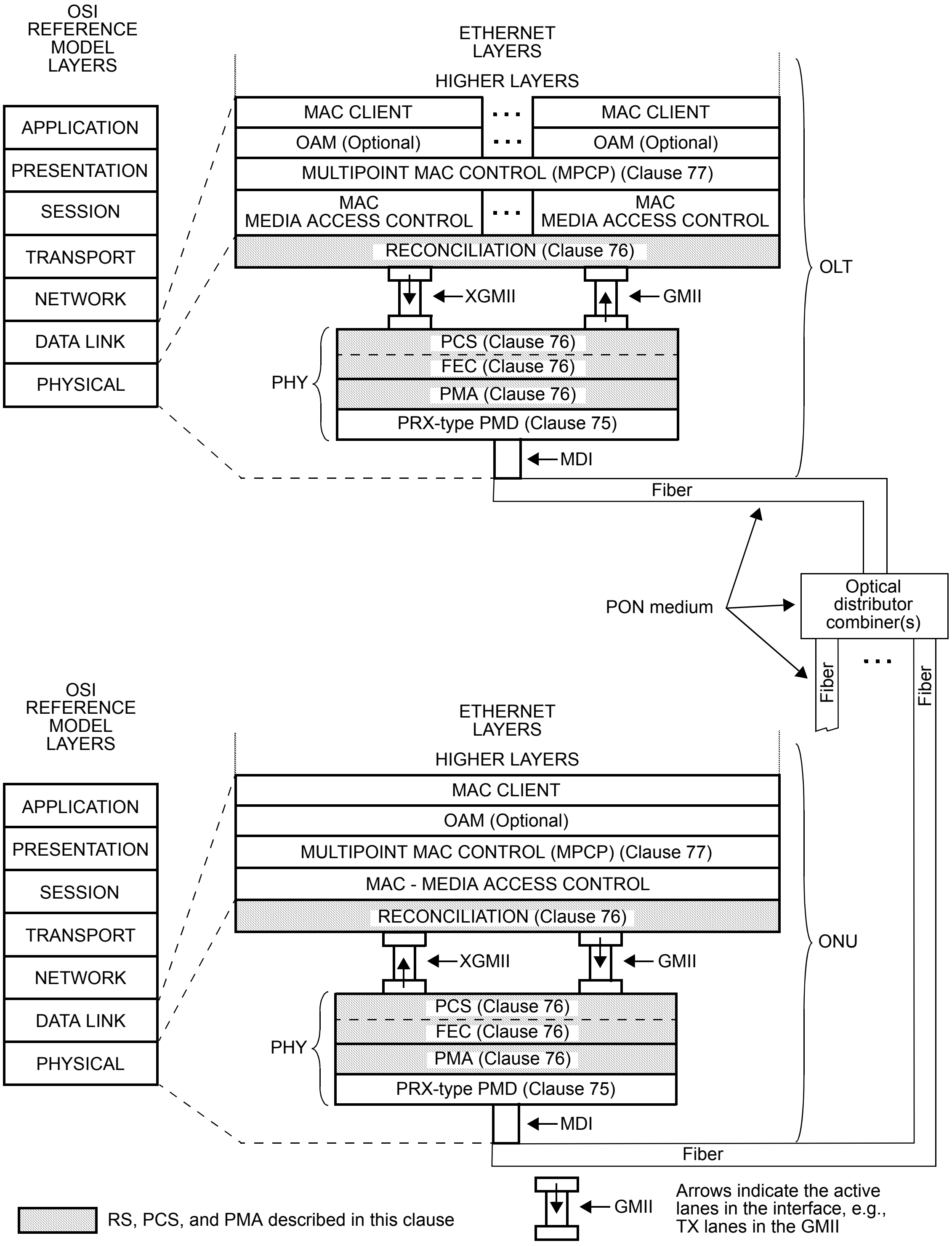
76.2.1 Overview

This subclause extends Clause 46 to enable multiple MACs to interface with a single Physical Layer, and to enable data links with one data rate (e.g., 10 Gb/s) in one direction but another (e.g., 1 Gb/s) in the opposite direction. The number of MACs supported is limited only by the implementation. It is acceptable for only one MAC to be connected to this Reconciliation Sublayer. Figure 76–1 and Figure 76–2 show the relationship between this RS and the ISO/IEC OSI reference model. The mapping of GMII/XGMII signals to PLS service primitives is described in 35.2.1 for GMII and 46.1.7 for XGMII with exceptions noted herein.



XGMII= 10 GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION & MAINTENANCE
OLT = OPTICAL LINE TERMINAL
ONU = OPTICAL NETWORK UNIT
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 76–1—Relationship of 10/10G-EPON P2MP RS, PCS, and PMA to the ISO/IEC OSI reference model and the IEEE 802.3 Ethernet model



XGMII= 10 GIGABIT MEDIA INDEPENDENT INTERFACE
GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION & MAINTENANCE
OLT = OPTICAL LINE TERMINAL

ONU = OPTICAL NETWORK UNIT
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 76–2—Relationship of 10/1G-EPON P2MP RS, PCS, and PMA to the ISO/IEC OSI reference model and the IEEE 802.3 Ethernet model

76.2.2 Dual-speed Media Independent Interface

In 1G-EPON architectures, the GMII is the interface used to transfer data between the RS and the PCS. For 10/10G-EPON architectures, the XGMII is the interface used to transfer data between the RS and the PCS. When using a 10/1G-EPON architecture, a combination of both GMII and XGMII is needed in order to support transmission and reception at different speeds. Through the parallel use of the GMII and XGMII, the following modes are supported:

- Symmetric-rate 10 Gb/s operation for transmit and receive data paths, utilizing all of the functionality of the XGMII defined in Clause 46.
- Symmetric-rate 1 Gb/s operation for transmit and receive data paths, utilizing all of the functionality of the GMII defined in Clause 35.
- Asymmetric-rate operation for transmit and receive data paths at the OLT, utilizing transmit path functionality of the XGMII defined in Clause 46 and receive path functionality of the GMII defined in Clause 35.
- Asymmetric-rate operation for transmit and receive data paths at the ONU, utilizing transmit path functionality of the GMII defined in Clause 35 and receive path functionality of the XGMII defined in Clause 46.
- Coexistence of various ONU types by utilizing different data paths within the OLT.

76.2.2.1 10/10G-EPON

Figure 76–3(a) depicts the data paths used in 10/10G-EPON.

76.2.2.2 10/1G-EPON

At the OLT, the transmit path uses XGMII signals TXD<31:0>, TXC<3:0> and TX_CLK, while the receive path uses GMII signals RXD<7:0>, RX_ER, RX_CLK, and RX_DV. At the ONU, the transmit path uses GMII signals TXD<7:0>, TX_EN, TX_ER, and GTX_CLK, while the receive path uses XGMII signals RXD<31:0>, RXC<3:0> and RX_CLK.

Figure 76–3(b) depicts the data paths used in 10/1G-EPON.

76.2.2.3 Dual-rate mode

To support coexistence of 10/10G-EPON, 10/1G-EPON, and 1G-EPON ONUs on the same outside plant, the OLT may optionally support dual-rate mode. Dual-rate mode supports transmission and reception at both 10 Gb/s and 1 Gb/s. When operating in a dual-rate mode, a combination of XGMII and GMII data paths are used for transmission and reception. Figure 76–4 depicts the data paths used in an OLT operating in a dual-rate mode.

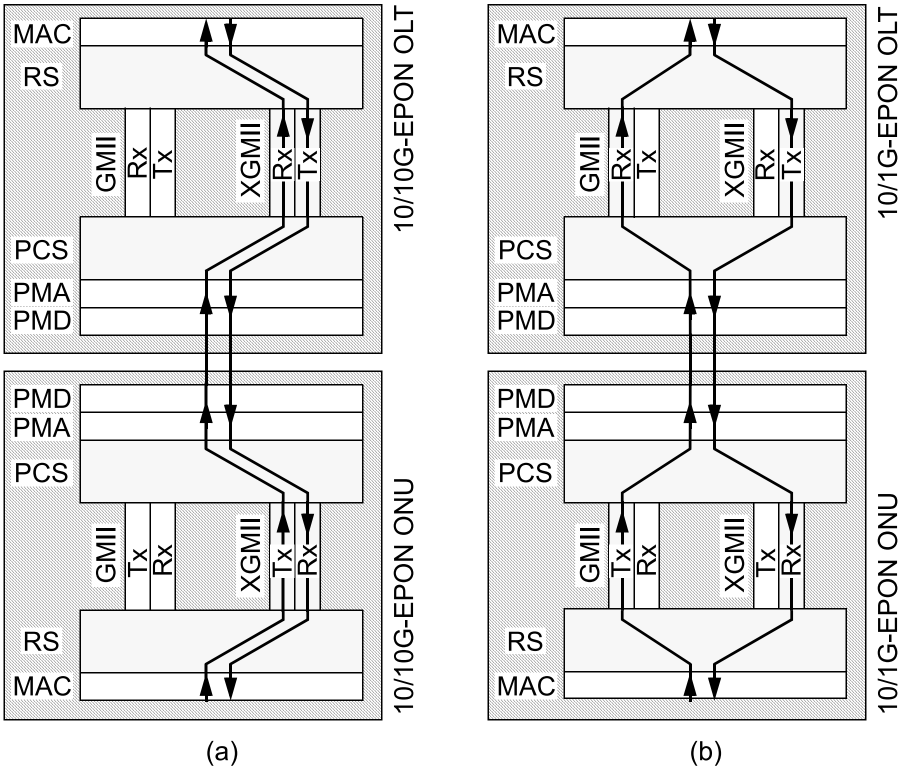


Figure 76–3—10/10G-EPON (a) and 10/1G-EPON (b) operation of OLT and ONU

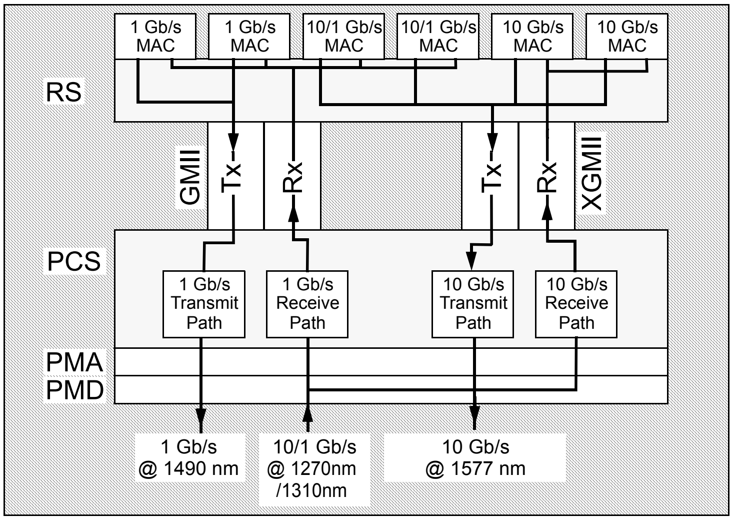


Figure 76–4—PCS and Reconciliation Sublayer for dual rate mode at OLT

76.2.2.4 Mapping of XGMII and GMII primitives

The mapping of XGMII/GMII signals to the PLS_DATA.request and PLS_DATA.indication primitives is described in 76.2.6. Additional details are provided in Table 76–1, which shows the mapping of PLS_-DATA.request primitives to transmit interface signals for different types of OLTs and ONUs. Table 76–2 shows the mapping of PLS_DATA.indication primitives to receive interface signals for different types of OLTs and ONUs.

76.2.3 Summary of major concepts

A successful registration process, described in 77.3.3, results in the assignment of values to the MODE and LLID variables associated with a MAC. This may be one of many MACs in an OLT or a single MAC in an ONU. The MODE and LLID variables are used to identify a packet transmitted from that MAC and how received packets are directed to that MAC. The RS in the OLT shall operate in unidirectional mode as defined in 66.4.

As described in 77.1.2, multiple MACs within an OLT are bound to a single XGMII in the case of a 10/10G-EPON OLT, or to an XGMII transmit path and a GMII receive path in the case of a 10/1G-EPON OLT. Only one PLS_DATA.request primitive is active at any time.

At the ONU, the MAC is either bound to an XGMII in the case of a 10/10G-EPON ONU, or to an XGMII receive path and a GMII transmit path in case the of an 10/1G-EPON ONU.

In the transmit direction, the RS maps the active PLS_DATA.request to either the GMII signals (TXD<7:0>, TX_EN, TX_ER, and GTX_CLK) or the XGMII signals (TXD<31:0>, TXC<3:0>, and TX_CLK) according to the MAC instance generating the request. The RS replaces octets of preamble with the values of the transmitting MAC's MODE and LLID variables.

In the receive direction, the MODE and LLID values embedded within the preamble identify the MAC to which this packet should be directed. The RS establishes a temporal mapping of either the GMII signals (RXD<7:0>, RX_ER, RX_CLK, and RX_DV) or the XGMII signals (RXD<31:0>, RXC<3:0> and RX_CLK) to the correct PLS_DATA.indication and PLS_DATA_VALID.indication primitives.

76.2.3.1 Application

This subclause applies to the interface between the MAC and PHY in an OLT or an ONU. The physical implementation of the interface is primarily intended to be chip-to-chip, but may also be used as a logical interface between ASIC logic modules within an integrated circuit. These interfaces are used to provide media independence, so that an identical media access controller may be used with all 10GBASE-PR and 10/1GBASE-PRX PHY types.

76.2.4 GMII structure

See Clause 35.

76.2.5 XGMII structure

The XGMII structure is discussed in 46.1.6, and Figure 46–2 depicts a schematic view of the RS inputs and outputs.

76.2.6 Mapping of XGMII and GMII signals to PLS service primitives

Except as noted in Table 76–1 and Table 76–2, the mapping of the signals provided at the XGMII to the PLS service primitives is defined in 46.1.7.

Table 76–1—Mapping of PLS_DATA.request primitive

MAC location	MAC operating speed	Transmit interface	Signals
OLT	1G-EPON (Tx: 1 Gb/s)	GMII	TXD<7:0>, TX_EN, TX_ER, GTX_CLK
OLT	10/10G-EPON (Tx: 10 Gb/s)	XGMII	TXD<31:0>, TXC<3:0>, TX_CLK
OLT	10/1G-EPON (Tx: 10 Gb/s)	XGMII	TXD<31:0>, TXC<3:0>, TX_CLK
ONU	1G-EPON (Tx: 1 Gb/s)	GMII	TXD<7:0>, TX_EN, TX_ER, GTX_CLK
ONU	10/10G-EPON (Tx: 10 Gb/s)	XGMII	TXD<31:0>, TXC<3:0>, TX_CLK
ONU	10/1G-EPON (Tx: 1 Gb/s)	GMII	TXD<7:0>, TX_EN, TX_ER, GTX_CLK

Table 76–2—Mapping of PLS_DATA.indication primitive

MAC location	MAC operating speed	Receive interface	Signals
OLT	1G-EPON (Rx: 1 Gb/s)	GMII	RXD<7:0>, RX_ER, RX_DV, RX_CLK
OLT	10/10G-EPON (Rx: 10 Gb/s)	XGMII	RXD<31:0>, RXC<3:0>, RX_CLK
OLT	10/1G-EPON (Rx: 1 Gb/s)	GMII	RXD<7:0>,RX_ER,RX_DV,RX_CLK
ONU	1G-EPON (Rx: 1 Gb/s)	GMII	RXD<7:0>, RX_ER, RX_DV, RX_CLK
ONU	10/10G-EPON (Rx: 10 Gb/s)	XGMII	RXD<31:0>, RXC<3:0>, RX_CLK
ONU	10/1G-EPON (Rx: 10 Gb/s)	XGMII	RXD<31:0>, RXC<3:0>, RX_CLK

76.2.6.1 Functional specifications for multiple MACs

76.2.6.1.1 Variables

The variables of 65.1.3.1 are inherited except as shown below.

logical_link_id
Value: 15 bits
This variable shall be set to the broadcast value of 0x7FFE for the unregistered ONU MAC.
Enabled OLT MACs may use any value for this variable. If the optional multicast LLID feature is supported, the OLT may use a multicast_link_id along with the mode bit set to 0.
Registered ONU MACs may use any value other than the reserved values listed in Table 76–4 or a multicast_link_id for this variable.

76.2.6.1.2 RS Transmit function

The transmit function is described in 65.1.3.2 except as noted below in Table 76–3, which shows the replacement mapping for 10G-EPON. The XGMII transmit function is described in 46.3.1.

Table 76–3—Preamble/SFD replacement mapping

Column	Lane	Field	Preamble/SFD	Modified preamble/SFD
0	0	—	0x55	Same
	1	—	0x55	Same
	2	SLD	0x55	0xd5
	3	—	0x55	Same
1	0	—	0x55	Same
	1	LLID[15:8]	0x55	<mode, logical_link_id[14:8]>[a]
	2	LLID[7:0]	0x55	<logical_link_id[7:0]>[b]
	3	CRC8	0xd5	The 8 bit CRC calculated over column 0 lane 2 through column 1 lane 2

[a] mode maps to TXD[15], logical_link_id[14] maps to TXD[14], logical_link_id[8] maps to TXD[8].
[b] logical_link_id[7] maps to TXD[23], logical_link_id[0] maps to TXD[16].

76.2.6.1.3 RS Receive function

The receive function is described in 65.1.3.3 except as noted below.

Table 65–2 is not applicable to 10G-EPON.

76.2.6.1.3.1 SLD

The 10 Gb/s RS transmit function maintains an alignment for its start control character to lane 0. The SLD is transmitted as the third octet and therefore is aligned to lane 2 in the same column containing the start control character. This is the only possibility considered when parsing the incoming octet stream for the SLD. If the SLD field is not found then the packet shall be discarded. If the packet is transferred, the SLD shall be replaced with a normal preamble octet and the two octets preceding the SLD and the one octet following the SLD are passed without modification. See Table 76–3.

76.2.6.1.3.2 LLID

This subclause supersedes the stipulations of 65.1.3.3.2.

The third and fourth octets following the SLD contain the mode and logical_link_id values. OLTs and ONUs act upon these values in a different manner.

If the device is an OLT, then the following comparison is made:

a) The received mode bit is ignored.
b) If the received logical_link_id value matches 0x7FFF or 0x7FFE and an enabled MAC exists with a logical_link_id variable with the same value, then the comparison is considered a match to that MAC.
c) If the received logical_link_id has a value other than 0x7FFF or 0x7FFE and an enabled MAC exists with a mode variable with a value of 0 and a logical_link_id variable matching the received logical_link_id value, then the comparison is considered a match to that MAC.

If the device is an ONU then the following comparison is made:

d) If the received mode bit is equal to 0 and the received logical_link_id value matches the logical_link_id variable, then the comparison is considered a match.

e) If the received mode bit is equal to 1 and the received logical_link_id value does not match the logical_link_id variable, or the received logical_link_id matches 0x7FFE, then the comparison is considered a match.
f) If the received logical_link_id value matches one of the assigned multicast LLIDs, then the comparison is considered a match.

If no match is found, then the packet shall be discarded within the RS. If a match is found, then the packet is intended to be transferred. If the packet is transferred, then both octets of the LLID field shall be replaced with normal preamble octets.

If the packet is transferred, the one octet preceding the LLID is passed without modification. A number of LLIDs have been reserved (see Figure 76–4) for various purposes including downstream broadcast, discovery messages, and upstream registration request messages. An additional block of LLIDs has been set aside for future use and definition. A registered ONU shall not transmit frames with one of these reserved LLIDs.

Table 76–4—Reserved LLID values

LLID value	Used in RS	Purpose
0x7FFF	1000BASE-PX	Downstream: 1 Gb/s SCB Upstream: ONU registration at 1 Gb/s
0x7FFE	10/1GBASE-PRX	Downstream: 10 Gb/s SCB Upstream: ONU registration at 1 Gb/s
	10GBASE-PR	Downstream: 10 Gb/s SCB Upstream: ONU registration at 10 Gb/s
0x7FFD–0x7F00	—	Reserved for future use

76.2.6.1.3.3 CRC-8

The CRC-8 field is as described in 65.1.3.3.3.

76.3 Physical Coding Sublayer (PCS) for 10G-EPON

76.3.1 Overview

This subclause defines the physical coding sublayers 10GBASE-PR and 10/1GBASE-PRX, supporting burst mode operation over the point-to-multipoint physical medium. The 10GBASE-PR PCS is specified to support 10/10G EPON, where both the receive and transmit paths operate at 10 Gb/s rate. The 10/1GBASE-PRX PCS supports 10/1G-EPON, in which OLT transmit path and ONU receive path operate at 10 Gb/s, while the ONU transmit path and the OLT receive path operate at 1 Gb/s rate.

This subclause also specifies a forward error correction (FEC) mechanism to increase the optical link budget or the fiber distance. Figure 76–1 and Figure 76–2 show the relationship between the PCS sublayer and the ISO/IEC OSI reference model.

76.3.1.1 10/1GBASE-PRX PCS

Conceptually, the 10/1GBASE-PRX PCS represents a combination of transmit and receive functions defined in the 10GBASE-PR PCS (specified in this clause) and the 1000BASE-PX PCS (specified in Clause 65). At the OLT, the 10/1GBASE-PRX consists of the 10GBASE-PR transmit function and the 1000BASE-PX receive function (see Figure 76–5). Reciprocally, at the ONU, the 10/1GBASE-PRX PCS consists of the 10GBASE-PR receive function and the 1000BASE-PX transmit function (see Figure 76–6).

Deriving a specification for the 10/1GBASE-PRX PCS from the 10GBASE-PR PCS and the 1000BASE-PX PCS specifications as described previously is a straightforward process; therefore, no further explicit specification for the 10/1GBASE-PRX PCS is necessary.

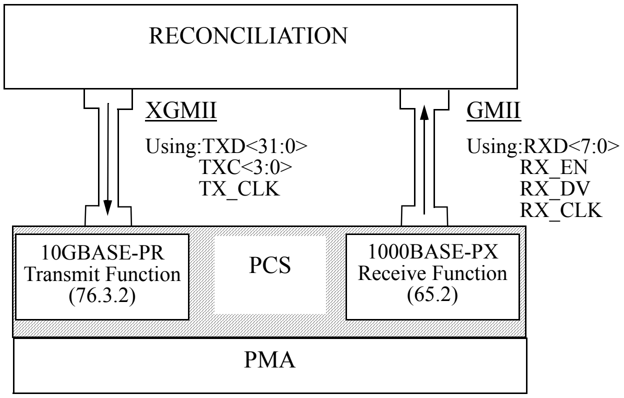


Figure 76–5—Conceptual diagram of 10/1GBASE-PRX PCS, OLT Side

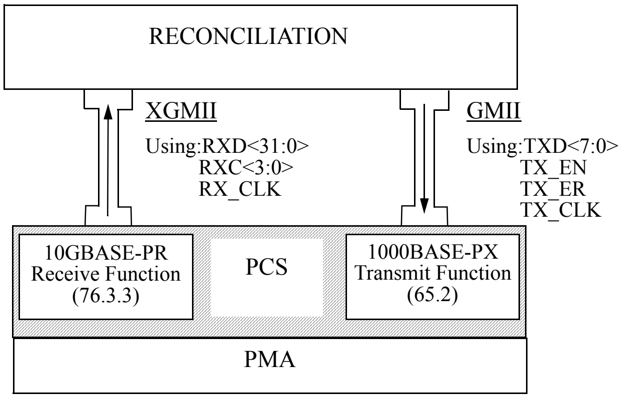


Figure 76–6—Conceptual diagram of 10/1GBASE-PRX PCS, ONU Side

76.3.1.2 10GBASE-PR PCS

The 10GBASE-PR PCS extends the physical coding sublayer described in Clause 49 to support burst mode operation over the point-to-multipoint physical medium. Figure 76–7 illustrates the functional block diagram of the downstream path and Figure 76–8 shows the functional block diagram of the upstream path.

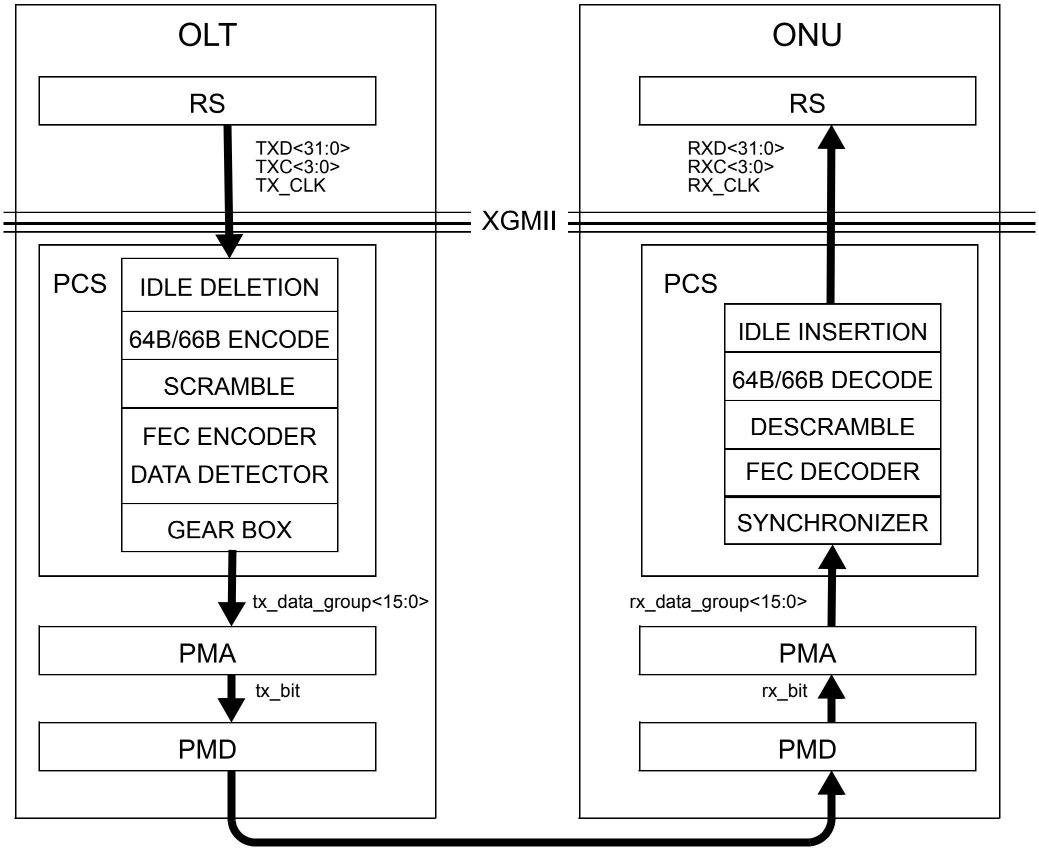


Figure 76–7—PCS functional block diagram, downstream path

76.3.2 PCS transmit function

This subclause defines the transmit direction of the physical coding sublayers for 10GBASE-PR and 10/1GBASE-PRX. In the OLT, the PCS transmit function operates at a 10 Gb/s rate in a continuous mode. In the ONU, the PCS transmit function may operate at a 10 Gb/s rate, as specified herein (10GBASE-PR), or at a 1 Gb/s rate, as specified in Clause 65 (10/1GBASE-PRX). For both 10GBASE-PR and 10/1GBASE-PRX, the ONU PCS always operates in a burst mode in the transmit direction. When operating at the 10 Gb/s rate, the PCS includes a mandatory FEC encoder. Figure 76–7 illustrates the transmit direction of OLT PCS. Figure 76–8 illustrates the transmit direction of the ONU PCS.

76.3.2.1 Idle control character deletion

The Idle Deletion process is responsible for deleting excess Idle characters to allow the parity data to be inserted without increasing the PMD line rate. This process deletes four 72 bit vectors containing Idle characters per every thirty-one 72 bit vectors received from the XGMII. The MPCP function ensures that sufficient Idle characters occur so that the minimum IPG is always preserved between two adjacent packets.

The Idle Deletion process is depicted in Figure 76–9 for OLTs and in Figure 76–10 for ONUs.

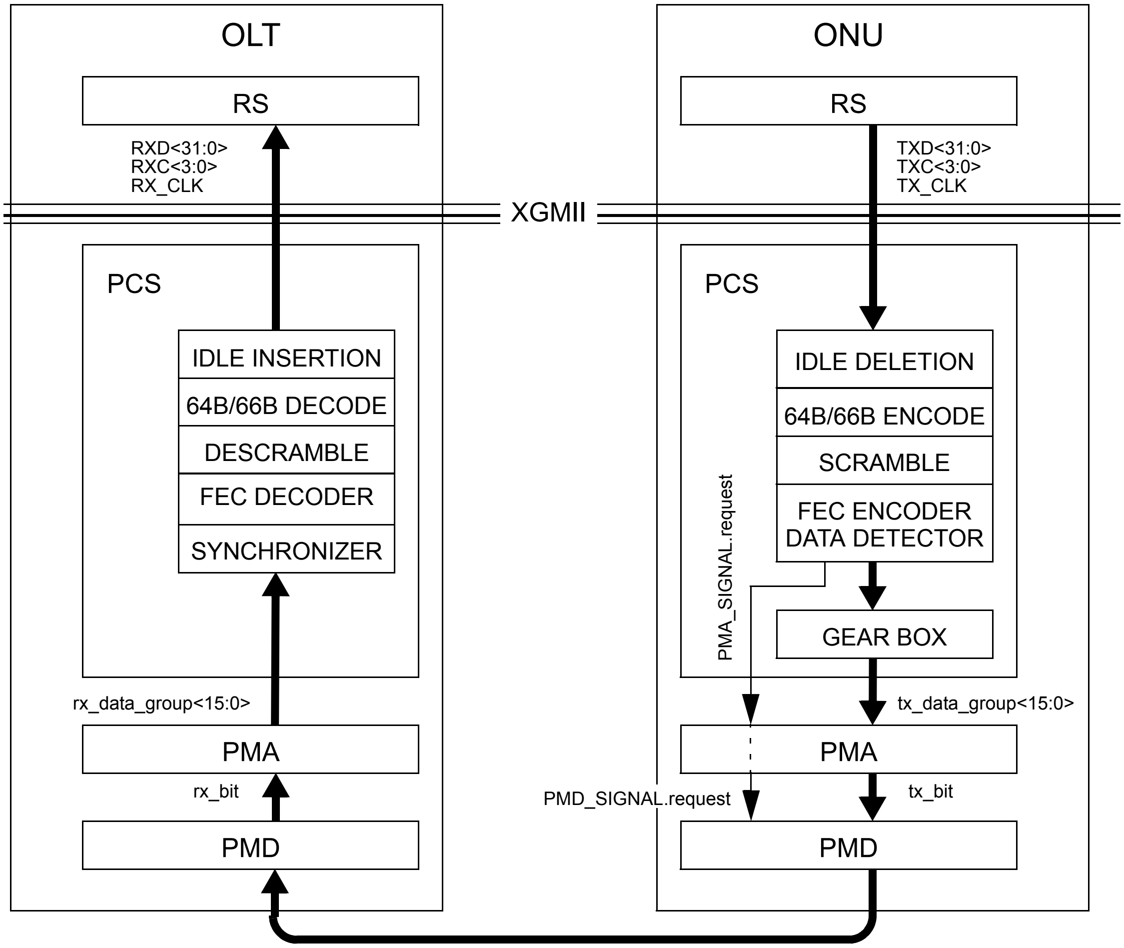


Figure 76–8—PCS functional block diagram, upstream path

76.3.2.1.1 Constants

FEC_DSize
TYPE: 16 bit unsigned
The number of 72 bit vectors constituting a payload of a FEC codeword. To normalize pre-FEC data rate, the Idle Deletion function removes FEC_PSize vectors per every FEC_DSize vectors transferred to the 64B/66B encoder.
Value: 27

FEC_PSize
TYPE: 16 bit unsigned
The number of 72 bit vectors constituting parity portion of a FEC codeword. To normalize pre-FEC data rate, the Idle Deletion function removes FEC_PSize vectors per every FEC_DSize vectors transferred to the 64B/66B encoder.
Value: 4

76.3.2.1.2 Variables

BEGIN
TYPE: Boolean

This variable is used when initiating operation of the state diagram. It is set to true following initialization and every reset.

DelayBound

TYPE: 16 bit unsigned

This value represents the delay sufficient to initiate the laser and to stabilize the receiver at the OLT (i.e., the maximum FIFO size expressed in 66 bit blocks). The value includes LaserOnTime (77.3.3.2), $T_{receiver\_settling}$, T_{CDR}, Burst Delimiter, and the two 66 bit blocks containing Idles, that precede the first packet in the burst. This variable is used only by the ONU.

tx_raw<71:0>

This variable is defined in 49.2.13.2.2.

tx_raw_out<71:0>

72 bit vector sent from the output of the Idle Deletion function to the 64B/66B encoder. The vector contains two XGMII transfers mapped as shown for tx_raw<71:0>.

76.3.2.1.3 Functions

T_TYPE(tx_raw<71:0>)

This function is defined in 49.2.13.2.3.

76.3.2.1.4 Counters

DelCount

TYPE: 16 bit unsigned

Counts the number of 72 bit vectors that need to be deleted.

IdleCount

TYPE: 16 bit unsigned

Counts the number of 72 bit vectors containing Idle control characters or other control vectors.

VectorCount

TYPE: 16 bit unsigned

Counts the number of 72 bit vectors transmitted.

76.3.2.1.5 State diagrams

The OLT PCS shall perform the Idle Deletion process as shown in Figure 76–9. The ONU PCS shall perform the Idle Deletion process as shown in Figure 76–10. Should there be a discrepancy between a state diagrams and descriptive text, the state diagrams prevail.

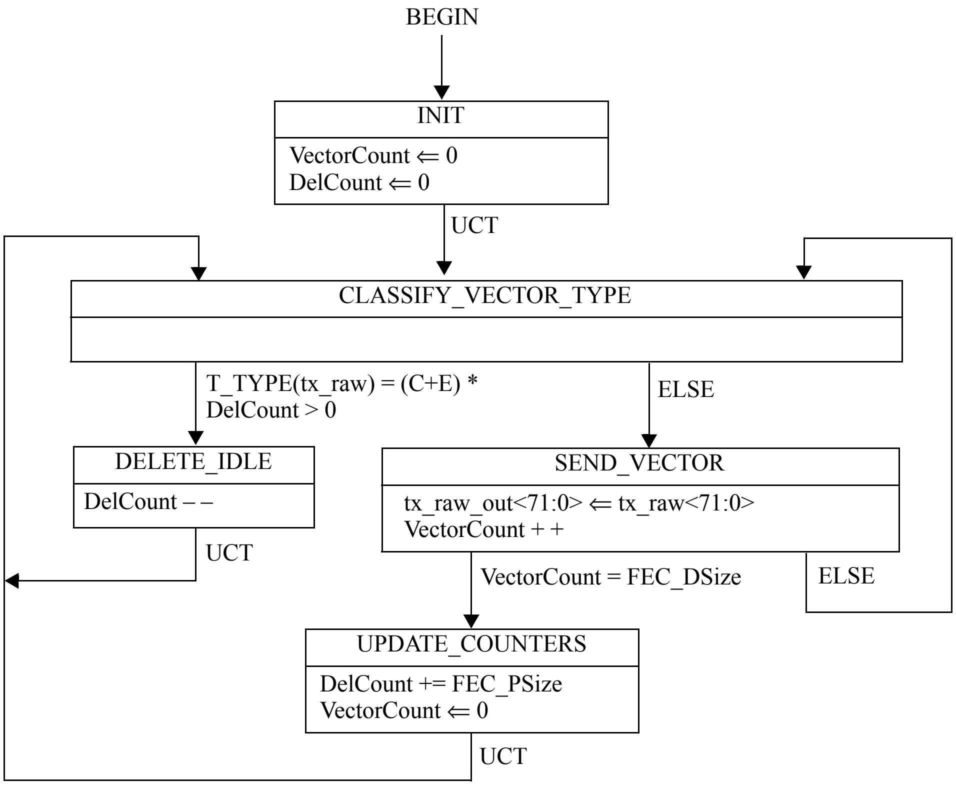


Figure 76–9—OLT Idle Deletion state diagram

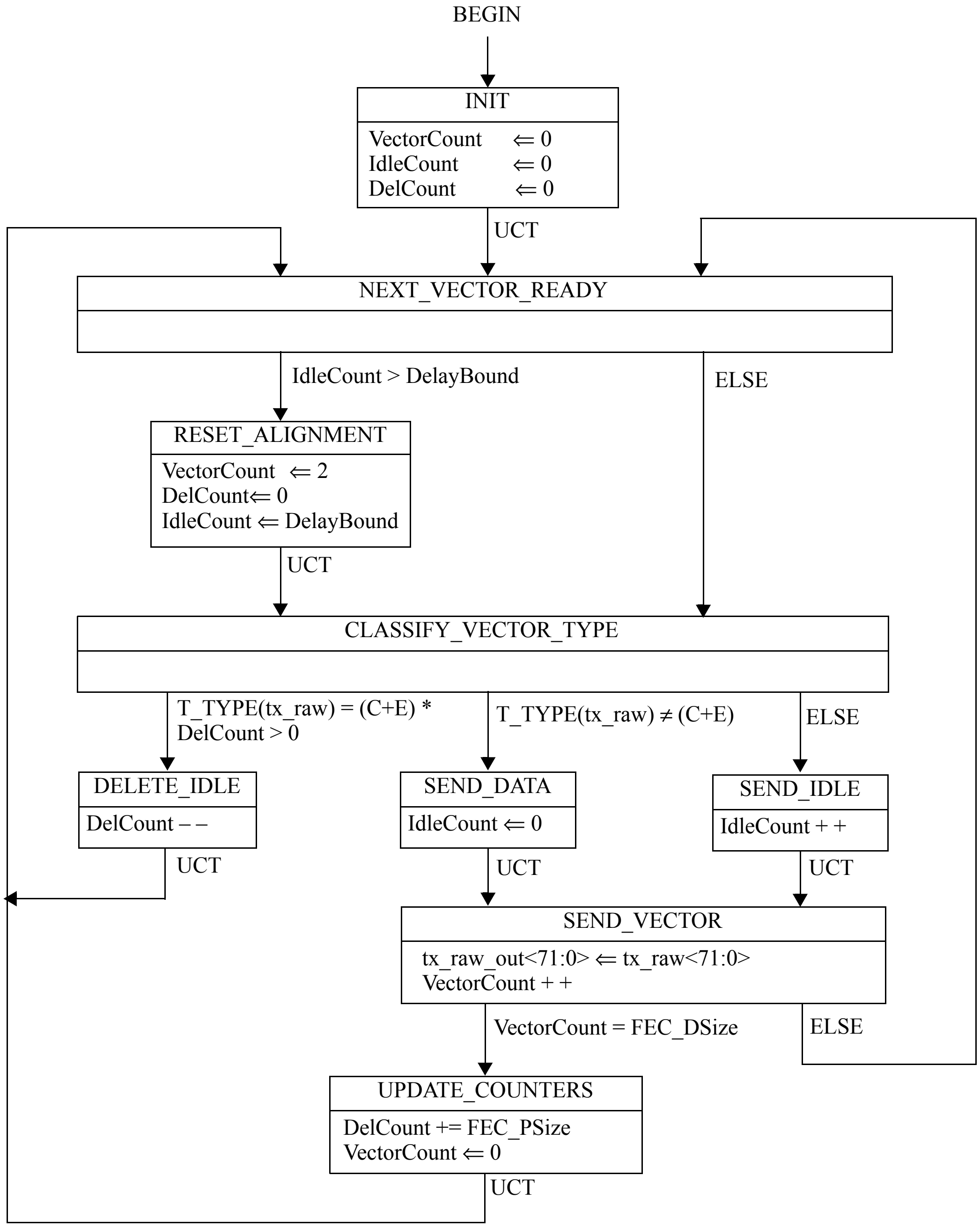


Figure 76–10—ONU Idle Deletion state diagram

76.3.2.2 64B/66B Encode

See 49.2.4 64B/66B transmission code. The encoder shall perform the functions specified in the state diagram shown in Figure 49–16.

76.3.2.3 Scrambler

See 49.2.6 Scrambler.

76.3.2.4 FEC encoding

The 10GBASE-PR-D, 10GBASE-PR-U, and 10/1GBASE-PRX-D PCS shall encode the transmitted data stream using Reed-Solomon code (255,223). Annex 76A gives an example of RS(255,223) FEC Encoding.

76.3.2.4.1 FEC Algorithm [RS(255,223)]

The FEC code used for 10GBASE-PR links is a linear cyclic block code—the Reed-Solomon code (255, 223) over the Galois Field of GF(2^8)—a code operating on 8 bit symbols. The code encodes 223 information symbols and adds 32 parity symbols. The code is systematic, meaning that the information symbols are not disturbed in any way in the encoder and the parity symbols are added separately to each block.

The code is based on the generating polynomial shown in Equation (76-1).

$$G(Z) = \prod_{i=0}^{31}(Z-\alpha^i) = A_{32}Z^{32} + A_{31}Z^{31} + \ldots + A_0Z^0 \tag{76–1}$$

where

α is a root of the binary primitive polynomial $x^8 + x^4 + x^3 + x^2 + 1$ and is represented as 0x02
A is a series representing the resulting polynomial coefficients of $G(Z)$, (A_{32} is equal to 0x01)
Z corresponds to an 8 bit GF(2^8) symbol
x corresponds to a bit position in a GF(2^8) symbol

The parity calculation shall produce the same result as the shift register implementation shown in Figure 76–11. Before calculation begins, the shift register shall be initialized to zero. The contents of the shift register are transmitted without inversion.

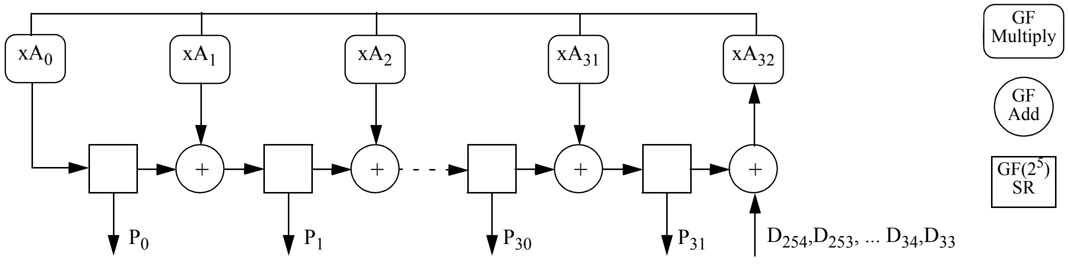


Figure 76–11—Circuit for generating FEC parity vector

A FEC parity vector is represented by Equation (76-2).

$$P(Z) = D(Z) \bmod G(Z) \tag{76–2}$$

where

> $D(Z)$ is the data vector $D(Z) = D_{222}Z^{254} + D_{221}Z^{253} + \ldots + D_0Z^{32}$. D_{222} is the first data octet and D_0 is the last.
>
> $P(Z)$ is the parity vector $P(Z) = P_{31}Z^{31} + P_{30}Z^{30} \ldots + P_0Z^0$. P_{31} is the first parity octet and P_0 is the last.

A data octet ($d_7, d_6, \ldots, d_1, d_0$) is identified with the element: $d_7\alpha^7 + d_6\alpha^6 + \ldots + d_1\alpha^1 + d_0$ in GF(2^8), the finite field with 2^8 elements. The code has a correction capability of up to sixteen symbols.

NOTE—For the (255,223) Reed-Solomon code, the symbol size equals one octet. The d_0 is identified as the LSB and d_7 is identified as the MSB for all octets in accordance with the conventions of 3.1.1.

Bit ordering shall be as illustrated in Figure 76–12.

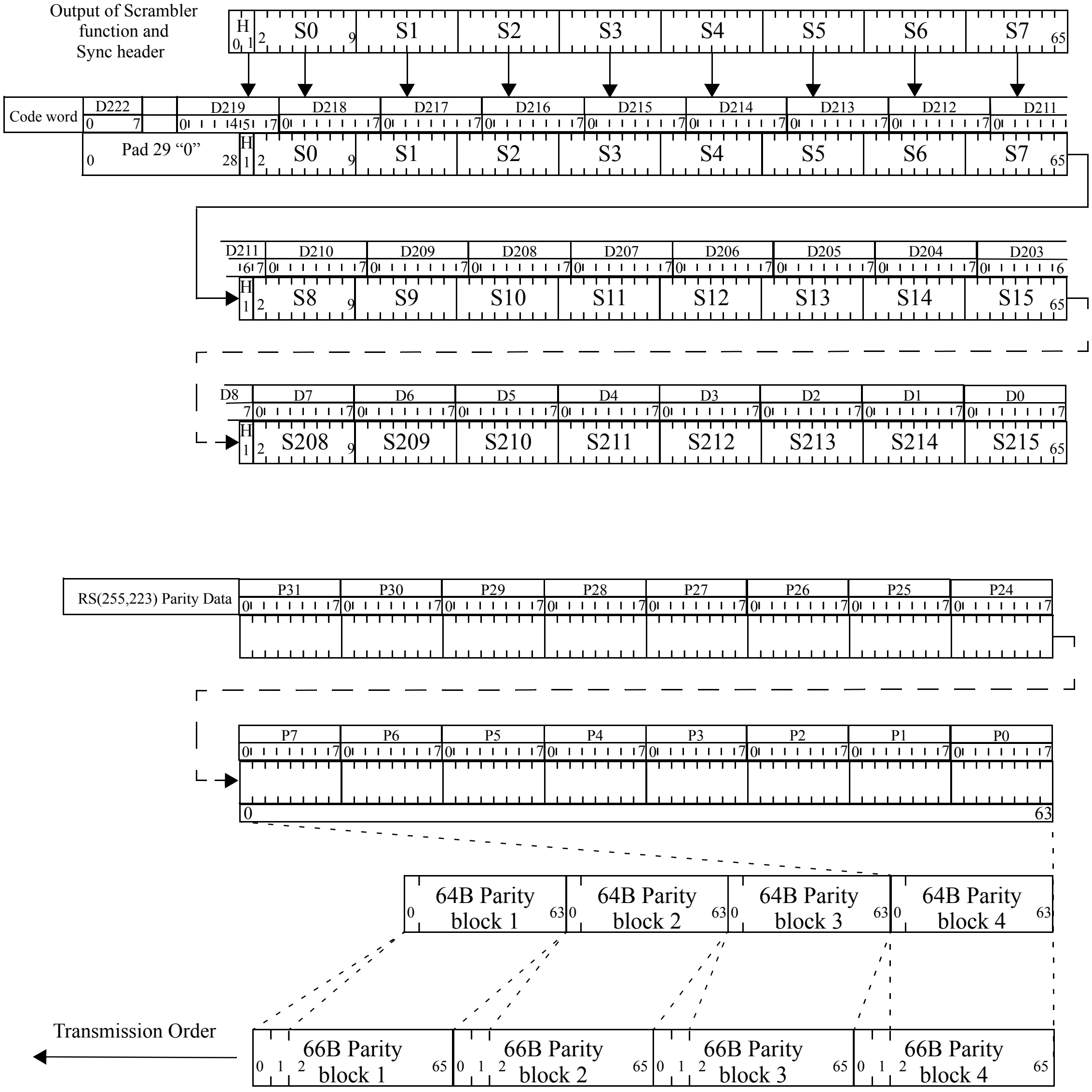


Figure 76–12—Bit ordering in FEC codeword generation

76.3.2.4.2 Parity calculation

Padding of FEC codewords and appending FEC parity octets in the 10GBASE-PR and 10/1GBASE-PRX OLT PCS transmitter is illustrated in Figure 76–13. The 64B/66B encoder and scrambler produce 66 bit blocks. The FEC encoder accumulates 27 of these 66 bit blocks to form the basis of an FEC codeword, removing the redundant first bit (i.e., sync header bit <0>) of each block (the first bit is guaranteed to be the complement of the second bit).

The FEC encoder then prepends 29 padding bits (binary 0) to the 27 blocks (65 bits each) to form the 223-octet payload portion of an FEC codeword. This data is then FEC-encoded, resulting in the 32-octet parity portion of the FEC codeword. The 223-octet payload portion and 32-octet parity portion combine to form the 255-octet Reed-Solomon codeword. The padding is used to generate the FEC codeword but is not transmitted.

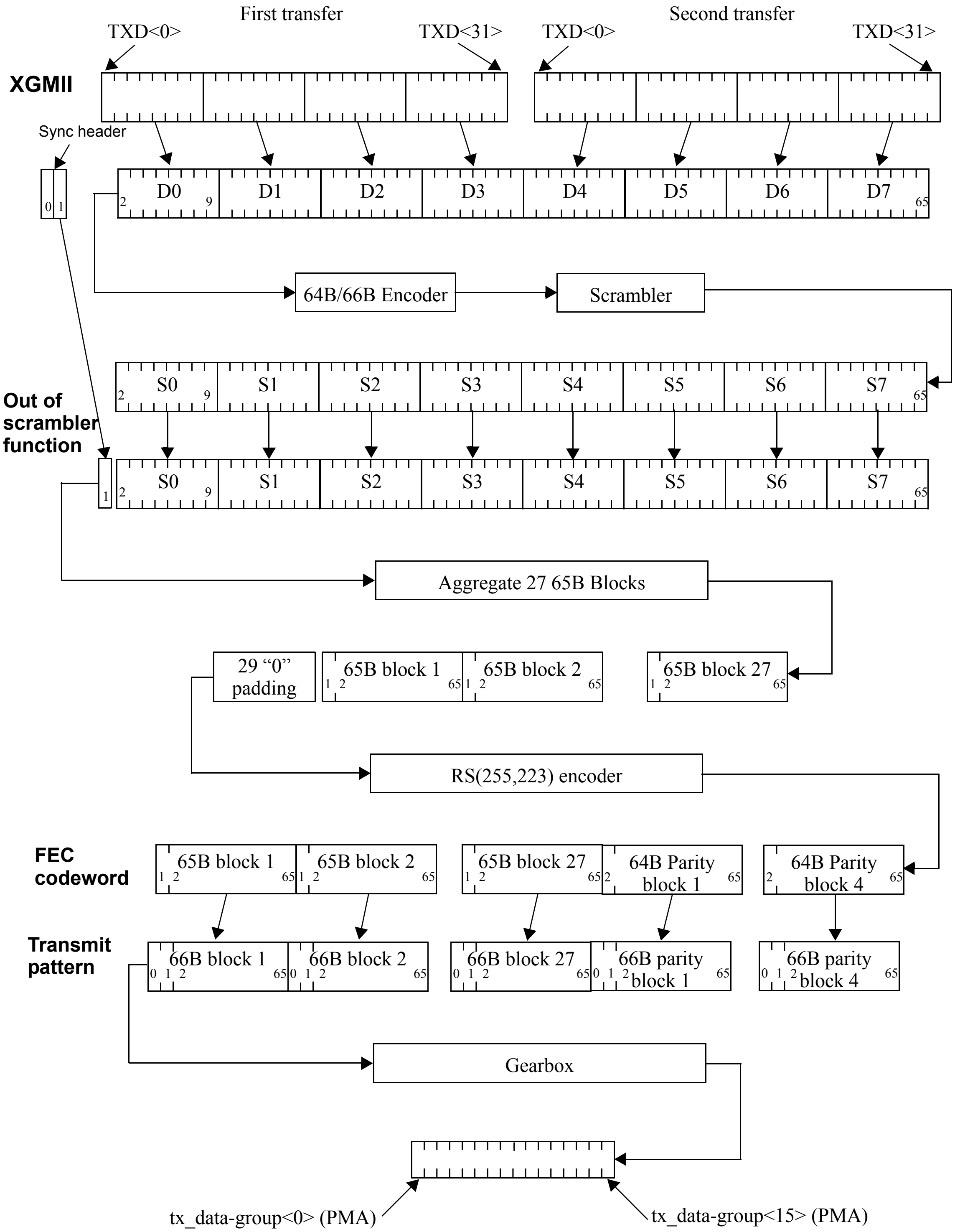


Figure 76–13—PCS Transmit bit ordering

76.3.2.4.3 FEC Transmission Block Formatting

As shown in Figure 76–13, after the Reed-Solomon codeword has been computed, the FEC encoder constructs the transmittable FEC codeword with the original sequence of twenty-seven 66 bit blocks (including the redundant sync bit, but not including the 29 “0” padding bits). The FEC encoder prepends a 2 bit sync header to each group of 64 parity bits to construct a properly formed 66 bit codeword, according to the predefined sync header pattern for the four 64 bit parity blocks: 00 11 11 00. Finally the four 66 bit parity blocks are appended following the twenty-seven 66 bit data blocks and transmitted to the PMA.

76.3.2.5 Data Detector

The 10GBASE-PR-D, 10GBASE-PR-U, and 10/1GBASE-PRX-D PCS transmit path includes the Data Detector process. This process contains a delay line (FIFO_DD buffer) that stores the 66 bit blocks to allow insertion of the FEC parity data into the transmitted data stream. The length of the FIFO_DD buffer should be large enough to hold the amount of data equal to the maximum amount of parity data that may be inserted within the transmission time of one packet of a maximum length (i.e., at most forty 66 bit blocks of parity data).

76.3.2.5.1 Burst Mode operation (ONU only)

In addition to inserting the parity data into the data stream, the Data Detector process in the 10GBASE-PR-U PCS generates the PMA_SIGNAL.request(tx_enable) primitive to turn the laser on and off at the correct times.

Upon initialization, the laser is turned off. When the first 66 bit block containing data arrives at the buffer, the Data Detector sets the PMA_SIGNAL.request(tx_enable) primitive to the value ON, instructing the PMD sublayer to start the process of turning the laser on.

When the buffer becomes empty (i.e., contains only 66 bit blocks with Idle characters), the Data Detector sends the End of Burst Delimiter and after that sets the PMA_SIGNAL.request(tx_enable) primitive to the value OFF, instructing the PMD sublayer to start the process of turning the laser off. Between packets, Idle blocks arrive at the buffer. If the number of these Idle blocks is insufficient to fill the buffer then the laser is not turned off.

The length of the FIFO_DD buffer at the ONU shall be chosen such that the delay introduced by the buffer together with any delay introduced by the PMA sublayer is long enough to turn the laser on and to allow a laser synchronization pattern, Burst Delimiter pattern, and a predefined number of Idle blocks to be transmitted. The laser synchronization pattern allows the receiving optical detector to adjust its gain ($T_{receiver\_settling}$) and synchronize its receive clock (T_{CDR}). The Burst Delimiter allows the receiver to easily identify the beginning of FEC protected portion of the ONU transmission. The Idle control characters are used to synchronize the descrambler and establish start-of-packet delineation.

Figure 76–14 illustrates the details of the ONU burst transmission. In particular, this figure shows the details of the synchronization time and the FEC protected portions of the burst transmission.

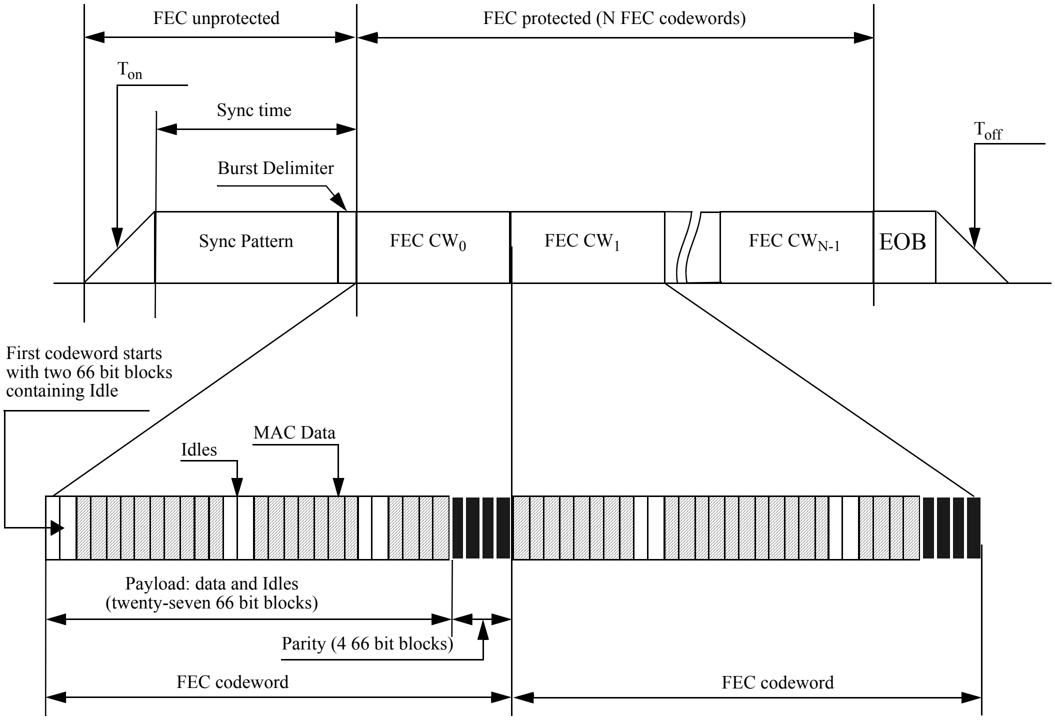


Figure 76–14—Details of burst composition

The ONU burst transmission begins with a Synchronization Pattern (see 76.3.2.5.2), which facilitates receiver clock recovery and gain control at the OLT. To facilitate FEC codeword synchronization, the ONU transmits a 66 bit BURST_DELIMITER (see Figure 76–15). When received at the OLT, the BURST_DELIMITER allows for FEC codeword alignment on the incoming data stream, even in the presence of bit errors. The BURST_DELIMITER is followed by two 66 bit blocks containing Idle codes. The first 66 bit block is used to synchronize the descrambler and a second 66 bit block is needed to provide packet delineation at the RS layer of the OLT. These two 66 bit Idle blocks are part of the first FEC codeword.

The ONU burst transmission ends with an END_BURST_DELIMITER (EOB) pattern of length TERMINATOR_LENGTH (see Figure 76–15). When received at the OLT, the burst terminator allows for the rapid reset of the OLT FEC synchronizer, so that it can search for the next burst. The burst terminator is not part of the last FEC codeword.

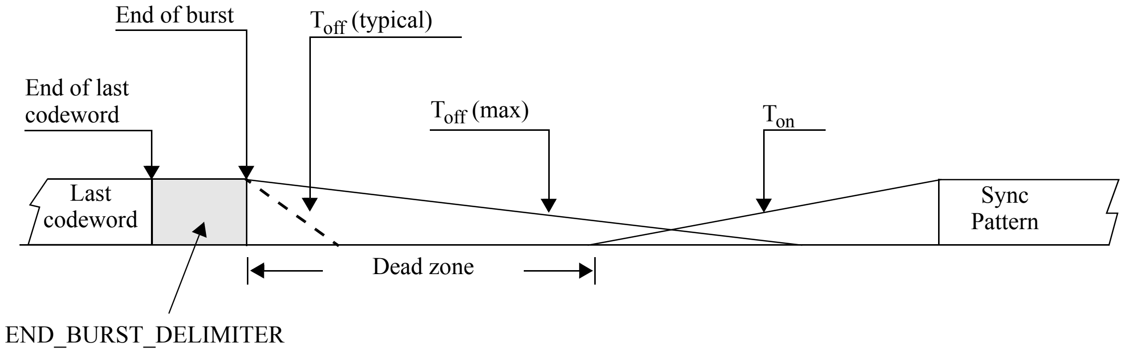


Figure 76–15—ONU burst transmission termination

The body of this subclause comprises state diagrams, including the associated definitions of variables, constants, and functions pertinent to the 10GBASE-PR and 10/1GBASE-PRX OLT PCS transmitters. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation used in the state diagrams in this clause follows the conventions in 21.5. State diagram variables follow the conventions of 21.5.2 except when the variable has a default value.

76.3.2.5.2 Constants

BURST_DELIMITER
TYPE: 66 bit unsigned
A 66 bit value used to find the beginning of the first FEC codeword in the upstream burst.
Value: binary 01 followed by 0x 6B F8 D8 12 D8 58 E4 AB (transmission bit sequence: 01 1101 0110 0001 1111 0001 1011 0100 1000 0001 1011 0001 1010 0010 0111 1101 0101)

END_BURST_DELIMITER
TYPE: 66 bit unsigned
A 66 bit value used to identify the end of the upstream burst transmission.
Value: binary 10 followed by 0x 55 55 55 55 55 55 55 55 (transmission bit sequence of 10 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010 1010)

FEC_DSize
See 76.3.2.1.1.

FEC_PSize
See 76.3.2.1.1.

SP
Type: 66 bit unsigned
A 66 bit value used to for the burst mode synchronization pattern.
Value: binary 10 followed by 0x BF 40 18 E5 C5 49 BB 59 (transmission bit sequence 10 1111 1101 0000 0010 0001 1000 1010 0111 1010 0011 1001 0010 1101 1101 1001 1010)

TERMINATOR_LENGTH
Type: 8 bit unsigned
Number of END_BURST_DELIMITER blocks that are transmitted at the end of each burst.
Value: 3

SH_DATA

Type: 2-bit unsigned
The value of synchronization header indicating that the given 66-bit block is a data block, as defined in 49.2.4.3.
Value: 0x02 (binary representation 10)

SH_CTRL

Type: 2-bit unsigned
The value of synchronization header indicating that the given 66-bit block is a control block, as defined in 49.2.4.3.
Value: 0x01 (binary representation 01)

NOTE—The binary representation of the sync header in here is different than that in Clause 49. In Clause 49, binary values are shown with the first transmitted bit (the LSB) on the left.

76.3.2.5.3 Variables

CLK

TYPE: Boolean
This Boolean is true on every negative edge of TX_CLK (See 46.3.1) and represents instances of time at which a 66 bit block should be passed from Data Detector to the GearBox. This variable is reset to false upon read.

DelayBound

This variable is defined in 76.3.2.1.2.

FIFO_DD

TYPE: Array of 66 bit unsigned elements
A FIFO array used to store tx_coded<65:0> blocks while the parity is inserted and while burst preamble is generated (at the ONU only).

FifoSize

TYPE: 16 bit unsigned
Variable representing a number of elements stored in FIFO_DD.

SyncLength

TYPE: 16 bit unsigned
Required number of sync blocks per burst. The value of this variable is derived from the syncTime (excluding BURST_DELIMITER) and laserOnTime parameters defined in 77.3.3.

Transmitting

TYPE: Boolean
Boolean variable indicating whether the device is transmitting or not. At the ONU, the default value of Transmitting is false. At the OLT, this variable is always set to true.

tx_coded<65:0>

TYPE: 66 bit unsigned
66 bit block containing the output of the scrambler. The format for this vector is shown in Figure 49–7. The left-most bit in the figure is tx_coded<0> and the right-most bit is tx_coded<65>.

tx_coded_out<65:0>

TYPE: 66 bit unsigned

66 bit block containing the output of Data Detector being passed to the Gearbox. The format for this vector is shown in Figure 49–7. The left-most bit in the figure is tx_coded<0> and the right-most bit is tx_coded<65>.

76.3.2.5.4 Functions

RemoveFifoHead()

This function removes the first block in FIFO_DD and decrements the variable FifoSize by 1.

```
RemoveFifoHead()
   {
      // shift FIFO_DD forward
      FIFO_DD[0] = FIFO_DD[1]
      FIFO_DD[1] = FIFO_DD[2]
         ...
      FIFO_DD[FifoSize-2] = FIFO_DD[FifoSize-1]
      FifoSize --
   }
```

76.3.2.5.5 Messages

PMA_SIGNAL.request(tx_enable)

This primitive is used to turn the laser on and off at the PMD sublayer. In the OLT, this primitive shall always take the value ON. In the ONU, the value of this variable is controlled by the Data detector state diagram (see Figure 76–17).

SCRAMBLER_UNITDATA.request(tx_coded<65:0>)

A primitive generated by the SCRAMBLER transmit process conveying the next 66 bit block to be transmitted.

SUDR

Alias for SCRAMBLER_UNITDATA.request(tx_coded<65:0>).

76.3.2.5.6 Counters

IdleBlockCount

TYPE: 32 bit unsigned

The number of consecutive non-data blocks ending with the most recently received block. The non-data blocks are represented by sync header 10 (binary).

ParityBlockCount

TYPE: 8 bit unsigned

The number of parity blocks transmitted in a current FEC codeword. After reaching the full parity size (FEC_PSize=4), this counter is reset to 0.

ProtectedBlockCount

TYPE: 8 bit unsigned

The number of blocks added to a payload of a current FEC codeword. After reaching the full payload size (FEC_DSize = 27), this counter is reset to 0.

SyncBlockCount

TYPE: 16 bit unsigned

The number of synchronization blocks transmitted in current burst.

76.3.2.5.7 State diagrams

The OLT and the ONU shall implement the Data Detector input process as depicted in Figure 76–16. The OLT shall implement the Data Detector output process as depicted in Figure 76–17(a). The ONU shall implement the Data Detector output process as depicted in Figure 76–17(b).

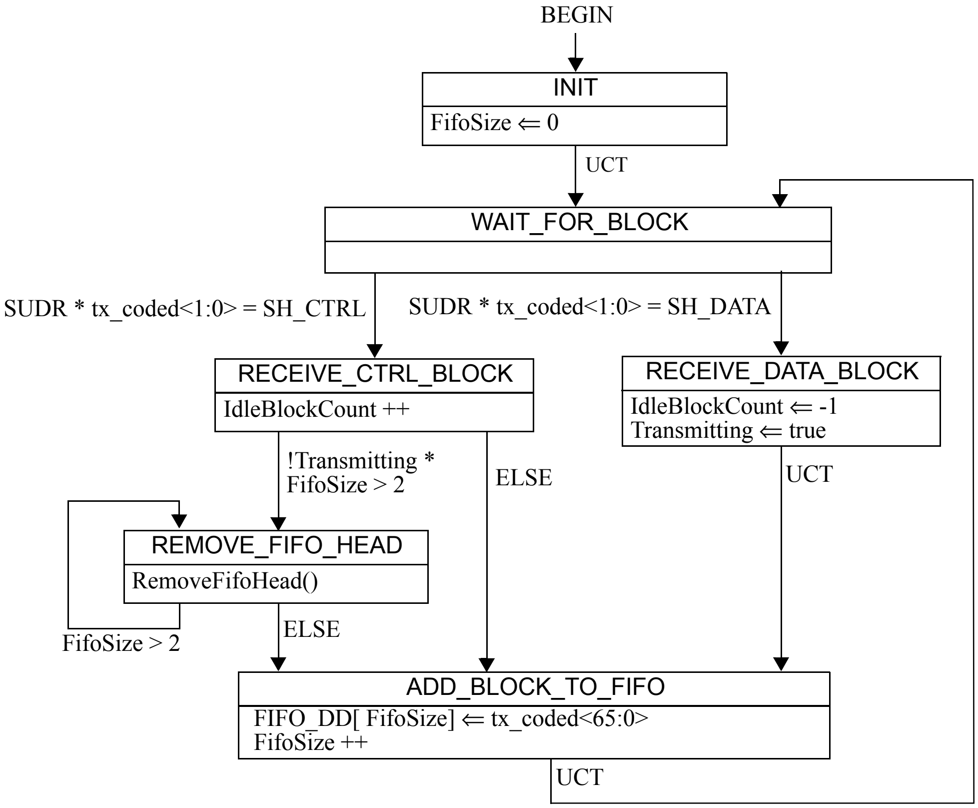
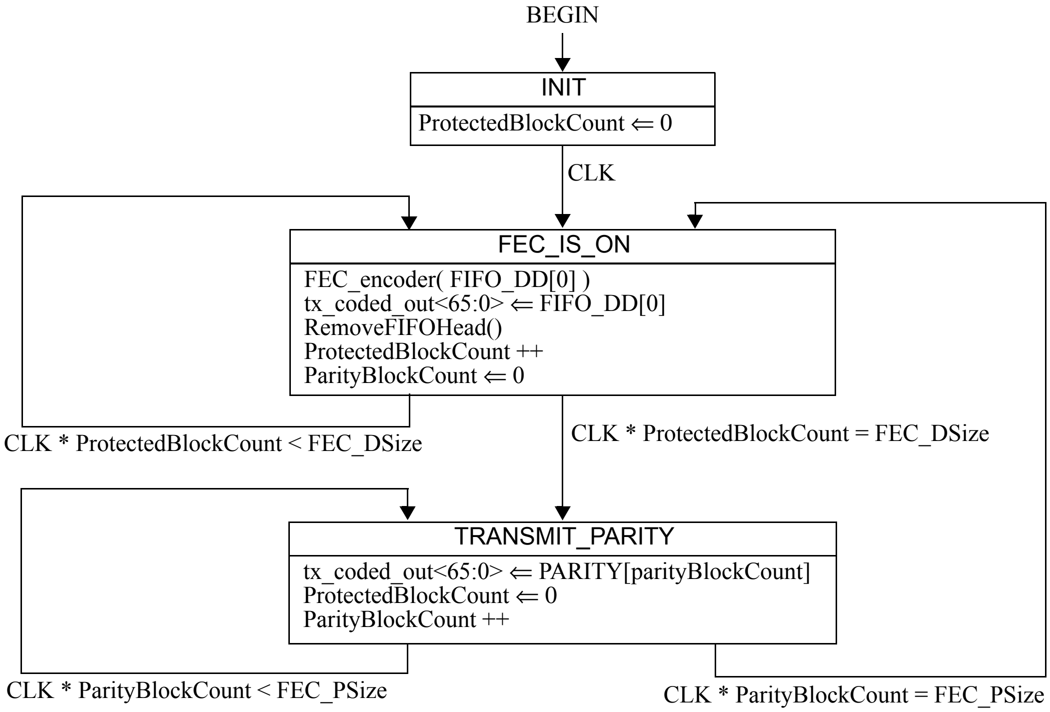


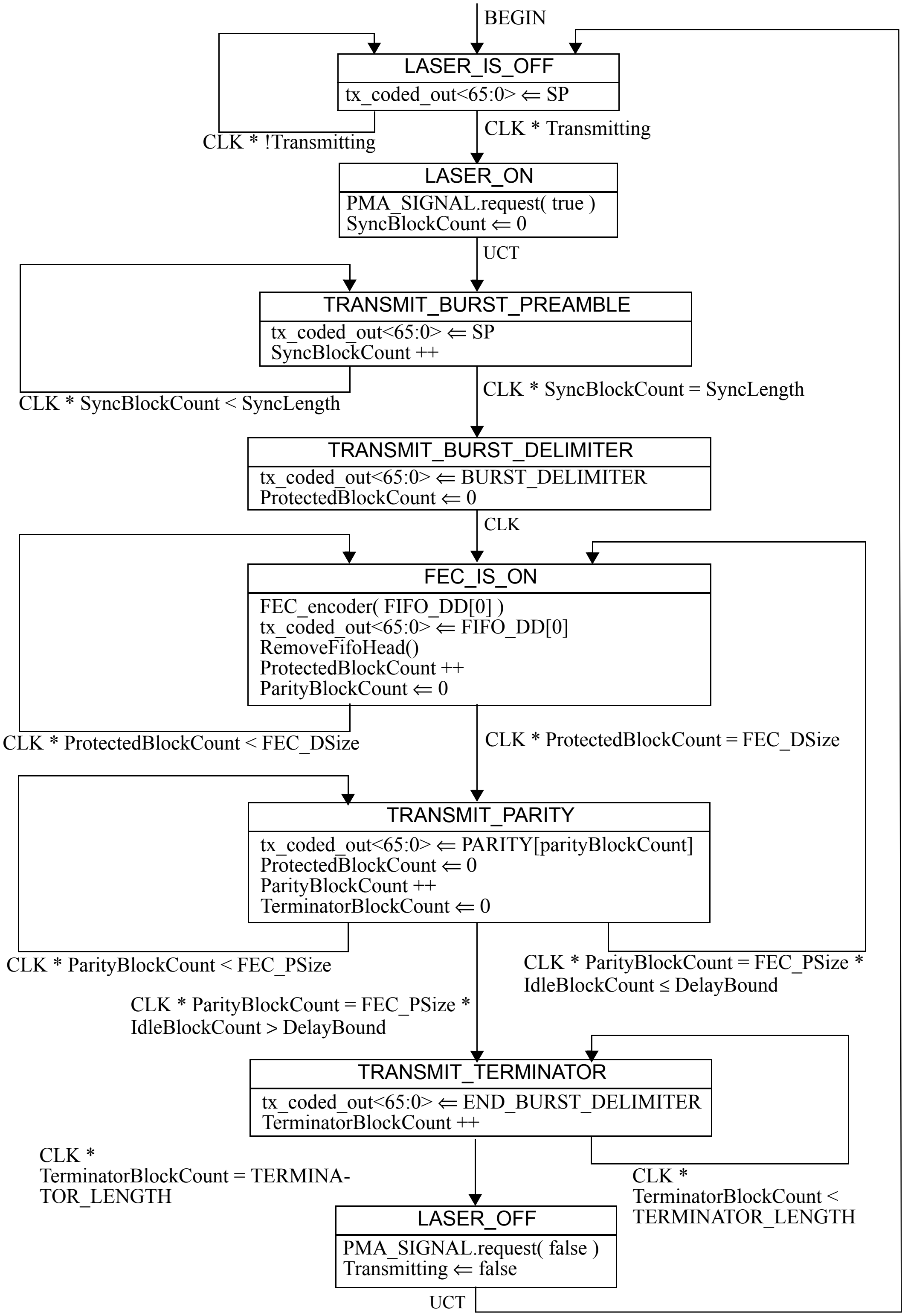
Figure 76–16—Data Detector, input process state diagram

76.3.2.6 Gearbox

See 49.2.7 Gearbox.



(a) OLT state diagram



(b) ONU state diagram

Figure 76–17—Data Detector, output process state diagram

76.3.3 PCS receive Function

This subclause defines the receive direction of physical coding sublayers for 10GBASE-PR and 10/1GBASE-PRX. In the ONU, the PCS operates at a 10 Gb/s rate in a continuous mode. In the OLT, the PCS may operate at a 10 Gb/s rate, as specified herein (10GBASE-PR), or at a 1 Gb/s rate, compliant with Clause 65 (10/1GBASE-PRX). For both 10GBASE-PR and 10/1GBASE-PRX, the OLT PCS always operates in burst mode. When operating at the 10 Gb/s rate, the PCS includes a mandatory FEC decoder. The receive direction of ONU PCS is illustrated in Figure 76–7 and receive direction for the OLT PCS is illustrated in Figure 76–8.

76.3.3.1 OLT synchronizer

The OLT codeword synchronization function receives data via the 16 bit PMA_UNITDATA.indication primitive.

The OLT synchronizer forms a bit stream from the primitives by concatenating requests with the bits of each primitive in order from rx_data-group<0> to rx_data-group<15> (see Figure 76–18). It obtains lock to the thirty-one 66 bit blocks in the bit stream by looking for the burst delimiter. Lock is obtained as specified in the codeword lock state diagram shown in Figure 76–18. While in codeword lock, the synchronizer copies the FEC-protected bits from each data block and the parity bits of the codeword into an input buffer. When the codeword is complete, the FEC decoder is triggered, and the input buffer is freed for the next codeword. When in codeword lock, the state diagram looks for the end of the burst. When this is observed, then the state diagram deasserts codeword lock. The state diagram then goes back to searching for the burst delimiter.

76.3.3.1.1 Variables

BD_valid
TYPE:Boolean
Indication that is set true if received block rx_coded matches the BURST_DELIMITER with less than 12 bits difference, and de-asserted otherwise.

cword_lock
TYPE: Boolean
Boolean variable that is set true when receiver acquires codeword delineation.

CurrentBlock<65:0>
TYPE: 66 bit vector
The last 66 bit block received. This variable has an initial value of 0.

decode_success
TYPE: Boolean
Indication that is set true if the codeword was successfully decoded by the FEC algorithm, and false otherwise.

EOB_valid
TYPE: Boolean
Indication that is set true if:

$$\mathrm{DistanceFromEob}(\mathrm{CurrentBlock}) + \mathrm{DistanceFromEob}(\mathrm{PreviousBlock}) < 11$$

It is set to false otherwise.

inbuffer
TYPE: bit array
An array of 2040 bits that holds the input to the FEC decoder.

input_buffer_location
TYPE: integer
An integer that points to the next appending location in the input buffer.

persist_dec_fail
TYPE: Boolean
Indication that is set when three consecutive decoding failures have occurred.

PreviousBlock<65:0>
TYPE: 66 bit vector
The 66 bit block received previous to the current block. This variable has an initial value of 0.

reset
This variable is inherited from 49.2.13.2.2.

rx_coded<65:0>
This variable is inherited from 49.2.13.2.2.

signal_ok
This variable is inherited from 49.2.13.2.2.

76.3.3.1.2 Counters

decode_failures
TYPE:
Counter that holds the number of consecutive decoding failures.

sh_wndw_cnt
Count of the number of sync headers checked within the current 62-block window (composed of 2 codewords of 31 blocks each).

76.3.3.1.3 Functions

Append_inbuffer()
Appends the newly arrived 66 bit block into the input buffer of the FEC decoding algorithm, taking care to only insert the bits to be protected, and discarding the unwanted bits.

```
Append_inbuffer()
{
   BlockFromPMA()
   if (sh_wndw_cnt<27)
   {
      inbuffer[input_buffer_location]=rx_coded<1>
      input_buffer_location++
   }
   for(i=2, i<66, i++)
   {
      inbuffer[input_buffer_location]=rx_coded<i>
      input_buffer_location++
   }
}
```

BlockFromPMA()

Function that accepts the next received data from the PMA. Conceptually, this function serializes the 16 bit rx_data_group<15:0> to a bit stream at 10.3125 Gb/s, and then deserializes the resulting bit stream into a 66 bit wide rx_coded<65:0> block of data. It does not return until 66 bits have been transferred. Note that the internal design by which this function is accomplished is an implementation choice; however, the design operates such that a new 66 bit block is made available at the regular interval of 6.4 ns, and the transfers are made synchronous to the XGMII clock.

Decode()

Triggers the FEC decoding algorithm to accept the contents of the input buffer, and do its decoding work. Note that this function is not blocking, and returns immediately. It is assumed that the FEC decoding algorithm copies the input buffer contents into its own internal memory, so that the input buffer is released to accept the next codeword.

DecodeWhenReady()

Determines if the inbuffer contains a full codeword, and if so, it triggers the Decode function, and then clears the inbuffer for the next codeword.

```
DecodeWhenReady()
{
   if (sh_wndw_cnt=0 or sh_wndw_cnt=31)
   {
      if (cword_lock)
      {
         Decode();
      }
      Flush_inbuffer();
   }
}
```

DistanceFromEob(block<65:0>)

Returns the Hamming distance between the supplied block and the END_BURST_DELIMITER

Flush_inbuffer()

Flushes the input buffer of the FEC decoding algorithm block.

```
Flush_inbuffer()
{
   for(i=0, i<2040, i++)
   {
      inbuffer[i]=0
   }
   input_buffer_location = 29
}
```

SLIP_One_Bit

Causes the next candidate block sync position to be tested. The next candidate is exactly one bit later than the previous candidate – no burst alignments may be skipped. Following the conceptual model mentioned in “BlockFromPMA,” this function transfers one more bit from the 16 bit serializer to the 66 bit deserializer.

76.3.3.1.4 State diagram

The OLT Synchronizer shall implement the state diagram as depicted in Figure 76–18. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

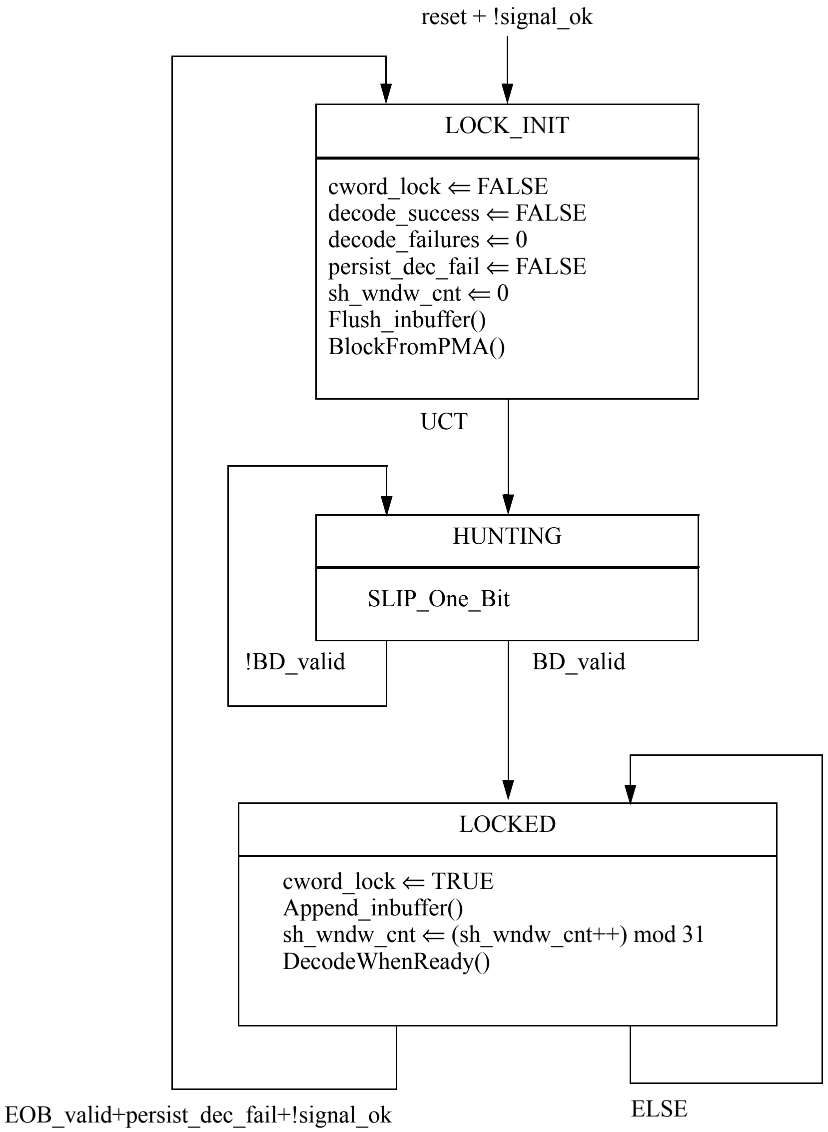


Figure 76–18—OLT Synchronizer state diagram

76.3.3.2 ONU Synchronizer

The codeword synchronization function receives data via the 16 bit PMA_UNITDATA.indication primitive.

The synchronizer forms a bit stream from the primitives by concatenating requests with the bits of each primitive in order from rx_data-group<0> to rx_data-group<15> (see Figure 76–19). It obtains lock to the thirty-one 66 bit blocks in the bit stream using the sync headers and outputs 2040 bit codewords to the FEC decoder function.

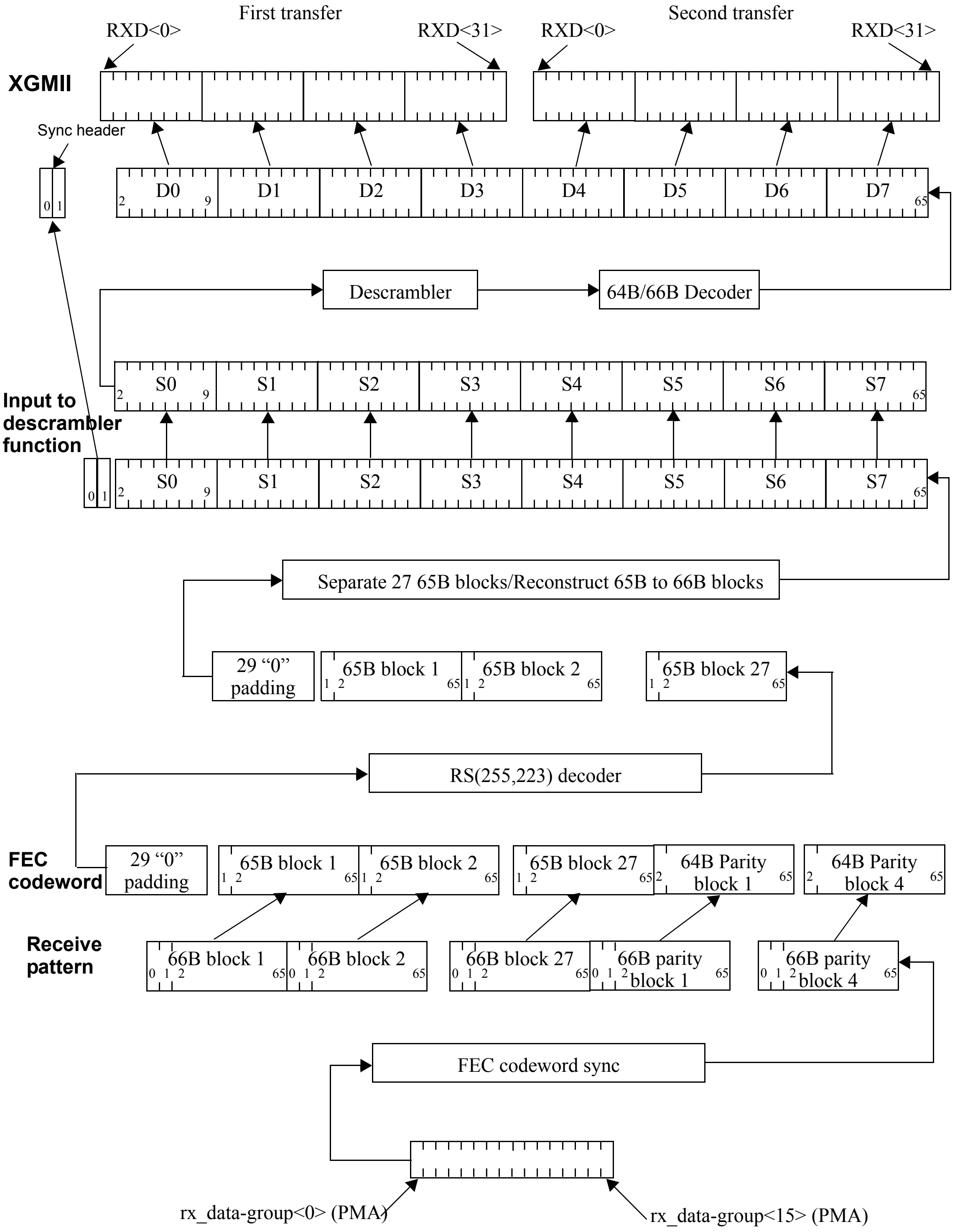


Figure 76–19—PCS Receive bit ordering

The incoming sync header pattern is 27 conventional (Clause 49) sync headers (binary 01 or 10), and then binary 00, 11, 11, and finally binary 00. The ONU synchronizer attempts to match this pattern to the received data stream, and when it finds a perfect match of two full codewords (62 blocks), it then asserts codeword lock.

While in codeword lock, the synchronizer copies the FEC-protected bits from each data block and the parity bits of the codeword into an input buffer. When the codeword is complete, the FEC decoder is triggered, and the input buffer is freed for the next codeword.

When in codeword lock, the state diagram continues to check for sync header validity. If 16 or more sync headers in a codeword pair (62 blocks) are invalid, then the state diagram deasserts codeword lock. In addition, if the persist_dec_fail signal becomes set, then codeword lock is deasserted (this check ensures that certain false-lock cases are not persistent.)

76.3.3.2.1 Constants

All the relevant constants defined in 49.2.13.2.1 are inherited. In addition, the following items are defined.

SH_CW_PATTERN
TYPE: array of 8 bit unsigned
31 element array of codeword sync header bit counts, where each element is set to the value 1 except for:
Value:
SH_CW_PATTERN[27]=0
SH_CW_PATTERN[28]=2
SH_CW_PATTERN[29]=2
SH_CW_PATTERN[30]=0

76.3.3.2.2 Variables

cword_lock
See 76.3.3.1.1.

decode_success
See 76.3.3.1.1.

persist_dec_fail
See 76.3.3.1.1.

reset
This variable is inherited from 49.2.13.2.2.

sh_valid
TYPE: Boolean array
Indication that is set true if received block rx_coded has valid sync header bits for the supposed current position in the FEC codeword. That is, sh_valid[i] is asserted if (rx_coded<0> + rx_coded<1>) = SH_CW_PATTERN[i mod 31] and de-asserted otherwise.

signal_ok
This variable is inherited from 49.2.13.2.2.

slip_done
This variable is inherited from 49.2.13.2.2.

test_sh
This variable is inherited from 49.2.13.2.2.

76.3.3.2.3 Counters

decode_failures
See 76.3.3.1.2.

FEC_cnt
TYPE: 8 bit unsigned
This counter keeps track of the parity sync header index that is currently being tested.

sh_wndw_cnt
See 76.3.3.1.2.

sh_valid_cnt
This counter is inherited from 49.2.13.2.4.

76.3.3.2.4 Functions

Append_inbuffer()
See 76.3.3.1.3.

DecodeWhenReady()
See 76.3.3.1.3.

SLIP
This function is inherited from 49.2.13.2.3.

76.3.3.2.5 State diagram

The ONU Synchronizer shall implement the state diagram as depicted in Figure 76–20. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

76.3.3.3 FEC decoding process

The 10GBASE-PR-D, 10GBASE-PR-U, and 10/1GBASE-PRX-U PCS shall correct errors in the received data stream using Reed-Solomon code (255,223). The FEC decoder corrects or confirms the correctness of the twenty-seven 66 bit blocks contained in the FEC codeword based on the four 66 bit blocks of parity information. The FEC decoding process then forwards the 66 bit data blocks to the descrambler and discards the parity blocks. The FEC decoding process is also responsible for setting bit 0 of the sync header to the inverse of bit 1 of the sync header. The handling of data leaving the FEC decoder and going to the descrambler is specified in the FEC decoding process state diagram shown in Figure 76–21. Implementations shall be capable of correcting up to 16 symbols in a codeword and detecting uncorrectable codewords.

The synchronizer state diagram accumulates a full codeword in a buffer. If the synchronizer is locked, then the FEC decoding process is triggered. The FEC algorithm then processes the buffer. The algorithm produces two outputs: the decode_success signal and (if successful) the corrected buffer. The data portion of the buffer is then read out to the descrambler logic in 66 bit blocks, as normal. Note that the rate of 66 bit transfers here is reduced due to the removal of the FEC parity blocks. This is corrected in the Idle Insertion step (see Figure 76–23).

If decode_success is false, then a counter is incremented (see 45.2.3.40). If there are three decoding failures in a row, then the Persist_dec_fail signal is asserted. This signal then resets the synchronizer.

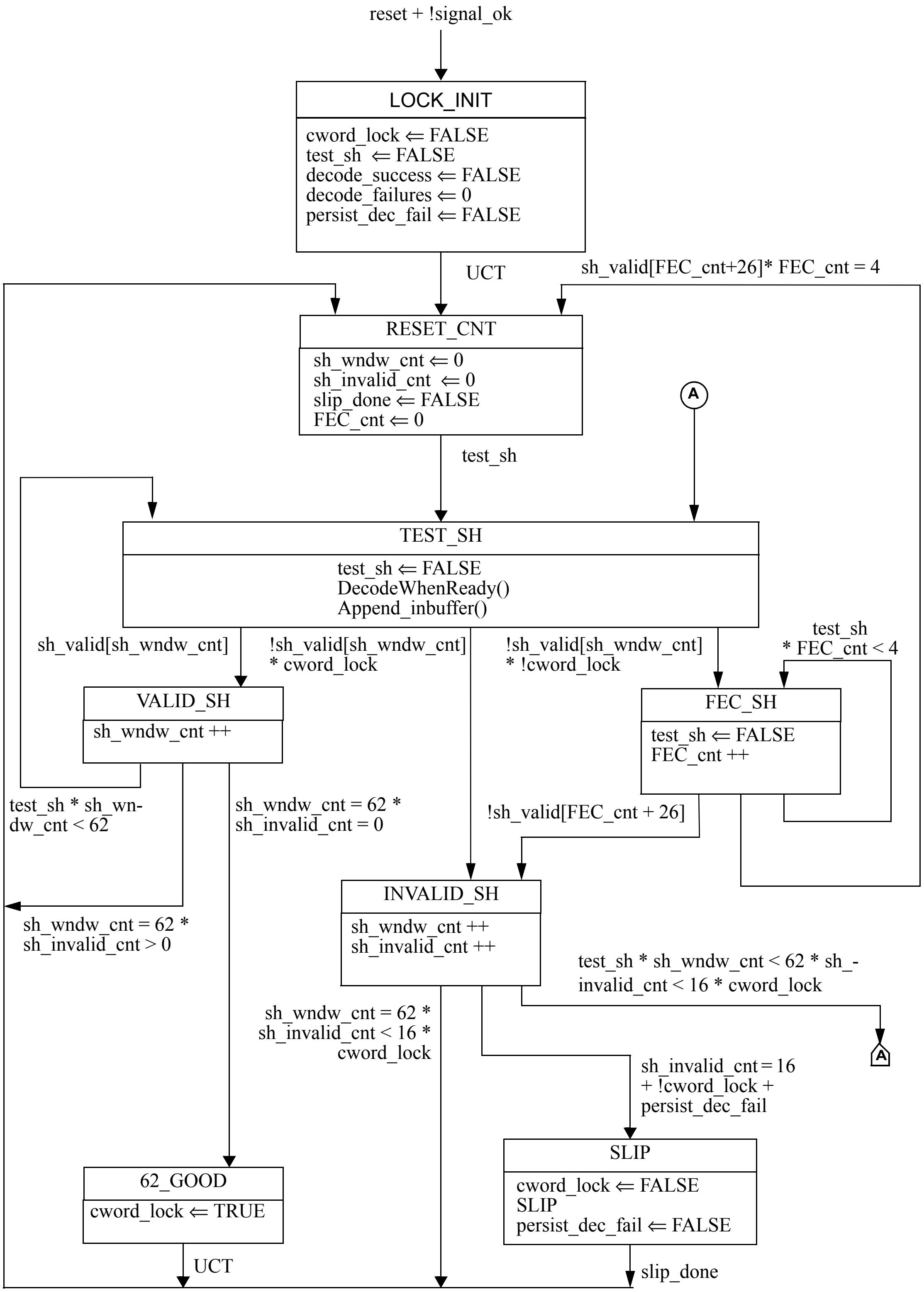


Figure 76–20—ONU Synchronizer state diagram

The FEC decoding process shall provide a user option to indicate an uncorrectable FEC codeword (due to an excess of symbols containing errors) to higher layers. If this option is set to be true, the FEC decoding process checks for the value of decode_success. If the variable decode_success is set to false, then each sync header of the received payload blocks in the FEC codeword is set to a value of binary 00. However, the data blocks are nevertheless passed to the descrambler to maintain descrambling synchronization. When this option is set to FALSE and decode_success is FALSE then each received payload block is passed unchanged.

76.3.3.3.1 Variables

decode_done
TYPE: Boolean
Indication that is transiently set when the FEC decoder algorithm has completed its processing and the corrected data is present in the output buffer.

decode_success
See 76.3.3.1.1.

mark_uncorrectable
TYPE: Boolean
Control variable that is set to true if the uncorrectable errors are to be marked.
Default: TRUE

outbuffer
TYPE: bit array
An array of 2040 bits that holds the output of the FEC decoder.

persist_dec_fail
See 76.3.3.1.1.

rx_code_corrected
Type: 66 bit vector
The next block of data to be sent to the scrambler.

76.3.3.3.2 Counters

decode_failures
See 76.3.3.1.2.

corrected_FEC_codewords_counter
A corrected block is an FEC codeword that was received with one or more errored symbols, and that has been corrected by the FEC decoder.
corrected_FEC_codewords_counter counts once for each corrected FEC codeword processed. This is a 32 bit counter. This variable is provided by a management interface that may be mapped to the 45.2.3.39 register (3.76, 3.77).

FEC_uncorrected_blocks_counter
An uncorrected block is an FEC codeword that was received with 17 or more errored symbols, and that has not been corrected by the FEC decoder.
FEC_uncorrected_blocks_counter counts once for each uncorrected FEC codeword processed. This is a 32 bit counter. This variable is provided by a management interface that may be mapped to the 45.2.3.40 register (3.78, 3.79).

76.3.3.3.3 Functions

All the relevant functions defined in 49.2.13.2.3 are inherited. In addition, the following items are defined.

BlockFromPMA()
See 76.3.3.1.3.

BlockToDescrambler()
Function that sends the next rx_coded_corrected<65:0> block to the descrambler. It does not return until the transfer is completed, and each transfer takes 6.4 ns and is synchronized to the XGMII clock.

Flush_inbuffer()
See 76.3.3.1.3.

Read_outbuffer(i)
Passes output buffer contents to the descrambler, with the appropriate format.

```
Read_outbuffer[i]
{
   int offset = 29+i*65
   for(j=0, j<65, j++)
   {
      rx_coded_corrected<j+1> = outbuffer[j+offset]
   }
   if (!decode_success AND mark_uncorrectable)
   {
      rx_coded_corrected<0> = 0
      rx_coded_corrected<1> = 0
   }
   else
   {
      rx_coded_corrected<0> = !rx_coded_corrected<1>
   }
   BlockToDescrambler()
}
```

SLIP
This function is inherited from 49.2.13.2.3.

76.3.3.3.4 State diagrams

The body of this subclause comprises state diagrams, including the associated definitions of variables, constants, and functions pertinent to the 10GBASE-PR-D, 10GBASE-PR-U, and 10/1GBASE-PRX-U PCS receivers. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation used in the state diagrams in this clause follows the conventions in 21.5.

The FEC decoding process shall be implemented in the PCS as depicted in Figure 76–21. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

76.3.3.4 BER monitor

The BER monitor is described in Figure 76–22. This BER monitor function operates on the uncorrected incoming data stream.

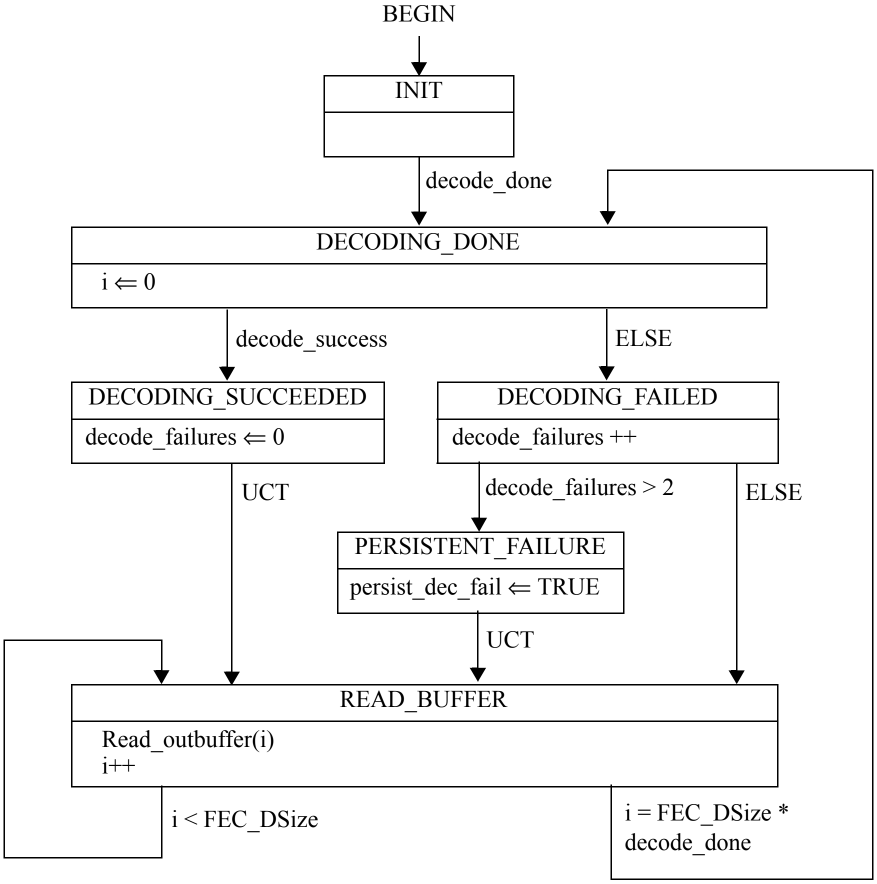


Figure 76–21—FEC decoding process state diagram

76.3.3.4.1 Variables

BER_Monitor_Interval
Indicates the time window associated with the BER monitor function. The timers in the BER monitor state diagram depend on this configurable variable. This value is reflected in MDIO register 3.80.

ber_test_sh
This variable is inherited from 49.2.13.2.2.

BER_Threshold
Indicates the threshold value of invalid sync headers associated with the BER monitor function. When BER_Threshold bad sync headers are encountered within the BER Monitor_Interval period, the BER monitor raises the hi_ber flag. When the number of bad sync headers encountered within the BER_Monitor_interval period less than the BER_Threshold, the hi_ber flag is turned off. This value is reflected in MDIO register 3.82.

hi_ber
This variable is inherited from 49.2.13.2.2.

reset
This variable is inherited from 49.2.13.2.2.

ber_test_sh

This variable is inherited from 49.2.13.2.2.

76.3.3.4.2 Timers

State diagram timers follow the conventions of 14.2.3.2.

interval_timer

Timer that is triggered every BER_monitor_interval μs +1%, –25%.

76.3.3.4.3 Counters

ber_cnt

This counter is inherited from 49.2.13.2.4.

76.3.3.4.4 State diagrams

The BER monitor state diagram is present only in the ONU. It is shown in Figure 76–22.

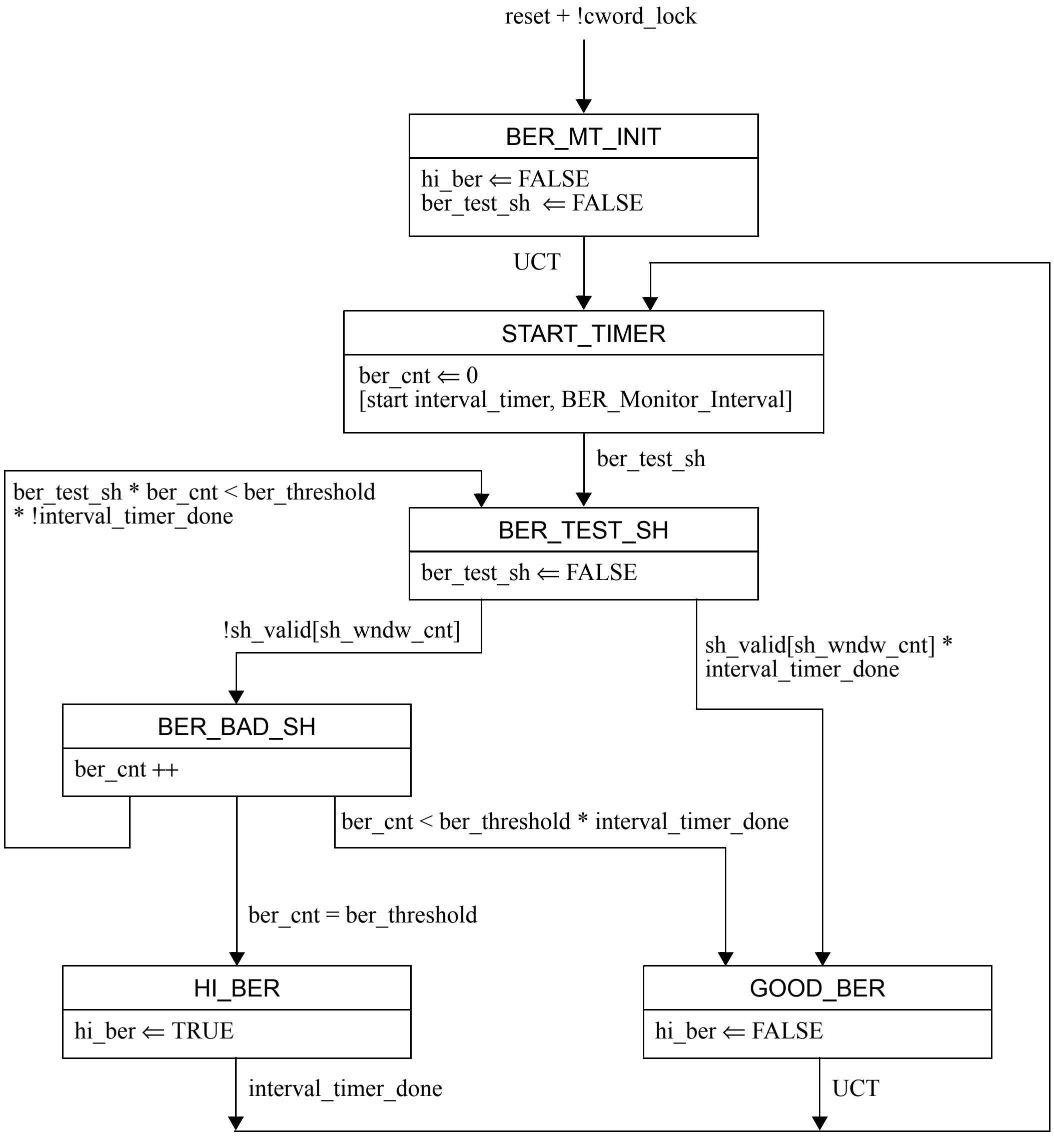


Figure 76–22—BER monitor state diagram (ONU only)

76.3.3.5 Descrambler

See 49.2.10 Descrambler.

76.3.3.6 64B/66B Decode

See 49.2.11 Receive process. The decoder shall perform functions specified in the state diagram shown in Figure 49–17.

76.3.3.7 Idle Insertion

The receiving PCS inserts the Idle control characters to compensate for the removed FEC parity octets. The Idle Insertion function (see Figure 76–23) receives 72 bit vectors from the 64B/66B decoder and writes them into the Idle Insertion FIFO (called FIFO_II) and reads 72 bit vectors from the FIFO_II and transfers them to the XGMII.

The Idle Insertion process receives 72 bit vectors at a slower rate than the nominal XGMII rate due to the fact that the FEC parity blocks are removed by the FEC decoder and not put through the descrambler and 64B/66B decoder. The Idle Insertion process outputs 72 bit vectors at the nominal XGMII rate. To match the input and output rates, the Idle Insertion process inserts additional 72 bit vectors containing Idle codes. The additional blocks are inserted between packets and not necessarily at the same locations where parity blocks have been removed.

The body of this subclause comprises state diagrams, including the associated definitions of variables, constants, and functions pertinent to the 10GBASE-PR-D, 10GBASE-PR-U and 10/1GBASE-PRX-U PCS receivers. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation used in the state diagrams in this clause follows the conventions in 21.5.

76.3.3.7.1 Constants

FEC_DSize
This constant is defined in 76.3.2.1.1.

FEC_PSize
This constant is defined in 76.3.2.1.1.

FIFO_II_SIZE
TYPE: 16 bit unsigned
This constant represents the size of Idle Insertion FIFO buffer. This buffer should be able to accommodate the number of 66 bit blocks sufficient to fill the gap introduced by removing the parity blocks from a maximum size MAC frame.
Value: 42

IDLE_VECTOR
TYPE: 72 bit binary
This constant represents a 72 bit vector containing Idle characters.

LBLOCK_R
This constant is defined in 49.2.13.2.1.

76.3.3.7.2 Variables

FIFO_II
TYPE: Array of 72 bit vectors received from 64B/66B decoder.
This FIFO is internal to the Idle Insertion process. Upon initialization, all elements of this array are filled with IDLE_VECTORs. FIFO_II is a zero-based array of size FIFO_II_SIZE (see 76.3.3.7.1).

RX_CLK
TYPE: Boolean
This variable represents the RX_CLK signal defined in 46.3.2.1.

rx_raw_in<71:0>
TYPE: 72 bit binary

Vector received from the output of the 64B/66B decoder. RXD<0> through RXD<31> for the second transfer are placed in rx_raw<40> through rx_raw<71>, respectively.

rx_raw_out<71:0>
TYPE: 72 bit binary
72 bit vector passed from the Idle Insertion process to XGMII. The vector is mapped to two XGMII transfers as follows:
Bits rx_raw<3:0> are mapped to RXC<3:0> for the first transfer;
Bits rx_raw<7:4> are mapped to RXC<3:0> for the second transfer;
Bits rx_raw<39:8> are mapped to RXD<31:0> for the first transfer;
Bits rx_raw<71:40> are mapped to RXD<31:0> for the second transfer.

VectorCount
TYPE: 16 bit unsigned
This variable tracks the number of 72 bit vectors stored in the FIFO_II.

76.3.3.7.3 Functions

T_TYPE(rx_raw)
This function is defined in 49.2.13.2.3.

76.3.3.7.4 Messages

DECODER_UNITDATA.indicate(rx_raw_in<71:0>)
A signal sent by the PCS Receive process conveying the next received 72 bit vector.

DUDI
Alias for DECODER_UNITDATA.indicate(rx_raw_in<71:0>).

76.3.3.7.5 State diagrams

The PCS Idle Insertion function shall implement the state diagram as shown in Figure 76–23. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

76.4 10GBASE-PR and 10/1GBASE-PRX PMA

The 10GBASE-PR PMA is derived from the 10GBASE-R PMA defined in Clause 51. This clause specifies 10GBASE-R extensions necessary to support P2MP operation. The 10/1GBASE-PRX PMA conceptually consists of a combination of transmit and receive functions specified for 10GBASE-PR and 1000BASE-PX defined in 65.3.2, as shown in Table 76–5.

76.4.1 Extensions for 10GBASE-PR-U and 10/1GBASE-PRX-U

76.4.1.1 Physical Medium Attachment (PMA) sublayer interfaces

In addition to the primitives of Clause 51, the following primitive is defined:

PMA_SIGNAL.request(tx_enable)
This primitive is mapped to PMD_SIGNAL.request(tx_enable). It is generated by the PCS's Data Detector. The effect of reception of PMD_SIGNAL.request(tx_enable) is defined in 75.3.1.4.

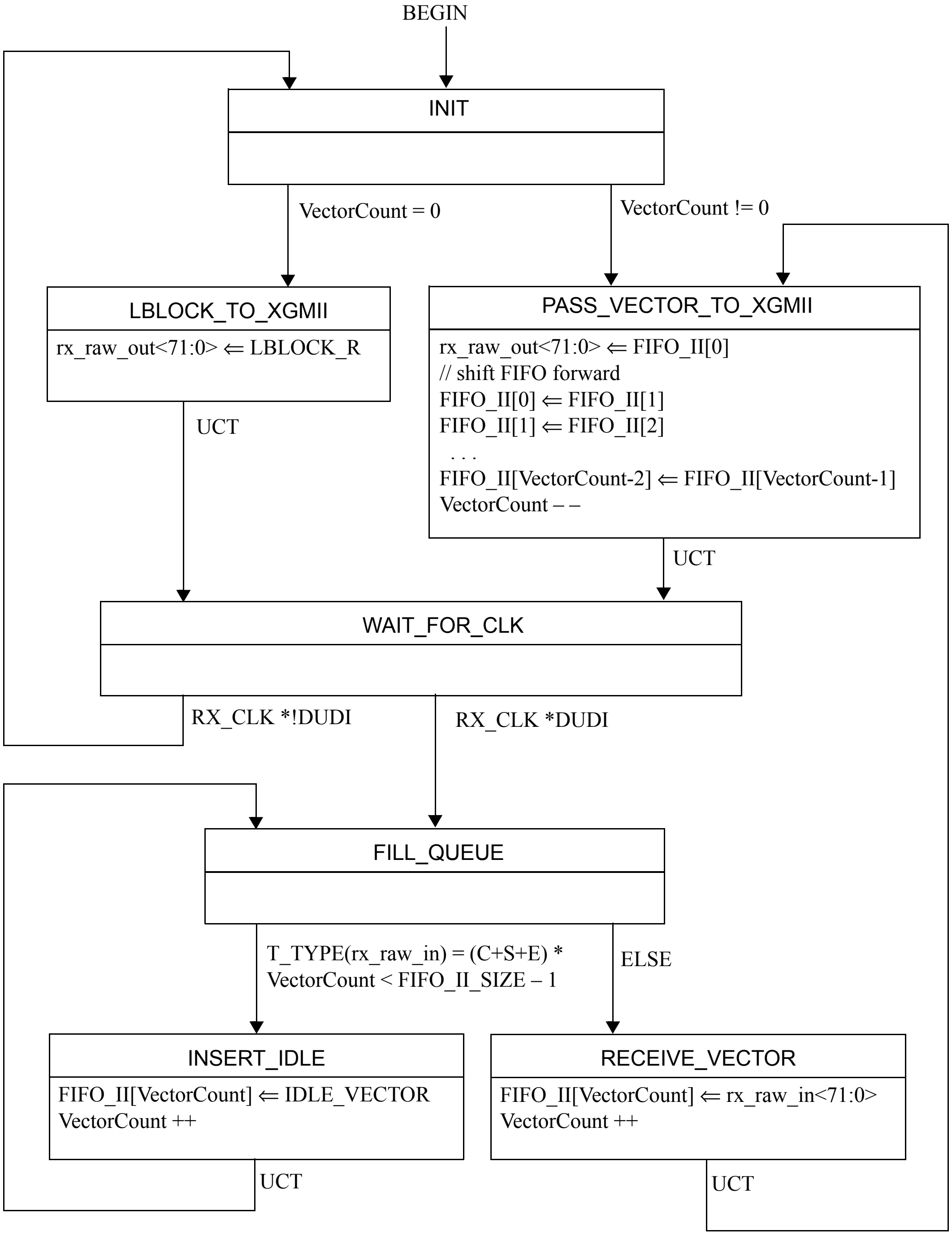


Figure 76–23—PCS Idle Insertion

tx_enable

The tx_enable parameter can take one of two values, ON or OFF.

Table 76–5—Derivation of PMA transmit and receive functions for 10GBASE-PR and 10/1GBASE-PRX

PMA	Transmit function	Receive function
10GBASE-PR-U	As specified in Clause 51 with extensions defined in 76.4.1.	
10/1GBASE-PRX-U	Identical to 1000BASE-PX-U. See 65.3.1.	Identical to 10GBASE-PR-U. See 76.4.1.
10GBASE-PR-D	As specified in Clause 51 with extensions defined in 76.4.2.	
10/1GBASE-PRX-D	Identical to 10GBASE-PR-D.	Identical to 1000BASE-PX-D. See 65.3.2.

76.4.1.2 Loop-timing specifications for ONUs

ONUs shall operate at the same time basis as the OLT, i.e., the ONU TX clock tracks the ONU RX clock, which in turn locks to OLT TX clock. Jitter transfer masks are defined in 75.7.

For the 10/1GBASE-PRX-U devices, the received clock PMA_RX_CLK is 644.53125 MHz (10.3125 GBd/16), however, the transmit clock PMA_TX_CLK is 125 MHz (1.25 GBd/10). The loop timing is achieved by multiplying the PMA_RX_CLK by 32 and dividing by 165.

76.4.2 Extensions for 10GBASE-PR-D and 10/1GBASE-PRX-D

76.4.2.1 CDR lock timing measurement for the upstream direction

CDR lock time (denoted T_{CDR}) is defined as a time interval required by the receiver to acquire phase lock on the incoming data stream. T_{CDR} is measured as the time elapsed from the moment when the electrical signal after the PMD at TP8, as illustrated in Figure 75–3, reaches the conditions specified in 75.7.15 for receiver settling time to the moment when the signal phase is recovered and jitter is maintained for a network with BER of no more than 10^{-3}.

A PMA instantiated in an OLT becomes synchronized at the bit level within 400 ns (T_{CDR}) after the appearance of a valid synchronization pattern (as defined in 76.3.2.5.2) at TP8.

76.4.2.1.1 Test specification

The test of the OLT PMA receiver T_{CDR} time assumes that there is an optical PMD transmitter at the ONU with well known T_{on} time as defined in 75.7.14, and an optical PMD receiver at the OLT with well-known $T_{receiver\_settling}$ time as defined in 75.7.15. After $T_{on} + T_{receiver\_settling}$ time, the parameters at TP8 reach within 15% of their steady state values, measure T_{CDR} as the time from the TX_ENABLE assertion, minus the known $T_{on} + T_{receiver\_settling}$ time, to the time the electrical signal at the output of the receiving PMA reaches up to the phase difference from the input signal of the transmitting PMA assuring BER of 10^{-3}, and maintaining its jitter specifications. The signal throughout this test is the synchronization pattern, as illustrated in Figure 76–14.

76.5 Protocol implementation conformance statement (PICS) proforma for Clause 76, Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for 10G-EPON[33]

76.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 76, Reconciliation Sublayer, Physical Coding Sublayer and Physical Media Attachment for 10G-EPON, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

76.5.2 Identification

76.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

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[33] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

76.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 76, Reconciliation Sublayer (RS), Physical Coding Sublayer (PCS), and Physical Media Attachment (PMA) for point-to-point media, types 10GBASE–PR and 10/1GBASE–PRX
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

76.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*OLT	OLT functionality	76.2.1	Device supports functionality required for OLT	O.1	Yes [ ] No [ ]
*ONU	ONU functionality	76.2.1	Device supports functionality required for ONU	O.1	Yes [ ] No [ ]

76.5.4 PICS proforma tables for Reconciliation Sublayer (RS), Physical Coding Sublayer (PCS), and Physical Media Attachment (PMA) for point-to-multipoint media, types 10GBASE–PR and 10/1GBASE–PRX

76.5.4.1 Operating modes of OLT MACs

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Unidirectional mode	76.2.3	Device operates in unidirectional transmission mode	OLT:M	Yes [ ]
OM2	Dual-rate mode	76.2.2.3	Device operates in dual-rate mode	OLT:O	Yes [ ] No [ ]

76.5.4.2 ONU and OLT variables

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	enable variable	65.1.3.1	True for ONU MAC, TRUE for OLT MAC if enabled, FALSE for OLT MAC if not enabled	M	Yes [ ]
FS2	mode variable	65.1.3.1	0 for ONU MAC, 0 or 1 for enabled OLT MAC	M	Yes [ ]
FS3	logical_link_id variable	76.2.6.1.1	Set to 0x7FFE until ONU MAC is registered Set to any value for enabled OLT MAC. Set to any value other then 0x7FFE for registered ONU MAC	M	Yes [ ]
FS4	multicast LLID support	76.2.6.1.1	Supports multicast LLID, multicast_link_id variable	O	Yes [ ] No [ ]

76.5.4.3 Preamble mapping and replacement

Item	Feature	Subclause	Value/Comment	Status	Support
PM1	CRC-8 generation	65.1.3.2	CRC calculation produces same result as serial implementation	M	Yes [ ] No [ ]
PM2	CRC-8 initial value	65.1.3.2	CRC shift register initialized to 0x00 before each new calculations	M	Yes [ ] No [ ]
PM3	SLD parsing	76.2.6.1.3.1	If SLD is not found then discard packet	M	Yes [ ] No[ ]
PM4	SLD replacement	76.2.6.1.3.1	Replace SLD with preamble	M	Yes [ ] No [ ]
PM5	LLID matching	76.2.6.1.3.2	If LLID does not match then discard packet	M	Yes [ ] No [ ]
PM6	multicast LLID matching	76.2.6.1.3.2	If multicast LLID matches accept the packet	*FS4 :M	Yes [ ] No [ ]
PM7	LLID replacement	76.2.6.1.3.2	Replace LLID with preamble	M	Yes [ ] No [ ]
PM8	Reserved LLID	76.2.6.1.3.2	registered ONU shall not transmit frames with a reserved LLID	M	Yes [ ] No [ ]
PM9	CRC-8 checking	65.1.3.3.3	If CRC does not match then discard packet	M	Yes [ ] No [ ]
PM10	CRC-8 replacement	65.1.3.3.3	Replace CRC with preamble	M	Yes [ ] No [ ]

76.5.4.4 Coding Rules

Item	Feature	Subclause	Value/Comment	Status	Support
C1	Encoder implements the code as specified	76.3.2.2		M	Yes [ ] No [ ]
C2	Decoder implements the code as specified	76.3.3.6		M	Yes [ ] No [ ]

76.5.4.5 Data detection

Item	Feature	Subclause	Value/Comment	Status	Support
DD1	Buffer depth	76.3.2.5.1	Depth sufficient to turn on laser and send laser synchronization pattern, Burst Delimiter pattern and a predefined number of Idle control character (receiver settle).	ONU:M	Yes [ ] No [ ]
DD2	OLT laser control	76.3.2.5.5	Always takes the value ON	OLT:M	Yes [ ] No [ ]
DD3	ONU State diagrams	76.3.2.5.7	Meets the requirements of Figure 76–16 and Figure 76–17	ONU:M	Yes [ ] No[ ]
DD4	OLT State diagrams	76.3.2.5.7	Meets the requirements of Figure 76–16 and Figure 76–17	OLT:M	Yes [ ] No[ ]

76.5.4.6 Idle control character deletion

Item	Feature	Subclause	Value/Comment	Status	Support
AIC1	Idle Deletion function implementation in ONU	76.3.2.1.5	Meets the requirements of Figure 76–10	ONU:M	Yes [ ] No [ ]
AIC2	Idle Deletion function implementation in OLT	76.3.2.1.5	Meets the requirements of Figure 76–9	OLT:M	Yes [ ] No [ ]

76.5.4.7 FEC requirements

Item	Feature	Subclause	Value/Comment	Status	Support
FE1	FEC Encoder	76.3.2.4	RS(255,223)	M	Yes [ ] No [ ]
FE2	FEC Decoder	76.3.3.3	RS(255,223)	M	Yes [ ] No [ ]

Item	Feature	Subclause	Value/Comment	Status	Support
FE3	Uncorrectable block indication	76.3.3.3	When activated, mark all 66 bit blocks in an uncorrectable block by setting all sync headers for the received payload blocks of the FEC codeword to the value of 00.	M	Yes [ ] No [ ]
FE4	Correctable codewords	76.3.3.3	Correct up to 16 symbols in a codeword and detect uncorrectable codewords	M	Yes [ ] No [ ]

76.5.4.8 FEC state diagrams

Item	Feature	Subclause	Value/Comment	Status	Support
SM1	Transmit	76.3.2.4.1	Meets the requirements of Figure 76–12	M	Yes [ ]
SM2	ONU synchronization	76.3.3.2.5	Meets the requirements of Figure 76–20	ONU:M	Yes [ ] No [ ]
SM3	OLT synchronization	76.3.3.1.4	Meets the requirements of Figure 76–18	OLT:M	Yes [ ] No [ ]
SM4	FEC decoding process	76.3.3.3.4	Meets the requirements of Figure 76–21	M	Yes [ ] No [ ]

76.5.4.9 PCS Idle Insertion

Item	Feature	Subclause	Value/Comment	Status	Support
PI1	Idle Insertion	76.3.3.7.5	Meets the requirements of Figure 76–23	M	Yes [ ] No [ ]

76.5.4.10 PMA

Item	Feature	Subclause	Value/Comment	Status	Support
BMC1	Loop timing	76.4.1.2	ONU RX clock tracks OLT TX clock	ONU:M	Yes [ ] No [ ]

76.5.4.11 Delay variation

Item	Feature	Subclause	Value/Comment	Status	Support
DV1	Delay variation	76.1.2	Combined delay variation through RS, PCS, and PMA sublayers is limited to 1 time_quantum	M	Yes [ ] No [ ]

77. Multipoint MAC Control for 10G–EPON

77.1 Overview

This clause deals with the mechanism and control protocols required in order to reconcile the 10 Gb/s P2MP topology into the Ethernet framework. The P2MP medium is a passive optical network (PON), an optical network with no active elements in the signal's path from source to destination. The only interior elements used in a PON are passive optical components, such as optical fiber, splices, and splitters. When combined with the Ethernet protocol, such a network is referred to as Ethernet passive optical network (EPON).

P2MP is an asymmetric medium based on a tree (or tree-and-branch) topology. The DTE connected to the trunk of the tree is called optical line terminal (OLT) and the DTEs connected at the branches of the tree are called optical network units (ONU). The OLT typically resides at the service provider's facility, while the ONUs are located at the subscriber premises.

In the downstream direction (from the OLT to an ONU), signals transmitted by the OLT pass through a 1:N passive splitter (or cascade of splitters) and reach each ONU. In the upstream direction (from the ONUs to the OLT), the signal transmitted by an ONU would only reach the OLT, but not other ONUs. To avoid data collisions and increase the efficiency of the subscriber access network, the ONU's transmissions are arbitrated. This arbitration is achieved by allocating a transmission window (grant) to each ONU. An ONU defers transmission until its grant arrives. When the grant arrives, the ONU transmits frames at wire speed during its assigned time slot.

A simplified P2MP topology example is depicted in Figure 77–1. Clause 67 provides additional examples of P2MP topologies.

Topics dealt with in this clause include allocation of upstream transmission resources to different ONUs, discovery and registration of ONUs into the network, and reporting of congestion to higher layers to allow for dynamic bandwidth allocation schemes and statistical multiplexing across the PON.

This clause does not deal with topics including bandwidth allocation strategies, authentication of end-devices, quality-of-service definition, provisioning, or management.

This clause specifies the multipoint control protocol (MPCP) to operate an optical multipoint network by defining a Multipoint MAC Control sublayer as an extension of the MAC Control sublayer defined in Clause 31, and supporting current and future operations as defined in Clause 31and annexes.

Each PON consists of a node located at the root of the tree assuming the role of OLT, and multiple nodes located at the tree leaves assuming roles of ONUs. The network operates by allowing only a single ONU to transmit in the upstream direction at a time. The MPCP located at the OLT is responsible for timing the different transmissions. Reporting of congestion by the different ONUs may assist in optimally allocating the bandwidth across the PON.

Automatic discovery of end stations is performed, culminating in registration through binding of an ONU to an OLT port by allocation of a Logical Link ID (see LLID in 76.2.6.1.3.2), and dynamic binding to a MAC connected to the OLT.

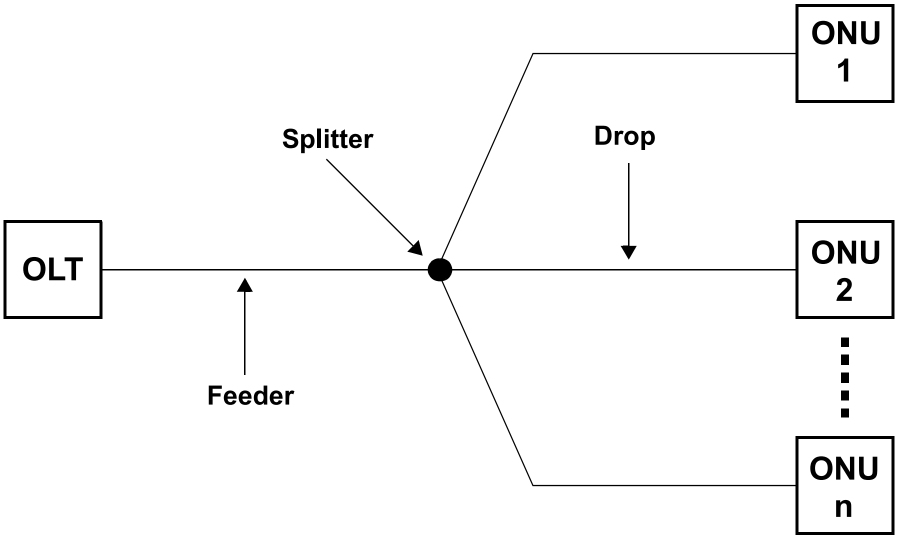


Figure 77–1—PON topology example

The Multipoint MAC Control functionality shall be implemented for subscriber access devices containing point-to-multipoint Physical Layer devices defined in Clause 75.

77.1.1 Goals and objectives

The goals and objectives of this clause are the definition of a point-to-multipoint Ethernet network utilizing an optical medium.

Specific objectives met include the following:

a) Support of point-to-point Emulation (P2PE) as specified
b) Support multiple LLIDs and MAC Clients at the OLT
c) Support a single LLID per ONU
d) Support a mechanism for single copy broadcast
e) Flexible architecture allowing dynamic allocation of bandwidth
f) Use of 32 bit timestamp for timing distribution
g) MAC Control based architecture
h) Ranging of discovered devices for improved network performance
i) Continuous ranging for compensating round trip time variation

77.1.2 Position of Multipoint MAC Control within the IEEE 802.3 hierarchy

Multipoint MAC Control defines the MAC control operation for optical point-to-multipoint networks. Figure 77–2 and Figure 77–3 depict the architectural positioning of the Multipoint MAC Control sublayer with respect to the MAC and the MAC Control client. The Multipoint MAC Control sublayer takes the place of the MAC Control sublayer to extend it to support multiple clients and additional MAC control functionality.

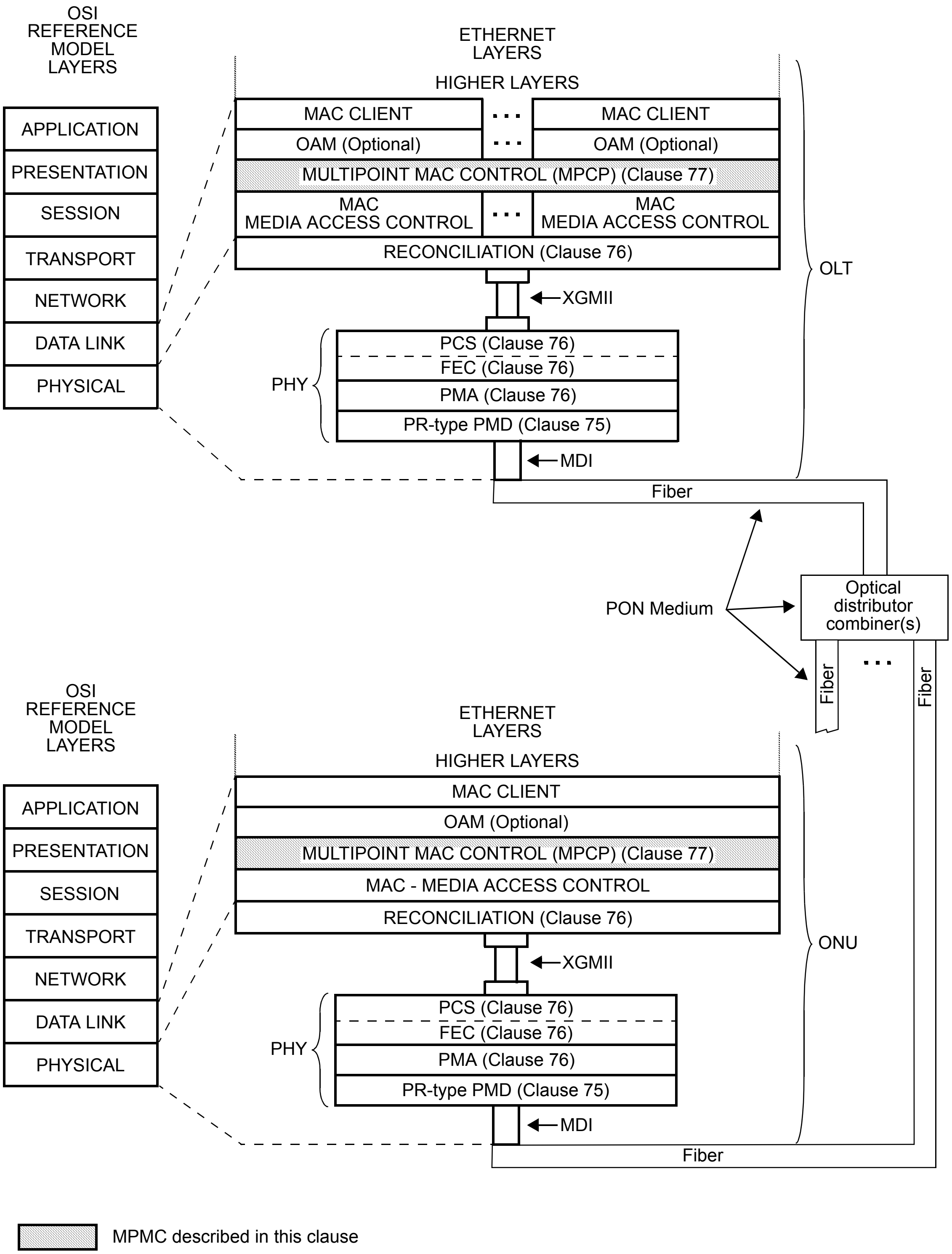
Multipoint MAC Control is defined using the mechanisms and precedents of the MAC Control sublayer. The MAC Control sublayer has extensive functionality designed to manage the real-time control and manipulation of MAC sublayer operation. This clause specifies the extension of the MAC Control mechanism to manipulate multiple underlying MACs simultaneously. This clause also specifies a specific protocol implementation for MAC Control.

The Multipoint MAC Control sublayer is specified such that it can support new functions to be implemented and added to this standard in the future. MultiPoint Control Protocol (MPCP), the management protocol for P2MP is one of these protocols. Non-real-time, or quasi-static control (e.g., configuration of MAC operational parameters) is provided by Layer Management. Operation of the Multipoint MAC Control sublayer is transparent to the MAC.

As depicted in Figure 77–2 and Figure 77–3, the layered system instantiates multiple MAC entities, using a single Physical Layer. The individual MAC instances offer a point-to-point emulation service between the OLT and the ONU. An additional MAC is instantiated to communicate to all 10G–EPON ONUs at once. This instance takes maximum advantage of the broadcast nature of the downstream channel by sending a single copy of a frame that is received by all 10G–EPON ONUs. This MAC instance is referred to as Single Copy Broadcast (SCB).

The ONU only requires one MAC instance since frame filtering operations are done at the RS layer before reaching the MAC. Therefore, MAC and layers above are emulation-agnostic at the ONU (see 76.2.6.1.3).

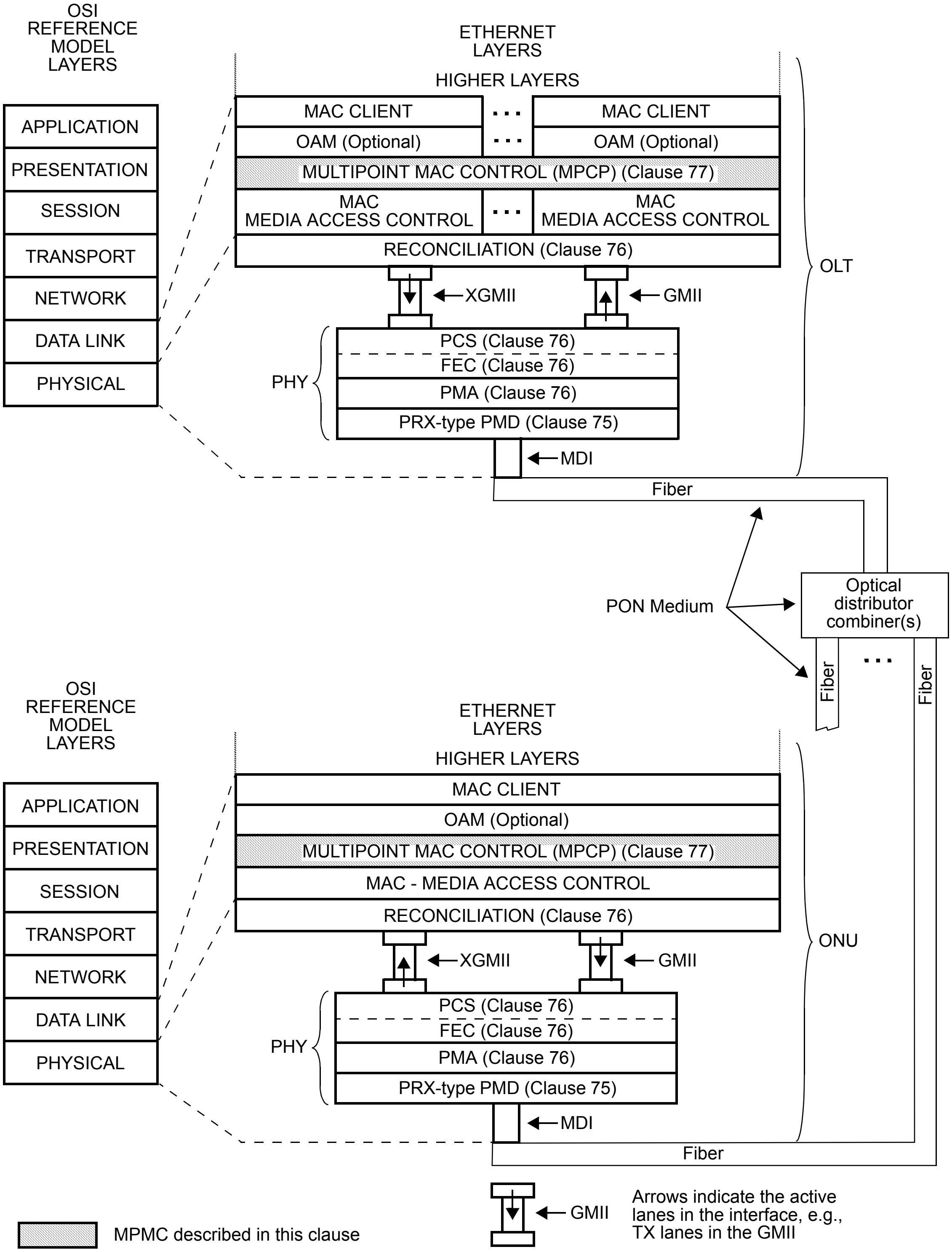
Although Figure 77–2 and Figure 77–3 and supporting text describe multiple MACs within the OLT, a single unicast MAC address may be used by the OLT. Within the EPON Network, MACs are uniquely identified by their LLIDs, which are dynamically assigned by the registration process.



XGMII = 10 GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION & MAINTENANCE
OLT = OPTICAL LINE TERMINAL

ONU = OPTICAL NETWORK UNIT
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 77–2—Relationship of Multipoint MAC Control and the OSI protocol stack for 10/10G–EPON (10 Gb/s downstream and 10 Gb/s upstream)



XGMII= 10 GIGABIT MEDIA INDEPENDENT INTERFACE
GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
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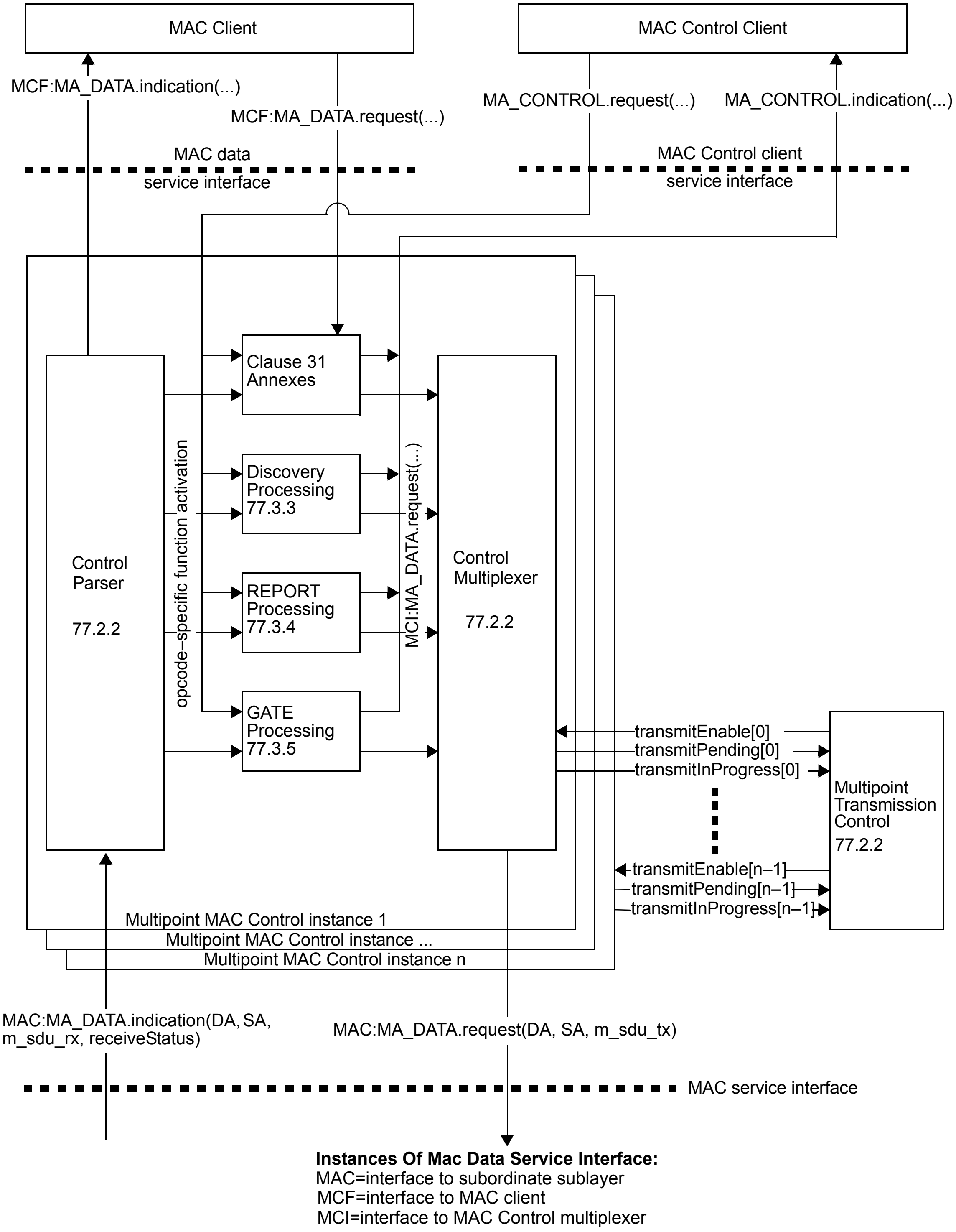
OLT = OPTICAL LINE TERMINAL

ONU = OPTICAL NETWORK UNIT
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 77–3—Relationship of Multipoint MAC Control and the OSI protocol stack for 10/1G–EPON (10 Gb/s downstream and 1 Gb/s upstream)

77.1.3 Functional block diagram

Figure 77–4 provides a functional block diagram of the Multipoint MAC Control architecture.



Instances Of Mac Data Service Interface:
MAC=interface to subordinate sublayer
MCF=interface to MAC client
MCI=interface to MAC Control multiplexer

Figure 77–4—Multipoint MAC Control functional block diagram

77.1.4 Service interfaces

The MAC Client communicates with the Control Multiplexer using the standard service interface specified in 2.3. Multipoint MAC Control communicates with the underlying MAC sublayer using the standard service interface specified in Annex 4A.3.2. Similarly, Multipoint MAC Control communicates internally using primitives and interfaces consistent with definitions in Clause 31.

77.1.5 State diagram conventions

The body of this standard comprises state diagrams, including the associated definitions of variables, constants, and functions. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails.

The notation used in the state diagrams follows the conventions of 21.5. State diagram timers follow the conventions of 14.2.3.2 augmented as follows:

a) [start x_timer, y] sets expiration of *y* to timer *x_timer*.
b) [stop x_timer] aborts the timer operation for *x_timer* asserting *x_timer_not_done* indefinitely.

The state diagrams use an abbreviation MACR as a shorthand form for MA_CONTROL.request and MACI as a shorthand form for MA_CONTROL.indication.

The vector notations used in the state diagrams for bit vector use 0 to mark the first received bit and so on (for example data[0:15]), following the conventions of 3.1 for bit ordering. When referring to an octet vector, 0 is used to mark the first received octet and so on (for example m_sdu[0..1]).

$a < b$: A function that is used to compare two (cyclic) time values. Returned value is true when b is larger than a allowing for wrap around of a and b. The comparison is made by subtracting b from a and testing the MSB. When MSB($a–b$) = 1 the value true is returned, else false is returned. In addition, the following functions are defined in terms of $a < b$:
$a > b$ is equivalent to !($a < b$ or $a = b$)
$a \geq b$ is equivalent to !($a < b$)
$a \leq b$ is equivalent to !($a > b$)

77.2 Multipoint MAC Control operation

As depicted in Figure 77–4, the Multipoint MAC Control functional block comprises the following functions:

a) *Multipoint Transmission Control*. This block is responsible for synchronizing Multipoint MAC Control instances associated with the Multipoint MAC Control. This block maintains the Multipoint MAC Control state and controls the multiplexing functions of the instantiated MACs.
b) *Multipoint MAC Control Instance n*. This block is instantiated for each MAC and respective MAC and MAC Control clients associated with the Multipoint MAC Control. It holds all the variables and state associated with operating all MAC Control protocols for the instance.
c) *Control Parser*. This block is responsible for parsing MAC Control frames, and interfacing with Clause 31 entities, the opcode specific blocks, and the MAC Client.
d) *Control Multiplexer*. This block is responsible for selecting the source of the forwarded frames.
e) *Clause 31 annexes*. This block holds MAC Control actions as defined in Clause 31 annexes for support of legacy and future services.
f) *Discovery, Report, and Gate Processing*. These blocks are responsible for handling the MPCP in the context of the MAC.

77.2.1 Principles of Multipoint MAC Control

As depicted in Figure 77–4, Multipoint MAC Control sublayer may instantiate multiple Multipoint MAC Control instances in order to interface multiple MAC and MAC Control clients above with multiple MACs below. A unique unicast MAC instance is used at the OLT to communicate with each ONU. The individual MAC instances utilize the point-to-point emulation service between the OLT and the ONU as defined in 76.2.

At the ONU, a single MAC instance is used to communicate with a MAC instance at the OLT. In that case, the Multipoint MAC Control contains only a single instance of the Control Parser/Multiplexer function.

Multipoint MAC Control protocol supports several MAC and client interfaces. Only a single MAC interface and Client interface is enabled for transmission at a time. There is a tight mapping between a MAC service interface and a Client service interface. In particular, the assertion of the MAC:MA_DATA.indication primitive in MAC *j* leads to the assertion of the MCF:MA_DATA.indication primitive to Client *j*. Conversely, the assertion of the request service interface in Client *i* leads to the assertion of the MAC:MA_DATA.request primitive of MAC *i*. Note that the Multipoint MAC sublayer need not receive and transmit packets associated with the same interface at the same time. Thus the Multipoint MAC Control acts like multiple MAC Controls bound together with common elements.

The scheduling algorithm is implementation dependent, and is not specified for the case where multiple transmit requests happen at the same time.

The reception operation is as follows. The Multipoint MAC Control instances generate MAC:MA_DATA.indication service primitives continuously to the underlying MAC instances. Since these MACs are receiving frames from a single PHY only one frame is passed from the MAC instances to Multipoint MAC Control. The MAC instance responding to the MAC:MA_DATA.indication is referred to as the enabled MAC, and its service interface is referred to as the enabled MAC interface. The MAC passes to the Multipoint MAC Control sublayer all valid frames. Invalid frames, as specified in 3.4, are not passed to the Multipoint MAC Control sublayer in response to a MAC:MA_DATA.indication service primitive.

The enabling of a transmit service interface is performed by the Multipoint MAC Control instance in collaboration with the Multipoint Transmission Control. Frames generated in the MAC Control are given priority over MAC Client frames, in effect, prioritizing the MA_CONTROL primitive over the MCF:MA_DATA primitive, and for this purpose MCF:MA_DATA.request primitives may be delayed, discarded or modified in order to perform the requested MAC Control function. For the transmission of this frame, the Multipoint MAC Control instance enables forwarding by the MAC Control functions, but the MAC Client interface is not enabled. The reception of a frame in a MAC results in generation of the MAC:MA_DATA.indication primitive on that MAC’s interface. Only one receive MAC interface is enabled at any given time since there is only one PHY interface.

The information of the enabled interfaces is stored in the controller state variables, and accessed by the Multiplexing Control block.

The Multipoint MAC Control sublayer uses the services of the underlying MAC sublayer to exchange both data and control frames.

Receive operation (MAC:MA_DATA.indication) at each instance:

a) A frame is received from the underlying MAC
b) The frame is parsed according to Length/Type field
c) MAC Control frames are demultiplexed according to opcode and forwarded to the relevant processing functions
d) Data frames (see 31.5.1) are forwarded to the MAC Client by asserting MCF:MA_DATA.indication primitives

Transmit operation (MAC:MA_DATA.request) at each instance:

e) The MAC Client signals a frame transmission by asserting MCF:MA_DATA.request, or

f) A protocol processing block attempts to issue a frame, as a result of a previous MA_CONTROL.request or as a result of an MPCP event that generates a frame.

g) When allowed to transmit by the Multipoint Transmission Control block, the frame is forwarded.

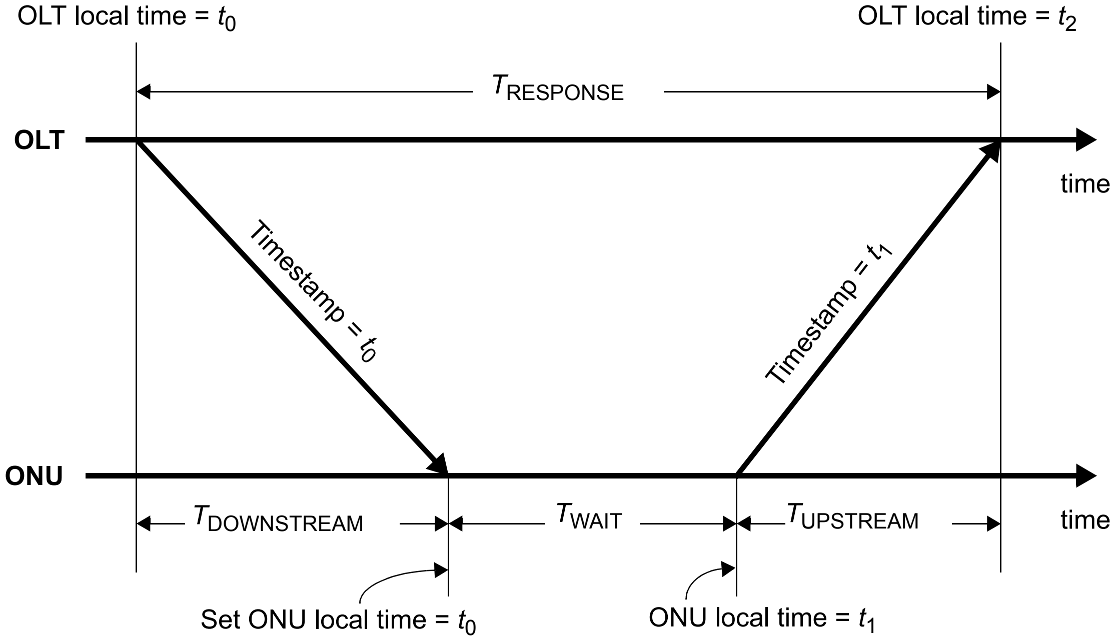
77.2.1.1 Ranging and timing process

Both the OLT and the ONU have 32 bit counters that increment every 16 ns. These counters provide a local time stamp. When either device transmits an MPCPDU, it maps its counter value into the timestamp field. The time of transmission of the first octet of the MPCPDU frame from the MAC Control to the MAC is taken as the reference time used for setting the timestamp value.

When the ONU receives MPCPDUs, it sets its counter according to the value in the timestamp field in the received MPCPDU.

When the OLT receives MPCPDUs, it uses the received timestamp value to calculate or verify a round trip time between the OLT and the ONU. The Round Trip Time (RTT) is equal to the difference between the timer value and the value in the timestamp field. The calculated RTT is notified to the client via the MA_CONTROL.indication primitive. The client can use this RTT for the ranging process.

A condition of *timestamp drift error* occurs when the difference between OLT's and ONU's clocks exceeds some predefined threshold. This condition can be independently detected by the OLT or an ONU. The OLT detects this condition when an absolute difference between new and old RTT values measured for a given ONU exceeds the value of guardThresholdOLT (see 77.2.2.1), as shown in Figure 77–11. An ONU detects the timestamp drift error condition when absolute difference between a timestamp received in an MPCPDU and the localTime counter exceeds guardThresholdONU (see 77.2.2.1), as is shown in Figure 77–12.



$T_{DOWNSTREAM}$ = downstream propagation delay

$T_{UPSTREAM}$ = upstream propagation delay

T_{WAIT} = wait time at ONU = $t_1 – t_0$

$T_{RESPONSE}$ = response time at OLT = $t_2 – t_0$

$$RTT = T_{DOWNSTREAM} + T_{UPSTREAM} = T_{RESPONSE} - T_{WAIT} = (t_2 - t_0) - (t_1 - t_0) = t_2 - t_1$$

Figure 77–5—Round trip time calculation

77.2.2 Multipoint transmission control, Control Parser, and Control Multiplexer

The purpose of the multipoint transmission control is to allow only one of the multiple MAC clients to transmit to its associated MAC and subsequently to the RS layer at one time by only asserting one transmitEnable signal at a time.

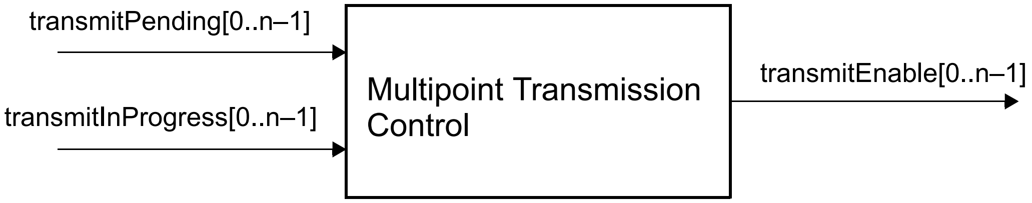


Figure 77–6—Multipoint Transmission Control service interfaces

Multipoint MAC Control Instance n function block communicates with the Multipoint Transmission Control using transmitEnable[n], transmitPending[n], and transmitInProgress[n] state variables (see Figure 77–4).

The Control Parser is responsible for opcode independent parsing of MAC frames in the reception path. By identifying MAC Control frames, demultiplexing into multiple entities for event handling is possible. Interfaces are provided to existing Clause 31 entities, functional blocks associated with MPCP, and the MAC Client.

The Control Multiplexer is responsible for forwarding frames from the MAC Control opcode-specific functions and the MAC Client to the MAC. Multiplexing is performed in the transmission direction. Given multiple MCF:MA_DATA.request primitives from the MAC Client, and MA_CONTROL.request primitives from the MAC Control Clients, a single MAC:MA_DATA.request service primitive is generated for transmission. At the OLT, multiple MAC instances share the same Multipoint MAC Control, as a result, the transmit block is enabled based on an external control signal housed in Multipoint Transmission Control for transmission overlap avoidance. At the ONU, the Gate Processing functional block interfaces for upstream transmission administration.

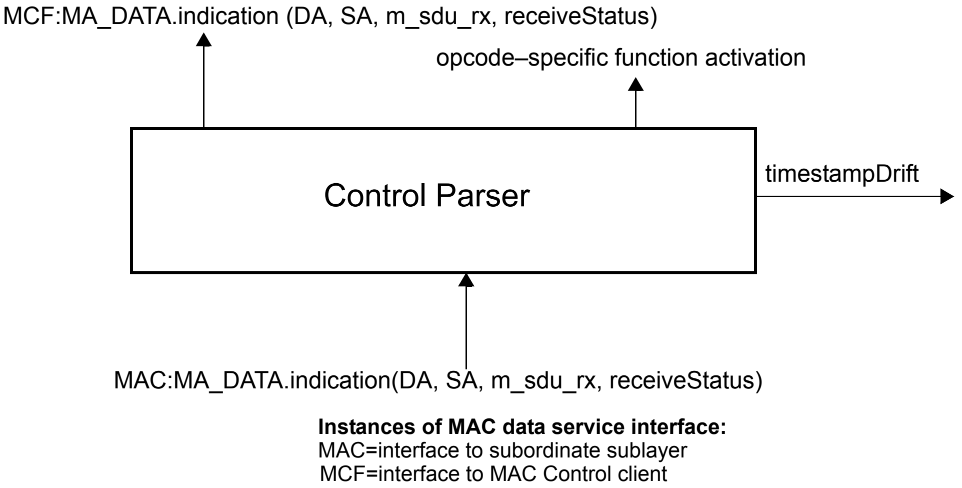
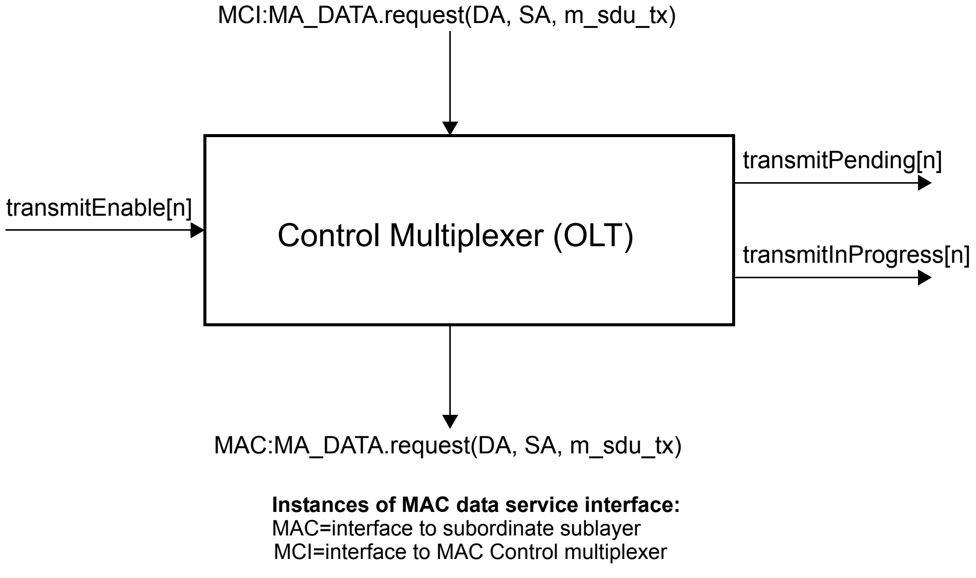
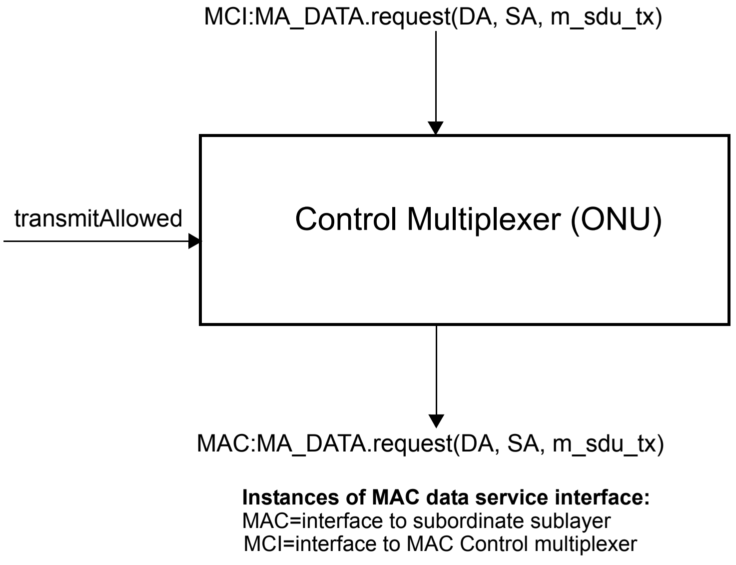


Figure 77–7—Control Parser service interfaces



NOTE—MAC:MA_DATA.request primitive may be issued from multiple MAC Control processing blocks.

Figure 77–8—OLT Control Multiplexer service interfaces



NOTE—MAC:MA_DATA.request primitive may be issued from multiple MAC Control processing blocks.

Figure 77–9—ONU Control Multiplexer service interfaces

77.2.2.1 Constants

FEC_CODEWORD_SIZE
TYPE: integer
This constant represents the size of FEC codeword in octets (FEC_PAYLOAD_SIZE + FEC_PARITY_SIZE).
Value: 248

FEC_PARITY_SIZE
TYPE: integer
This constant represents the size of FEC codeword parity field in octets.
Value: 32

FEC_PAYLOAD_SIZE
TYPE: integer
This constant represents the size of FEC codeword payload in octets.
VALUE: 216

guardThresholdOLT
TYPE: integer
This constant holds the maximum amount of drift allowed for a timestamp received at the OLT. This value is measured in units of time_quantum.
VALUE: 12

guardThresholdONU
TYPE: integer
This constant holds the maximum amount of drift allowed for a timestamp received at the ONU. This value is measured in units of time_quantum.
VALUE: 8

MAC_Control_type

TYPE: integer

The value of the Length/Type field as defined in 31.4.1.3.

VALUE: 0x8808

tailGuard

TYPE: integer

This constant holds the value used to reserve space at the end of the upstream transmission at the ONU in addition to the size of last MAC service data unit (m_sdu) in units of octets. Space is reserved for the MAC overheads including: preamble, SFD, DA, SA, Length/Type, FCS, and minimum interpacket gap. The sizes of the above listed MAC overhead items are described in 3.1.1. The size of the minimum IPG is described in 4A.4.2.

VALUE: 38

time_quantum

This variable is defined in 64.2.2.1.

tqSize

TYPE: integer

This constant represents time_quantum in octet transmission times.

VALUE: 20

77.2.2.2 Counters

localTime

TYPE: 32 bit unsigned

This variable holds the value of the local timer used to control MPCP operation. This variable is advanced by a timer at 62.5 MHz, and counts in time_quanta. At the OLT the counter shall track the transmit clock, while at the ONU the counter shall track the receive clock. For accuracy of receive clock see 76.4.1.2. It is reloaded with the received timestamp value (from the OLT) by the Control Parser (see Figure 77–12). Changing the value of this variable while running using Layer Management is highly undesirable and is unspecified.

77.2.2.3 Variables

BEGIN

TYPE: Boolean

This variable is used when initiating operation of the functional block state diagram. It is set to true following initialization and every reset.

fecOffset

TYPE: 32 bit unsigned

A variable that advances by 1 after every 8 bit times. After reaching the value of FEC_CODEWORD_SIZE, this variable is reset to zero. In the OLT, this variable is initialized to 0 at system initialization. In the ONU, this variable is assigned in the ONU Control Multiplexer state diagram (see Figure 77–14).

NOTE—Notation fecOffset[1:0] refers to two least significant bits of this variable.

data_rx

TYPE: bit array

This variable represents a 0–based bit array corresponding to the payload of a received MPCPDU. This variable is used to parse incoming MPCPDU frames.

data_tx
TYPE: bit array
This variable represents a 0-based bit array corresponding to the payload of an MPCPDU being transmitted. This variable is used to access payload of outgoing MPCPDU frames, for example to set the timestamp value.

grantStart
TYPE: Boolean
This variable indicates beginning of a grant transmission. It is set to true in the GATE Processing ONU Activation state diagram (see Figure 77–30) when a new grant activates. It is reset to false after the transmission of the first frame in the grant (see Figure 77–14). This variable is defined in ONU only.

IdleGapCount
TYPE: 32-bit unsigned
This variable represents length of gap between subsequent frames, expressed in the unit of octet time. This variable advances by 1 after every 8-bit times.

newRTT
TYPE: 16 bit unsigned
This variable temporary holds a newly–measured Round Trip Time to the ONU. The new RTT value is represented in units of time_quanta.

m_sdu_rx
TYPE: bit array
Equal to the concatenation of the Length/Type and data_rx variables.

m_sdu_tx
TYPE: bit array
Equal to the concatenation of the Length/Type and data_tx variables.

m_sdu_ctl
TYPE: bit array
Equal to the concatenation of the MAC_Control_type and data_tx variables.

OctetsRemaining
TYPE: 32 bit unsigned
This variable is an alias for the expression (((stopTime – localTime) × tqSize) – tqOffset). It denotes the number of octets that can be transmitted between the current time and the end of the grant.

OctetsRequired
TYPE: 16 bit unsigned
This variable represents a total transmission time of next packet and is used to check whether the next packet fits in the remainder of ONU’s transmission window. The value of OctetsRequired includes packet transmission time, tailGuard defined in 77.2.2.1, and FEC parity data overhead. This variable is measured in units of octets.

opcode_rx
TYPE: 16 bit unsigned
This variable holds an opcode of the last received MPCPDU.

opcode_tx
TYPE: 16 bit unsigned
This variable holds an opcode of an outgoing MPCPDU.

packet_initiate_delay
TYPE: 16 bit unsigned
This variable is used to set the time–out interval for packet_initiate_timer defined in 77.2.2.5. The packet_initiate_delay value is represented in units of octets.

ResetBound
TYPE: 32-bit unsigned
This variable represents the value of DelayBound (see 76.3.1.2) expressed in units of octet time (i.e., ResetBound = 8 * DelayBound).

RTT
TYPE: 16 bit unsigned
This variable holds the measured Round Trip Time to the ONU. The RTT value is represented in units of time_quanta.

stopTime
TYPE: 32 bit unsigned
This variable holds the value of the localTime counter corresponding to the end of the nearest grant. This value is set by the Gate Processing function as described in 77.3.5.

timestamp
TYPE: 32 bit unsigned
This variable holds the value of timestamp of the last received MPCPDU frame.

timestampDrift
TYPE: Boolean
This variable is used to indicate whether an error is signaled as a result of uncorrectable timestamp drift.

tqOffset
TYPE: 8 bit unsigned
This variable denotes the offset (in octet times) of the current actual time from the localTime variable (which maintains the current time in units of time_quanta).

transmitAllowed
TYPE: Boolean
This variable is used to control PDU transmission at the ONU. It is set to true when the transmit path is enabled, and is set to false when the transmit path is being shut down. transmitAllowed changes its value according to the state of the Gate Processing functional block.

transmitEnable
TYPE: Boolean array
This array contains one element per each Multipoint MAC Control instance. Elements of this array are used to control the transmit path in the Multipoint MAC Control instance at the OLT. Setting an element to TRUE indicates that the selected instance is permitted to transmit a frame. Setting it to FALSE inhibits the transmission of frames in the selected instance. Only one element of transmitEnable should be set to TRUE at a time.

transmitInProgress
TYPE: Boolean array

This array contains one element per each Multipoint MAC Control instance. The element *j* of this array set to on indicates that the Multipoint MAC Control instance *j* is in the process of transmitting a frame.

transmitPending

TYPE: Boolean array

This array contains one element per each Multipoint MAC Control instance. The element *j* of this array set to on indicates that the Multipoint MAC Control instance *j* is ready to transmit a frame.

77.2.2.4 Functions

abs(n)

This function returns the absolute value of the parameter n.

Opcode–specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

CheckGrantSize(length)

This function calculates the future time at which the transmission of the current frame (including the FEC parity overhead) is completed.

$$\text{CheckGrantSize(length)} = \left\lceil \frac{\text{fecOffset} + \text{length}}{\text{FEC\_PAYLOAD\_SIZE}} \right\rceil \times \text{FEC\_CODEWORD\_SIZE} - \text{fecOffset}$$

NOTE—The notation $\lceil x \rceil$ represents a *ceiling* function, which returns the value of its argument *x* rounded up to the nearest integer.

FEC_Overhead(length)

This function calculates the additional amount of time (in octet times) that the MPCP control multiplexer waits following transmission of a frame of size ‘length’ by the MAC. The additional time is added to allow the insertion of parity data into the frame by the PHY layer. As described in 76.3.2.4, FEC encoder adds 32 parity octets for each block of 216 data or control octets. FEC_Overhead() returns the number of octets that the PHY inserts during transmission of a particular packet and its subsequent IPG. Parameter ‘length’ represents the size of an entire frame including preamble, SFD, DA, SA, Length/Type, FCS, and IPG. The following formula is used to calculate the overhead:

$$\text{FEC\_Overhead(length)} = 12 + \text{FEC\_PARITY\_SIZE} \times \left\lfloor \frac{\text{fecOffset} + \text{length}}{\text{FEC\_PAYLOAD\_SIZE}} \right\rfloor$$

NOTE—The notation $\lfloor x \rfloor$ represents a *floor* function, which returns the value of its argument *x* rounded down to the nearest integer.

select()

This function selects the next Multipoint MAC Control instance allowed to initiate transmission of a frame. The function returns an index to the transmitPending array for which the value is not false. The selection criteria in the presence of multiple active elements in the list is implementation dependent.

SelectFrame()

This function enables the interface, which has a pending frame. If multiple interfaces have frames waiting at the same time, only one interface is enabled. The selection criteria is not specified, except for the case when some of the pending frames have Length/Type = MAC_Control. In this case, one of the interfaces with a pending MAC Control frame shall be enabled.

sizeof(sdu)

This function returns the size of the sdu in octets.

transmissionPending()

This function returns true if any of the Multipoint MAC Control instances has a frame waiting to be transmitted. The function can be represented as:

```
transmissionPending() =
   transmitPending[0] +
   transmitPending[1] +
   ... +
   transmitPending[n-1]
```

where n is the total number of Multipoint MAC Control instances.

77.2.2.5 Timers

packet_initiate_timer

This timer is used to delay frame transmission from MAC Control to avoid variable MAC delay while MAC enforces IPG after a previous frame. In addition, this timer increases interframe spacing just enough to accommodate the extra parity data to be added by the FEC encoder.

77.2.2.6 Messages

MAC:MA_DATA.indication(DA, SA, m_sdu, receiveStatus)

The service primitive is defined in 31.3.

MCF:MA_DATA.indication(DA, SA, m_sdu, receiveStatus)

The service primitive is defined in 31.3.

MAC:MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 31.3. The action invoked by this service primitive is not considered to end until the transmission of the frame by the MAC has concluded. The ability of the MAC control layer to determine this is implementation dependent.

MCF:MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 31.3.

77.2.2.7 State diagrams

The Multipoint transmission control function in the OLT shall implement state diagram shown in Figure 77–10. Control parser function in the OLT shall implement state diagram shown in Figure 77–11. Control parser function in the ONU shall implement state diagram shown in Figure 77–12. Control multiplexer function in the OLT shall implement state diagram shown in Figure 77–13. Control multiplexer function in the ONU shall implement state diagram shown in Figure 77–14.

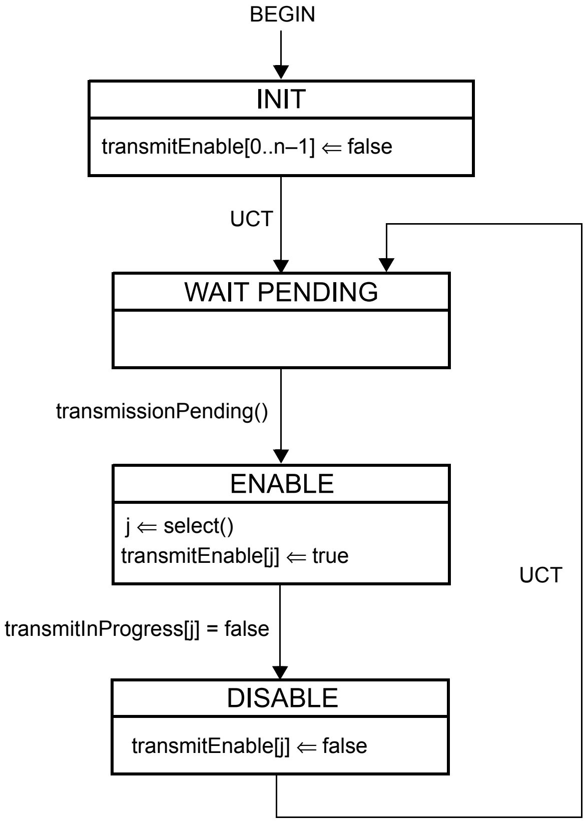
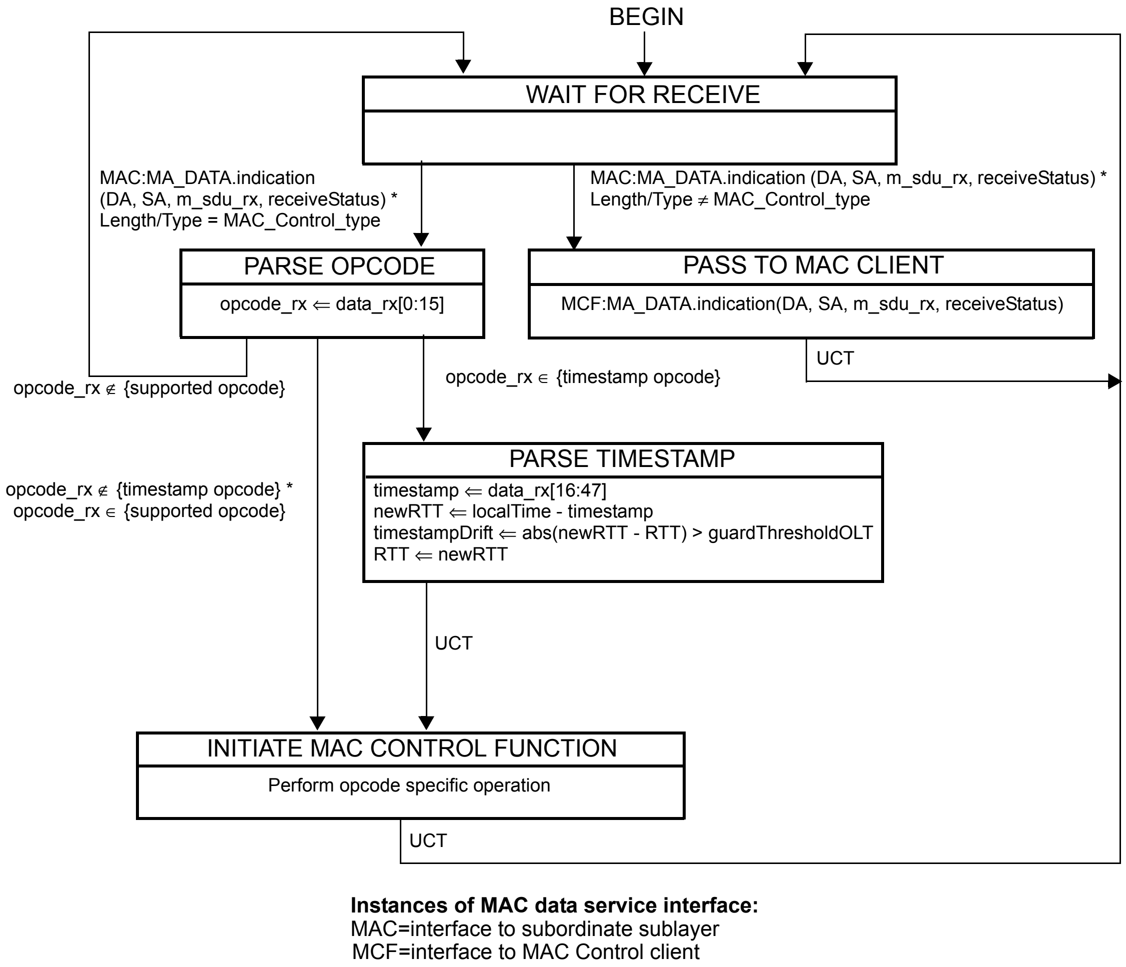


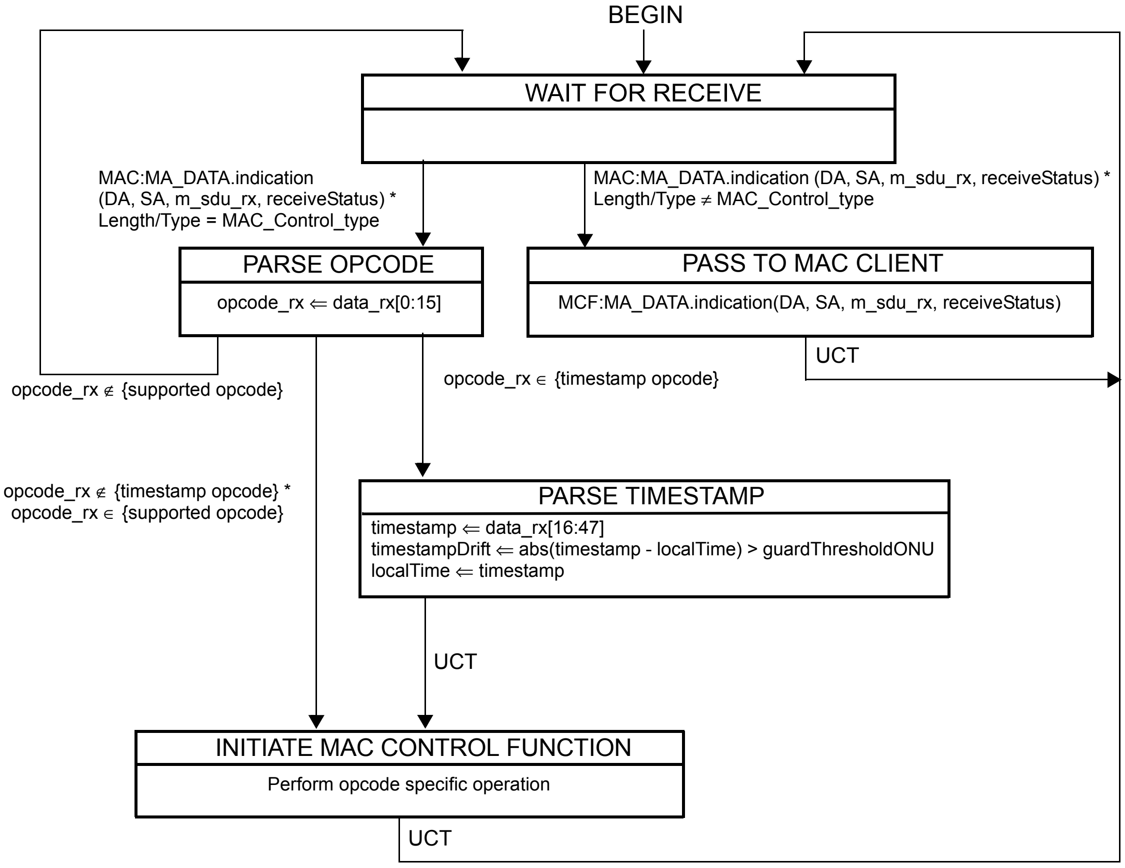
Figure 77–10—OLT Multipoint Transmission Control state diagram



NOTE—The opcode–specific operation is launched as a parallel process by the MAC Control sublayer, and not as a synchronous function. Progress of the generic MAC Control Receive state diagram (as shown in this figure) is not implicitly impeded by the launching of the opcode specific function.

Refer to Annex 31A for list of supported opcodes and timestamp opcodes.

Figure 77–11—OLT Control Parser state diagram

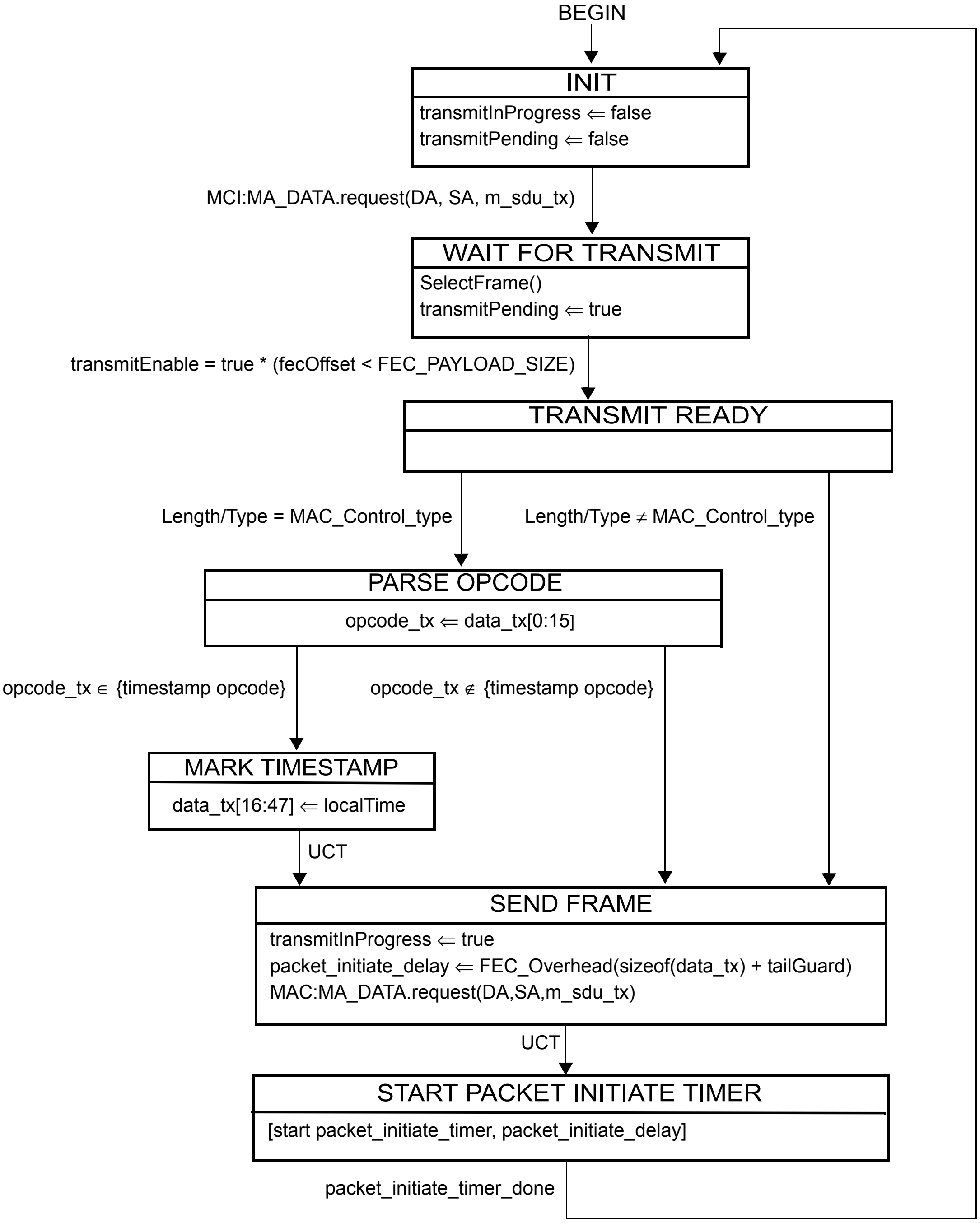


Instances of MAC data service interface:
MAC=interface to subordinate sublayer
MCF=interface to MAC Control client

NOTE—The opcode–specific operation is launched as a parallel process by the MAC Control sublayer, and not as a synchronous function. Progress of the generic MAC Control Receive state diagram (as shown in this figure) is not implicitly impeded by the launching of the opcode specific function.

Refer to Annex 31A for list of supported opcodes and timestamp opcodes.

Figure 77–12—ONU Control Parser state diagram



Instances of MAC data service interface:
MAC=interface to subordinate sublayer
MCI=interface to MAC Control multiplexer

Figure 77–13—OLT Control Multiplexer state diagram

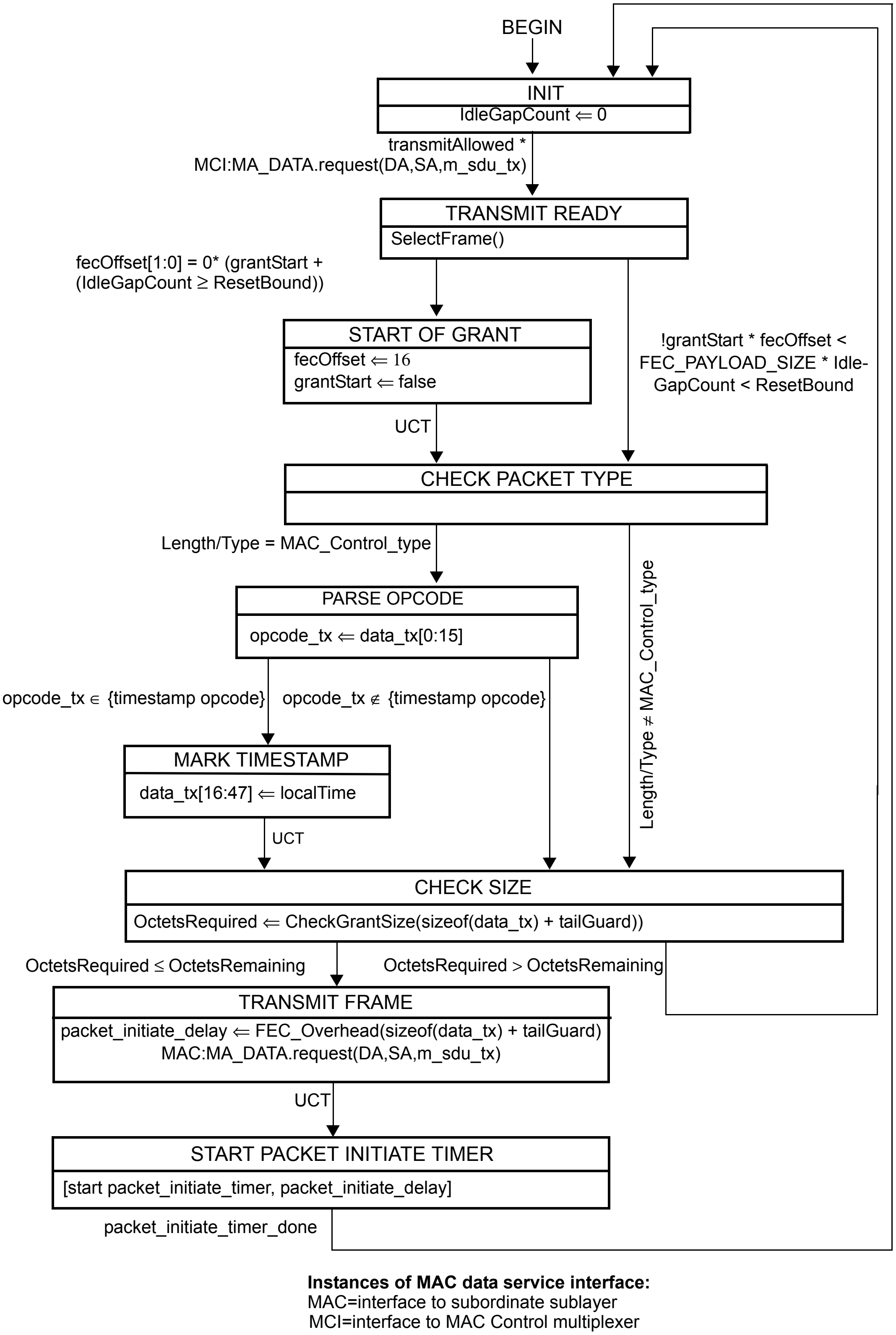


Figure 77–14—ONU Control Multiplexer state diagram

77.3 Multipoint Control Protocol (MPCP)

As depicted in Figure 77–4, the Multipoint MAC Control functional block comprises the following functions:

a) *Discovery Processing*. This block manages the discovery process, through which an ONU is discovered and registered with the network while compensating for RTT.
b) *Report Processing*. This block manages the generation and collection of report messages, through which bandwidth requirements are sent upstream from the ONU to the OLT.
c) *Gate Processing*. This block manages the generation and collection of gate messages, through which multiplexing of multiple transmitters is achieved.

As depicted in Figure 77–4, the layered system may instantiate multiple MAC entities, using a single Physical Layer. Each instantiated MAC communicates with an instance of the opcode specific functional blocks through the Multipoint MAC Control. In addition some global variables are shared across the multiple instances. Common state control is used to synchronize the multiple MACs using MPCP procedures. Operation of the common state control is generally considered outside the scope of this document.

77.3.1 Principles of Multipoint Control Protocol

Multipoint MAC Control enables a MAC Client to participate in a point-to-multipoint optical network by allowing it to transmit and receive frames as if it was connected to a dedicated link. In doing so, it employs the following principles and concepts:

a) A MAC client transmits and receives frames through the Multipoint MAC Control sublayer.
b) The Multipoint MAC Control decides when to allow a frame to be transmitted using the client interface Control Multiplexer.
c) Given a transmission opportunity, the MAC Control may generate control frames that would be transmitted in advance of the MAC Client's frames, utilizing the inherent ability to provide higher priority transmission of MAC Control frames over MAC Client frames.
d) Multiple MACs operate on a shared medium by allowing only a single MAC to transmit upstream at any given time across the network using a time-division multiple access (TDMA) method.
e) Such gating of transmission is orchestrated through the Gate Processing function.
f) New devices are discovered in the network and allowed transmission through the Discovery Processing function.
g) Fine control of the network bandwidth distribution can be achieved using feedback mechanisms supported in the Report Processing function.
h) The operation of P2MP network is asymmetric, with the OLT assuming the role of master, and the ONU assuming the role of slave.

77.3.2 Compatibility considerations

77.3.2.1 PAUSE operation

Even though MPCP is compatible with flow control, optional use of flow control may not be efficient in the case of large propagation delay. If flow control is implemented, then the timing constraints in Annex 31B supplement the constraints found at 77.3.2.4.

NOTE—MAC at an ONU can receive frames from unicast channel and SCB channel. If the SCB channel is used to broadcast data frames to multiple ONUs, the ONU's MAC may continue receiving data frames from SCB channel even after the ONU has issued a PAUSE request to its unicast remote-end.

77.3.2.2 Optional Shared LAN emulation

By combining P2PE, suitable filtering rules at the ONU, and suitable filtering and forwarding rules at the OLT, it is possible to emulate an efficient shared LAN. Support for shared LAN emulation is optional, and requires an additional layer above the MAC, which is out of scope for this document. Thus, shared LAN emulation is introduced here for informational purposes only.

Specific behavior of the filtering layer at the RS is specified in 76.2.6.1.3.2.

77.3.2.3 Multicast and single copy broadcast support

In the downstream direction, the PON is a broadcast medium. In order to make use of this capability for forwarding broadcast frames from the OLT to multiple recipients without multiple duplication for each ONU, the SCB and multicast LLID support is introduced.

The OLT has at least one MAC associated with every ONU. In addition one more MAC at the OLT is marked as the SCB MAC. Moreover, the OLT has a multicast MAC associated with each defined multicast LLID. The SCB MAC handles all downstream broadcast traffic, but is never used in the upstream direction for client traffic, except for client registration. Similarly, the multicast MACs handle downstream multicast traffic, but are never used in the upstream direction for client traffic. Optional higher layers may be implemented to perform selective broadcast and multicast of frames. Such layers may require additional MACs (multicast MACs) to be instantiated in the OLT for some or all ONUs increasing the total number of MACs beyond the number of ONUs + 1.

When connecting the SCB MAC or a multicast MAC to an IEEE 802.1D bridge port it is possible that loops may be formed due to the broadcast or multicast nature of the associated LLIDs. Thus it is recommended that this MAC not be connected to an IEEE 802.1D bridge port.

Configuration of SCB channels as well as filtering and marking of frames for support of SCB is defined in 76.2.6.1.3.2 for 10G–EPON compliant Reconciliation Sublayers.

77.3.2.4 Delay requirements

The MPCP protocol relies on strict timing based on distribution of timestamps. A compliant implementation needs to guarantee a constant delay through the MAC and PHY in order to maintain the correctness of the timestamping mechanism. The actual delay is implementation dependent; however, a complying implementation shall maintain a delay variation of no more than 1 time_quantum through the MAC.

The OLT shall not grant less than 1024 time_quanta into the future, in order to allow the ONU processing time when it receives a gate message. The ONU shall process all messages in less than this period. The OLT shall not issue more than one message every 1024 time_quanta to a single ONU. The unit of time_quantum is defined in 77.2.2.1.

77.3.3 Discovery processing

Discovery is the process whereby newly connected or off-line ONUs are provided access to the PON. The process is driven by the OLT, which periodically makes available Discovery Windows during which off-line ONUs are given the opportunity to make themselves known to the OLT. The periodicity of these windows is unspecified and left up to the implementer. The OLT signifies that a discovery period is occurring by broadcasting a discovery GATE MPCPDU, which includes the starting time and length of the discovery window, along with the Discovery Information flag field, as defined in 77.3.6.1. With the appropriate settings of individual flags contained in this 16 bit wide field, the OLT notifies all the ONUs about its upstream and downstream channel transmission capabilities. Note that the OLT may simultaneously support more than one data rate in the given transmission direction.

Off-line ONUs, upon receiving a Discovery GATE MPCPDU, wait for the period to begin and then transmit a REGISTER_REQ MPCPDU to the OLT. Discovery windows are unique in that they are the only times when multiple ONUs can access the PON simultaneously, and transmission overlap can occur. In order to reduce transmission overlaps, a contention algorithm is used by all ONUs. Measures are taken to reduce the probability for overlaps by artificially simulating a random distribution of distances from the OLT. Each ONU waits a random amount of time before transmitting the REGISTER_REQ MPCPDU that is shorter than the length of the discovery window. It should be noted that multiple valid REGISTER_REQ MPCPDUs can be received by the OLT during a single discovery window. Included in the REGISTER_REQ MPCPDU is the ONU's MAC address and number of maximum pending grants. Additionally, a registering ONU notifies the OLT of its transmission capabilities in the upstream and downstream channels by setting appropriately the flags in the Discovery Information field, as specified in 77.3.6.3.

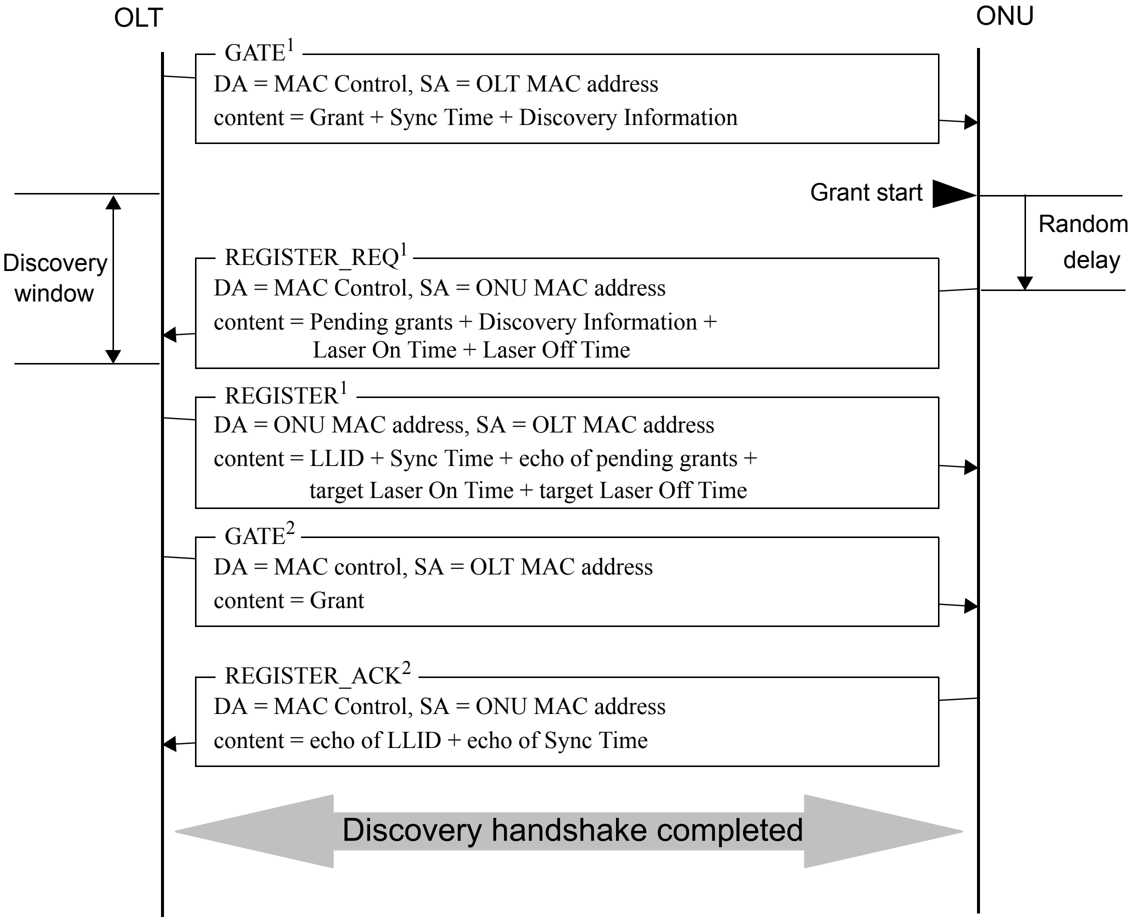
Note that even though a compliant ONU is not prohibited from supporting more than one data rate in any transmission channel, it is expected that a single supported data rate for upstream and downstream channel is indicated in the Discovery Information field. Moreover, in order to assure maximum utilization of the upstream channel and to decrease the required size of the guard band between individual data bursts, the registering ONU notifies the OLT of the laser on/off times, by setting appropriate values in the Laser On Time and Laser Off Time fields, where both values are expressed in the units of time_quanta.

Upon receipt of a valid REGISTER_REQ MPCPDU, the OLT registers the ONU, allocating and assigning a new port identity (LLID), and bonding a corresponding MAC to the LLID.

The next step in the process is for the OLT to transmit a REGISTER MPCPDU to the newly discovered ONU, which contains the ONU's LLID, and the OLT's required synchronization time. Moreover, the OLT echoes the maximum number of pending grants. The OLT also sends the target value of laser on time and laser off time, which may be different than laser on time and laser off time delivered by the ONU in the REGISTER_REQ MPCPDU.

The OLT now has enough information to schedule the ONU for access to the PON and transmits a standard GATE message allowing the ONU to transmit a REGISTER_ACK. Upon receipt of the REGISTER_ACK, the discovery process for that ONU is complete, the ONU is registered and normal message traffic can begin. It is the responsibility of Layer Management to perform the MAC bonding, and start transmission from/to the newly registered ONU. The discovery message exchange is illustrated in Figure 77–15.

There may exist situations when the OLT requires that an ONU go through the discovery sequence again and reregister. Similarly, there may be situations where an ONU needs to inform the OLT of its desire to deregister. The ONU can then reregister by going through the discovery sequence. For the OLT, the REGISTER message may indicate a value, Reregister or Deregister, that if either is specified forces the receiving ONU into reregistering. For the ONU, the REGISTER_REQ message contains the Deregister bit that signifies to the OLT that this ONU should be deregistered.



[1] Messages sent on a broadcast channel
[2] Messages sent on unicast channels

Figure 77–15—Discovery handshake message exchange

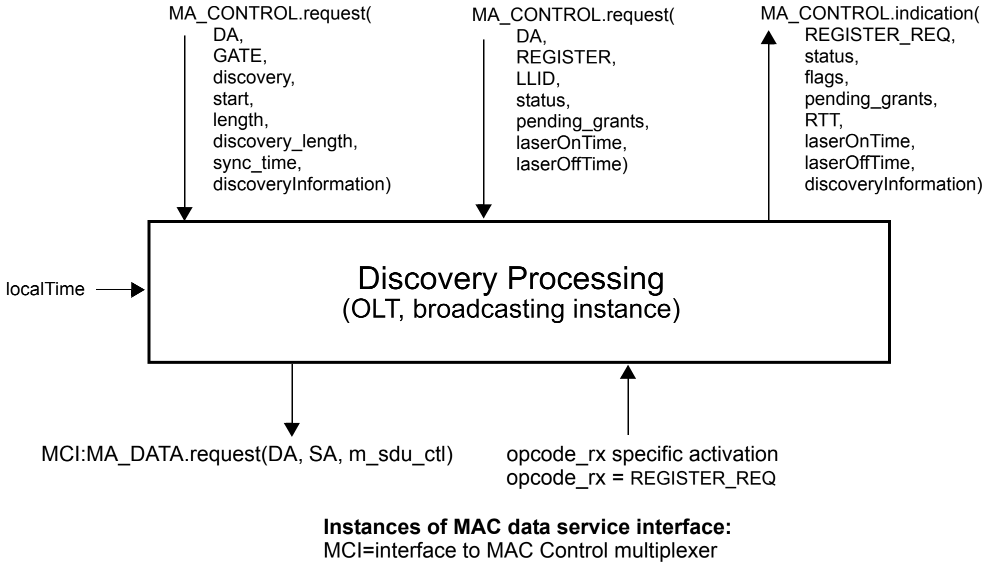


Figure 77–16—Discovery Processing service interfaces (OLT, broadcasting instance)

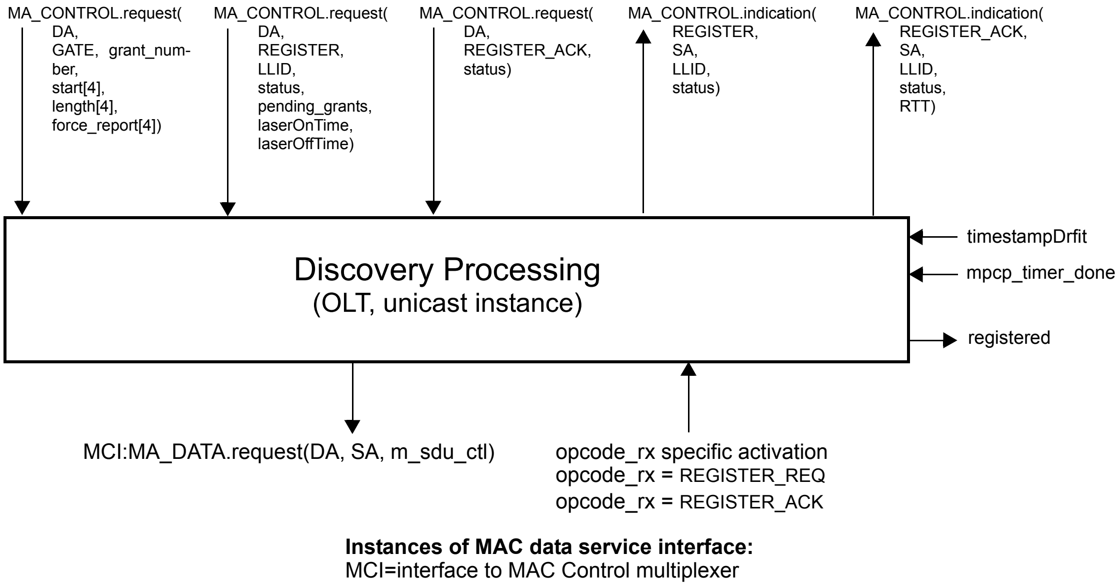
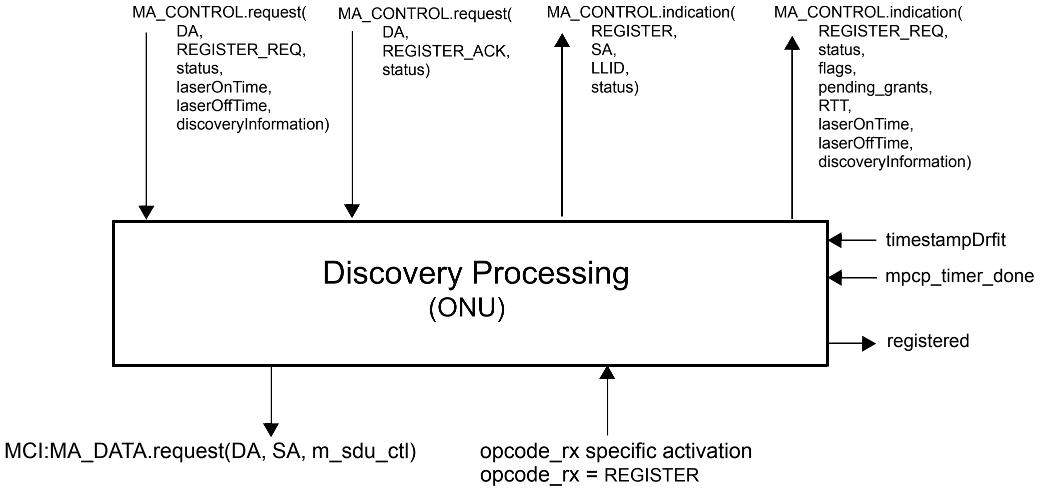


Figure 77–17—Discovery Processing service interfaces (OLT, unicasting instance)



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 77–18—Discovery Processing service interfaces (ONU)

77.3.3.1 Constants

laserOffTimeCapability

TYPE: 8 bit unsigned

This constant represents the time required to terminate the laser, in units of time_quantum. While the default value corresponds to a maximum allowed T_{off} (as specified in Table 75–8 and Table 75–9), implementations may set it to the actual value time period required for turning off the PMD, as specified in 75.7.14.

VALUE: 0x20 (512 ns, default value)

laserOnTimeCapability

TYPE: 8 bit unsigned

This constant represents the time required to initialize the laser, in units of time_quantum. While the default value corresponds to a maximum allowed T_{on} (as specified in Table 75–8 and Table 75–9), implementations may set it to the actual value time period required for turning on the PMD, as specified in 75.7.14.

VALUE: 0x20 (512 ns, default value)

77.3.3.2 Variables

BEGIN

This variable is defined in 77.2.2.3.

data_rx

This variable is defined in 77.2.2.3.

data_tx

This variable is defined in 77.2.2.3.

grantEndTime

TYPE: 32 bit unsigned

This variable holds the time at which the OLT expects the ONU grant to complete. Failure of a

REGISTER_ACK message from an ONU to arrive at the OLT before grantEndTime is a fatal error in the discovery process, and causes registration to fail for the specified ONU, who may then retry to register. The value of grantEndTime is measured in units of time_quantum.

insideDiscoveryWindow
TYPE: Boolean
This variable holds the current status of the discovery window. It is set to true when the discovery window opens, and is set to false when the discovery window closes.

laserOffTime
TYPE: 8 bit unsigned
This variable holds the time required to terminate the laser. It counts in time_quanta units the time period required for turning off the PMD, as specified by the value of T_{off} in 75.7.14.
VALUE: laserOffTimeCapability (default value)

laserOnTime
TYPE: 8 bit unsigned
This variable holds the time required to initiate the PMD. It counts in time_quanta units the time period required for turning on the PMD, as specified by the value of T_{on} in 75.7.14.
VALUE: laserOnTimeCapability (default value)

localTime
This variable is defined in 77.2.2.2.

m_sdu_ctl
This variable is defined in 77.2.2.3.

opcode_rx
This variable is defined in 77.2.2.3.

pendingGrants
TYPE: 16 bit unsigned
This variable holds the maximum number of pending grants that an ONU is able to queue.

registered
TYPE: Boolean
This variable holds the current result of the Discovery Process. It is set to true once the discovery process is complete and registration is acknowledged.

syncTime
TYPE: 16 bit unsigned
This variable holds the time required to stabilize the receiver at the OLT. It counts time_quanta units from the point where transmission output is stable to the point where synchronization has been achieved. The value of syncTime includes gain adjustment interval ($T_{receiver\_settling}$), clock synchronization interval (T_{CDR}), and code–group alignment interval ($T_{code\_group\_align}$), as specified in 75.7.14. The OLT conveys the value of syncTime to ONUs in Discovery GATE and REGISTER messages. During the synchronization time a 10/1G–EPON ONU transmits only IDLE patterns, and a 10/10G–EPON ONU sends synchronization pattern (SP, see 76.3.2.5.2) followed by burst delimiter pattern (BURST_DELIMITER, see 76.3.2.5.2).

timestampDrift
This variable is defined in 77.2.2.3.

77.3.3.3 Functions

None.

77.3.3.4 Timers

discovery_window_size_timer
This timer is used to wait for the event signaling the end of the discovery window.
VALUE: The timer value is set dynamically based on the parameters received in a DISCOVERY GATE message.

mpcp_timer
This timer is used to measure the arrival rate of MPCP frames in the link. Failure to receive frames is considered a fatal fault and leads to deregistration.

77.3.3.5 Messages

MA_DATA.indication(DA, SA, m_sdu, receiveStatus)
The service primitive is defined in 2.3.2.

MA_DATA.request (DA, SA, m_sdu)
The service primitive is defined in 2.3.2.

MA_CONTROL.request(DA, GATE, discovery, start, length, discovery_length, sync_time, discoveryInformation)
The service primitive is used by the MAC Control client at the OLT to initiate the Discovery Process. This primitive takes the following parameters:

DA:	Multicast or unicast MAC address.
GATE:	Opcode for GATE MPCPDU as defined in Table 31A–1.
discovery:	Flag specifying that the given GATE message is to be used for discovery only.
start:	Start time of the discovery window.
length:	Length of the grant given for discovery.
discovery_length:	Length of the discovery window process.
sync_time:	The time interval required to stabilize the receiver at the OLT.
discoveryInformation:	This parameter represents the Discovery Information field in GATE MPCPDU as specified in 77.3.6.1, defining the speed(s) the OLT is capable of receiving and speed(s) at which the discovery window is opened for.

MA_CONTROL.request(DA, GATE, grant_number, start[4], length[4], force_report[4])
This service primitive is used by the MAC Control client at the OLT to issue the GATE message to an ONU. This primitive takes the following parameters:

DA:	Multicast MAC Control address as defined in Annex 31B.
GATE:	Opcode for GATE MPCPDU as defined in Table 31A–1.
grant_number:	Number of grants issued with this GATE message. The number of grants ranges from 0 to 4.
start[4]:	Start times of the individual grants. Only the first grant_number elements of the array are used.
length[4]:	Lengths of the individual grants. Only the first grant_number elements of the array are used.

force_report[4]: Flags indicating whether a REPORT message should be generated in the corresponding grant. Only the first grant_number elements of the array are used.

MA_CONTROL.request(DA, REGISTER_REQ, status, laserOnTime, laserOffTime, discoveryInformation)

The service primitive is used by a client at the ONU to request the Discovery Process to perform a registration. This primitive takes the following parameters:

DA: Multicast MAC Control address as defined in Annex 31B.

REGISTER_REQ: opcode for REGISTER_REQ MPCPDU as defined in Table 31A–1.

status: This parameter takes on the indication supplied by the flags field in the REGISTER_REQ MPCPDU as defined in Table 77–5.

laserOnTime: This parameter holds the laserOnTime value, expressed in units of time_quanta, as reported by MAC client and specified in 77.3.6.3.

laserOffTime: This parameter holds the laserOffTime value, expressed in units of time_quanta, as reported by MAC client and specified in 77.3.6.3.

discoveryInformation: This parameter represents the Discovery Information field, as specified in 77.3.6.3, defining the speed(s) the ONU is capable of transmitting and speed(s) at which the registration attempt is made.

MA_CONTROL.indication(REGISTER_REQ, status, flags, pending_grants, RTT, laserOnTime, laserOffTime, discoveryInformation)

The service primitive is issued by the Discovery Process to notify the client and Layer Management that the registration process is in progress. This primitive takes the following parameters:

REGISTER_REQ: Opcode for REGISTER_REQ MPCPDU as defined in Table 31A–1.

status: This parameter holds the values incoming or retry. Value incoming is used at the OLT to signal that a REGISTER_REQ message was received successfully. The value retry is used at the ONU to signal to the client that a registration attempt failed and needs to be repeated.

flags: This parameter holds the contents of the flags field in the REGISTER_REQ message. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

pending_grants: This parameter holds the contents of the pending_grants field in the REGISTER_REQ message. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

RTT: The measured round trip time to/from the ONU is returned in this parameter. RTT is stated in time_quanta units. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

laserOnTime: This parameter holds the contents of the laserOnTime field in the REGISTER_REQ message. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

laserOffTime: This parameter holds the contents of the laserOffTime field in the REGISTER_REQ message. This parameter holds a valid value only when the primitive is generated by the Discovery Process in the OLT.

discoveryInformation: This parameter holds the contents of the Discovery Information field in the REGISTER_REQ MPCPDU. This parameter holds a valid value only when the primitive is generated by the Discovery process in the OLT.

MA_CONTROL.request(DA, REGISTER, LLID, status, pending_grants, laserOnTime, laserOffTime)

The service primitive is used by the MAC Control client at the OLT to initiate acceptance of an ONU. This primitive takes the following parameters:

DA: Unicast MAC address or multicast MAC Control address as defined in Annex 31B.

REGISTER: Opcode for REGISTER MPCPDU as defined in Table 31A–1.

LLID: This parameter holds the logical link identification number assigned by the MAC Control client.

status: This parameter takes on the indication supplied by the flags field in the REGISTER MPCPDU as defined in Table 77–7.

pending_grants: This parameters echoes back the pending_grants field that was previously received in the REGISTER_REQ message.

laserOnTime: This parameter carries the target value of Laser On Time for the given ONU transmitter. This value may be different than the laserOnTime value carried in the REGISTER_REQ MPCPDU received from the corresponding ONU MAC during Discovery stage.

laserOffTime: This parameter carries the target value of Laser Off Time for the given ONU transmitter. This value may be different than the laserOffTime value carried in the REGISTER_REQ MPCPDU received from the corresponding ONU MAC during Discovery stage.

MA_CONTROL.indication(REGISTER, SA, LLID, status)

This service primitive is issued by the Discovery Process at the OLT or an ONU to notify the MAC Control client and Layer Management of the result of the change in registration status. This primitive takes the following parameters:

REGISTER: Opcode for REGISTER MPCPDU as defined in Table 31A–1.

SA: This parameter represents the MAC address of the OLT.

LLID: This parameter holds the logical link identification number assigned by the MAC Control client.

status: This parameter holds the value of accepted / denied / deregistered / reregistered.

MA_CONTROL.request(DA, REGISTER_ACK, status)

This service primitive is issued by the MAC Control clients at the ONU and the OLT to acknowledge the registration. This primitive takes the following parameters:

DA: Multicast MAC Control address as defined in Annex 31B.

REGISTER_ACK: Opcode for REGISTER_ACK MPCPDU as defined in Table 31A–1.

status: This parameter takes on the indication supplied by the flags field in the REGISTER MPCPDU as defined in Table 77–8.

MA_CONTROL.indication(REGISTER_ACK, SA, LLID, status, RTT)

This service primitive is issued by the Discovery Process at the OLT to notify the client and Layer Management that the registration process has completed. This primitive takes the following parameters:

REGISTER_ACK:	Opcode for REGISTER_ACK MPCPDU as defined in Table 31A–1.
SA:	This parameter represents the MAC address of the reciprocating device (ONU address at the OLT, and OLT address at the ONU).
LLID:	This parameter holds the logical link identification number assigned by the MAC Control client.
status:	This parameter holds the value of accepted/denied/reset/deregistered.
RTT:	The measured round trip time to/from the ONU is returned in this parameter. RTT is stated in time_quanta units. This parameter holds a valid value only when the invoking Discovery Process in the OLT.

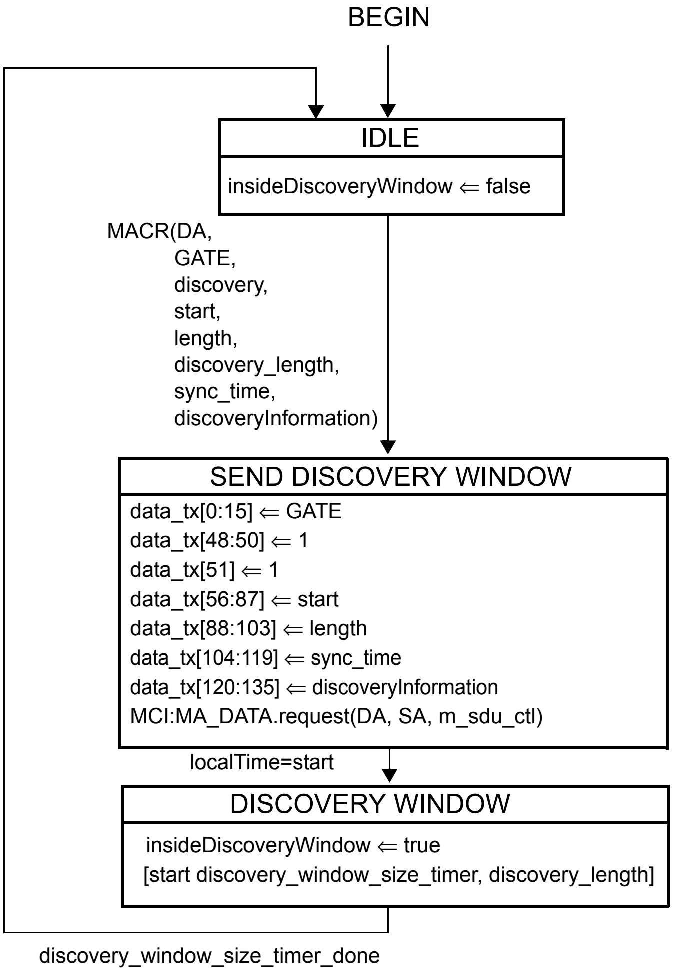
Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

77.3.3.6 State Diagrams

The Discovery Process in the OLT shall implement the discovery window setup state diagram shown in Figure 77–19, request processing state diagram as shown in Figure 77–20, register processing state diagram as shown in Figure 77–21, and final registration state diagram as shown in Figure 77–22. The discovery process in the ONU shall implement the registration state diagram as shown in Figure 77–23.

Instantiation of state diagrams as described in Figure 77–19, Figure 77–20, and Figure 77–21 is performed only at the Multipoint MAC Control instances attached to the broadcast LLID (0x7FFE). Instantiation of state diagrams as described in Figure 77–22 and Figure 77–23 is performed for every Multipoint MAC Control instance, except the instance attached to the broadcast channel.



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 77–19—Discovery Processing OLT Window Setup state diagram

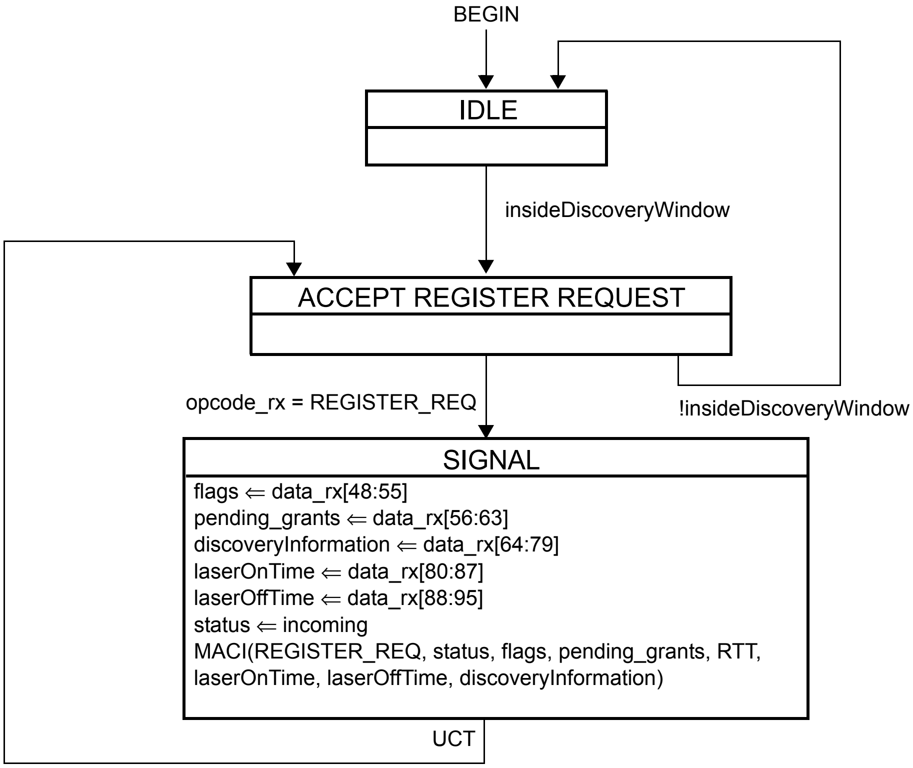
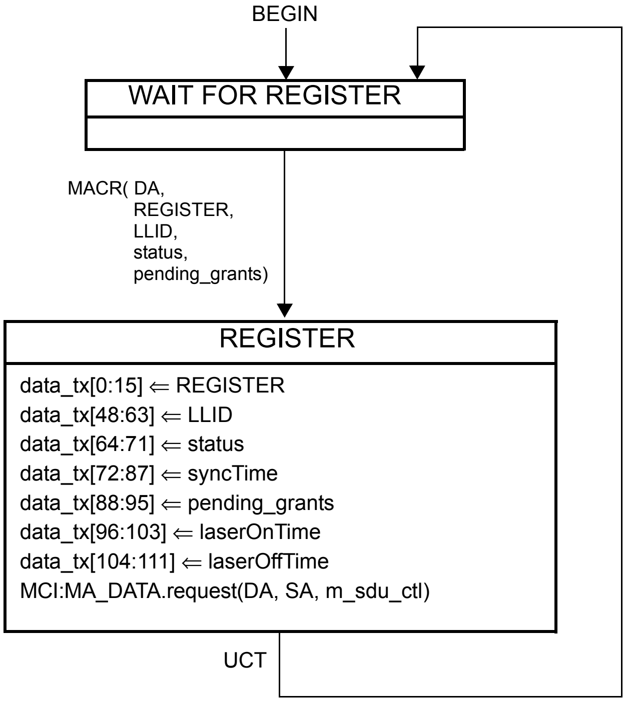
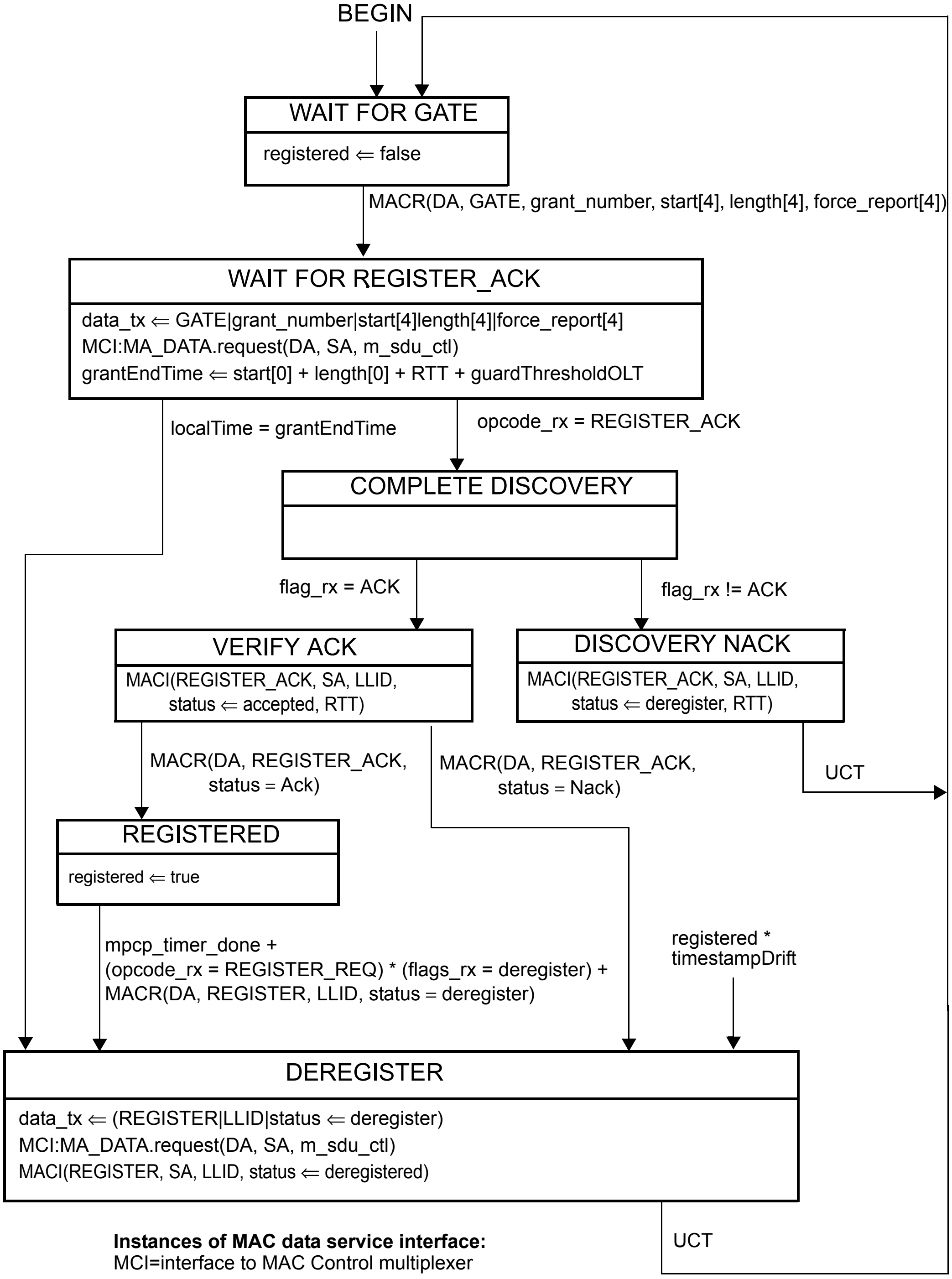


Figure 77–20—Discovery Processing OLT Process Requests state diagram



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 77–21—Discovery Processing OLT Register state diagram



NOTE—The MAC Control Client issues the grant following the REGISTER message, taking the ONU processing delay of REGISTER message into consideration.

Figure 77–22—Discovery Processing OLT Final Registration state diagram

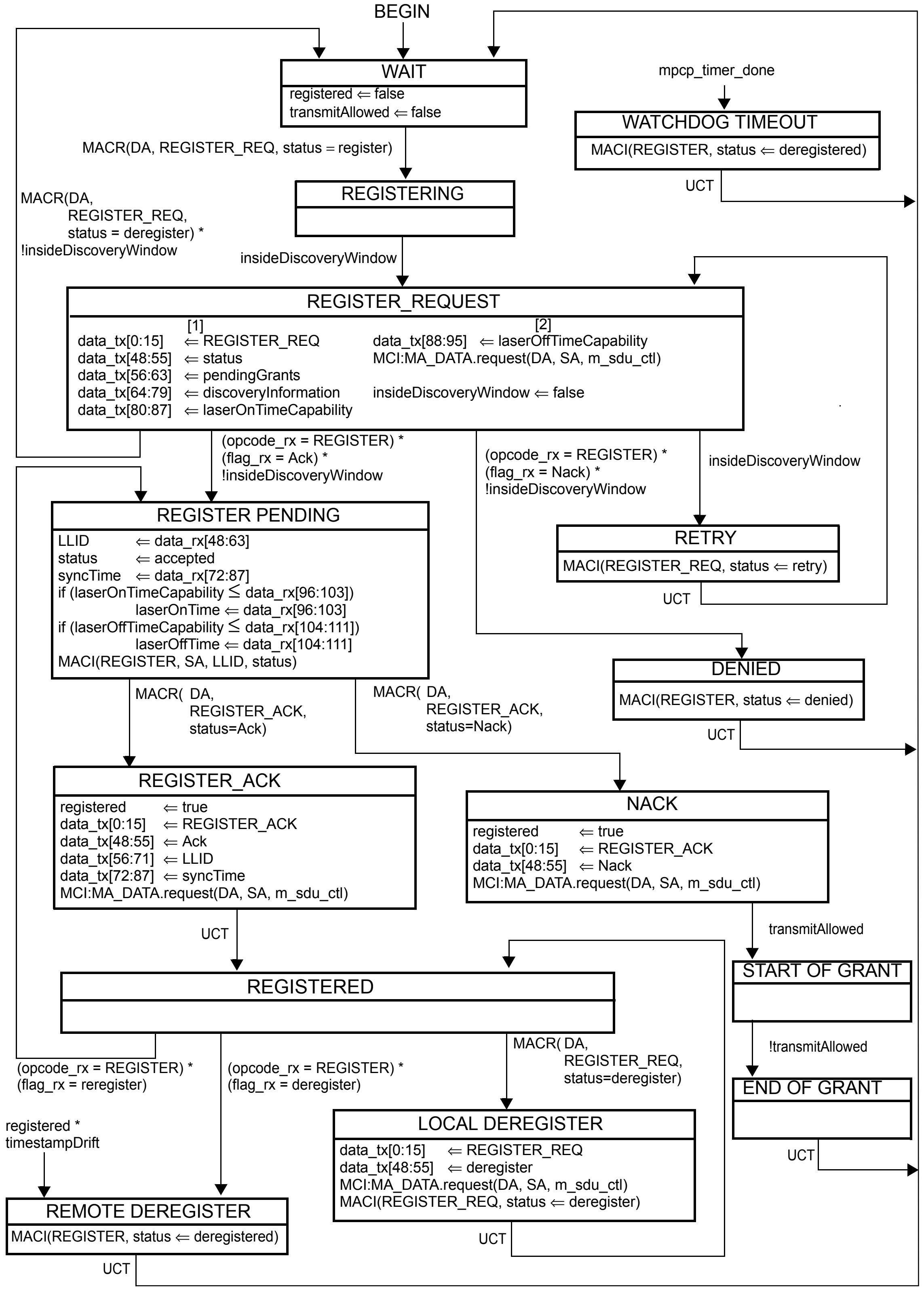


Figure 77–23—Discovery Processing ONU Registration state diagram

77.3.4 Report Processing

The Report Processing functional block has the responsibility of dealing with queue report generation and termination in the network. Reports are generated by higher layers and passed to the MAC Control sublayer by the MAC Control clients. Status reports are used to signal bandwidth needs as well as for arming the OLT watchdog timer.

Reports shall be generated periodically, even when no request for bandwidth is being made. This keeps a watchdog timer in the OLT from expiring and deregistering the ONU. For proper operation of this mechanism the OLT shall grant the ONU periodically.

The Report Processing functional block, and its MPCP protocol elements are designed for use in conjunction with an IEEE 802.1P capable bridge.

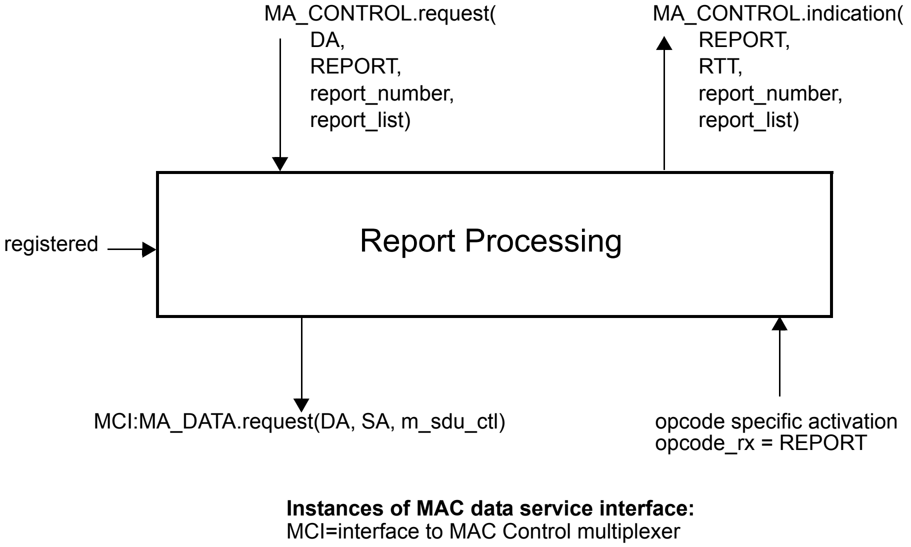


Figure 77–24—Report Processing service interfaces

77.3.4.1 Constants

None.

77.3.4.2 Variables

BEGIN
TYPE: Boolean
This variable is used when initiating operation of the functional block state diagram. It is set to true following initialization and every reset.

data_rx
This variable is defined in 77.2.2.3.

data_tx
This variable is defined in 77.2.2.3.

m_sdu_ctl
This variable is defined in 77.2.2.3.

mpcp_timeout

TYPE: 32 bit unsigned

This variable represents the maximum allowed interval of time between two MPCPDU messages. Failure to receive at least one frame within this interval is considered a fatal fault and leads to deregistration. This variable is expressed in units of time_quanta.

VALUE: 0x03B9ACA0 (1 s, default value)

opcode_rx

This variable is defined in 77.2.2.3.

registered

This variable is defined in 77.3.3.2.

report_timeout

TYPE: 32 bit unsigned

This variable represents the maximum allowed interval of time between two REPORT messages generated by the ONU, expressed in units of time_quanta.

VALUE: 0x002FAF08 (50 ms, default value)

77.3.4.3 Functions

None.

77.3.4.4 Timers

report_periodic_timer

ONUs are required to generate REPORT MPCPDUs with a periodicity of less than report_timeout value. This timer counts down time remaining before a forced generation of a REPORT message in an ONU.

mpcp_timer

This timer is defined in 77.3.3.4.

77.3.4.5 Messages

MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 2.3.2.

MA_CONTROL.request(DA, REPORT, report_number, report_list)

This service primitive is used by a MAC Control client to request the Report Process at the ONU to transmit a queue status report. This primitive may be called at variable intervals, independently of the granting process, in order to reflect the time varying aspect of the network. This primitive uses the following parameters:

DA:	Multicast MAC Control address as defined in Annex 31B.
REPORT:	Opcode for REPORT MPCPDU as defined in Table 31A–1.
report_number:	The number of queue status report sets located in report list. The report_number value ranges from 0 to a maximum of 13.
report_list:	The list of queue status reports. A queue status report consists of two fields: valid and status. The parameter valid is a Boolean array of length of 8. The index of an element of this array reflects the numbered priority queue in the IEEE 802.1P nomenclature. An element with the value of '0' or false indicates that the corresponding status field is not present (the

length of status field is 0),while '1' or true indicates that the corresponding status field is present (the length of status field is 2 octets). The parameter status is an array of 16 bit unsigned integer values. This array consists only of entries whose corresponding bit in field valid is set to true.

MA_CONTROL.indication(REPORT, RTT, report_number, report_list)

The service primitive is issued by the Report Process at the OLT to notify the MAC Control client and higher layers the queue status of the MPCP link partner. This primitive may be called multiple times, in order to reflect the time–varying aspect of the network. This primitive uses the following parameters:

REPORT:	Opcode for REPORT MPCPDU as defined in Table 31A–1.
RTT:	This parameter holds an updated round trip time value that is recalculated following each REPORT message reception.
report_number:	The number of queue status report sets located in report list. The report_number value ranges from 0 to a maximum of 13.
report_list:	The list of queue status reports. A queue status report consists of two fields: valid and status. The parameter valid is a Boolean array of length of 8. The index of an element of this array reflects the numbered priority queue in the IEEE 802.1P nomenclature. An element with the value of '0' or false indicates that the corresponding status field is not present (the length of status field is 0),while '1' or true indicates that the corresponding status field is present (the length of status field is 2 octets). The parameter status is an array of 16 bit unsigned integer values. This array consists only of entries whose corresponding bit in field valid is set to true.

Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

77.3.4.6 State diagrams

The report process in the OLT shall implement the report processing state diagram as shown in Figure 77–25. The report process in the ONU shall implement the report processing state diagram as shown in Figure 77–26. Instantiation of state diagrams as described is performed for Multipoint MAC Control instances attached to unicast LLIDs only.

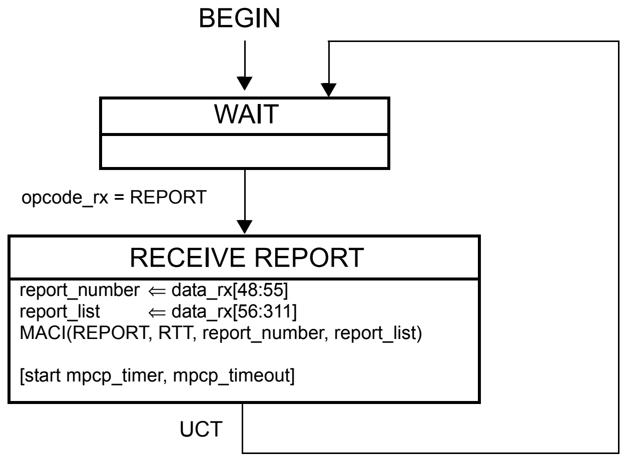
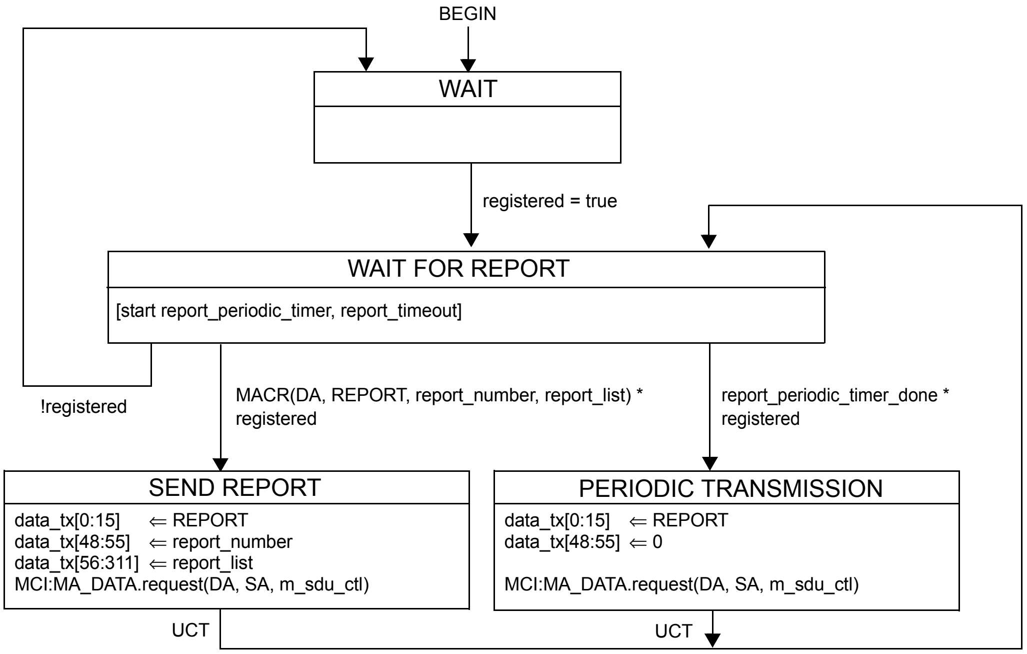


Figure 77–25—Report Processing state diagram at OLT



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 77–26—Report Processing state diagram at ONU

77.3.5 Gate Processing

A key concept pervasive in Multipoint MAC Control is the ability to arbitrate a single transmitter out of a plurality of ONUs. The OLT controls an ONU's transmission by the assigning of grants.

The transmitting window of an ONU is indicated in the GATE message where start time and length are specified. An ONU begins transmission when its localTime counter matches the start_time value indicated in the GATE message. An ONU concludes its transmission with sufficient margin to ensure that the laser is turned off before the grant length interval has elapsed.

Multiple outstanding grants may be issued to each ONU. The OLT shall not issue more than the maximum supported maximum outstanding grants as advertised by the ONU during registration (see pending grants in 77.3.6.3).

In order to maintain the watchdog timer at the ONU, grants are periodically generated. For this purpose empty GATE messages may be issued periodically.

When registered, the ONU ignores all gate messages where the Discovery flag is set.

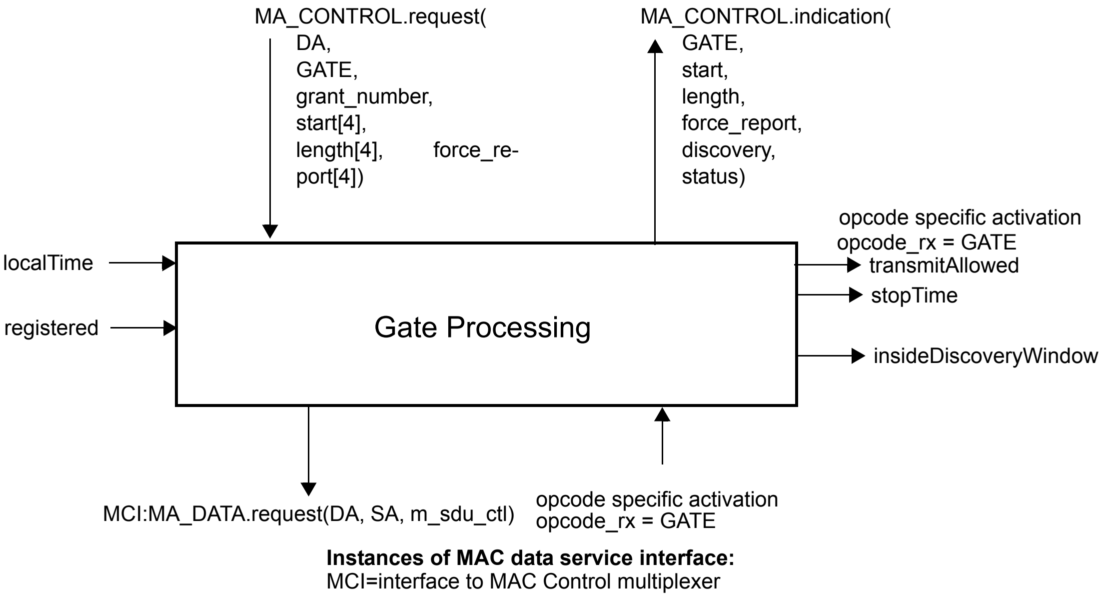


Figure 77–27—Gate Processing service interface

77.3.5.1 Constants

max_future_grant_time
    TYPE: 32 bit unsigned
    This constant holds the time limiting the future time horizon for a valid incoming grant.
    VALUE: 0x03B9ACA0 (1 s)

min_processing_time
    TYPE: 32 bit unsigned
    This constant is the time required for the ONU processing time.
    VALUE: 0x00000400 (16.384 µs)

minGrantLength
    TYPE: 32 bit unsigned
    This constant represents the minimum data portion of a grant. The minGrantLength is equal to one FEC codeword (see FEC_CODEWORD_SIZE in 77.2.2.1), less the initial 16 idle octets, expressed

in units of time_quanta. The minimum grant length accepted by an ONU is equal to minGrantLength + BurstOverhead (see 77.3.5.2).
VALUE: 12

tqSize
This constant is defined in 77.2.2.1.

77.3.5.2 Variables

BEGIN
TYPE: Boolean
This variable is used when initiating operation of the functional block state diagram. It is set to true following initialization and every reset.

BurstOverhead
TYPE: integer
This variable represents the burst overhead and equals the sum of laserOnTime, laserOffTime, syncTime and an additional two time_quanta to account for END_BURST_DELIMITER and two leading IDLE vectors of the payload. This variable is expressed in units of time_quanta.

counter
TYPE: integer
This variable is used as a loop iterator counting the number of incoming grants in a GATE message.

currentGrant
TYPE:

```
structure
{
    DA:           48 bit unsigned, a.k.a MAC address type
    start         32 bit unsigned
    length        16 bit unsigned
    force_report  Boolean
    discovery     Boolean
}
```

This variable is used for local storage of a pending grant state during processing. It is dynamically set by the Gate Processing functional block and is not exposed.
The state is a structure field composed of multiple subfields.

data_rx
This variable is defined in 77.2.2.3.

data_tx
This variable is defined in 77.2.2.3.

effectiveLength
TYPE: 32 bit unsigned
This variable is used for temporary storage of a normalized net time value. It holds the net effective length of a grant normalized for elapsed time, and compensated for the periods required to turn the laser on and off, and waiting for receiver lock.

gate_timeout
TYPE: 32 bit unsigned
This variable represents the maximum allowed interval of time between two GATE messages gen-

erated by the OLT to the same ONU, expressed in units of time_quanta.
VALUE: 0x002FAF08 (50 ms, default value)

grantList
TYPE: list of elements having the structure define in currentGrant
This variable is used for storage of the list of pending grants. It is dynamically set by the Gate Processing functional block and is not exposed. Each time a grant is received it is added to the list. The list elements are structure fields composed of multiple subfields. The list is indexed by the start subfield in each element for quick searches.

grantStart
This variable is defined in 77.2.2.3.

insideDiscoveryWindow
This variable is defined in 77.3.3.2.

maxDelay
TYPE: 16 bit unsigned
This variable holds the maximum delay that can be applied by an ONU before sending the REGISTER_REQ MPCPDU. This delay is calculated such that the ONU would have sufficient time to transmit the REGISTER_REQ message and its associated overhead (FEC parity data, end-of-frame sequence, etc.) and terminate the laser before the end of the discovery grant.

m_sdu_ctl
This variable is defined in 77.2.2.3.

nextGrant
TYPE: element having same structure as defined in currentGrant
This variable is used for local storage of a pending grant state during processing. It is dynamically set by the Gate Processing functional block and is not exposed. The content of the variable is the next grant to become active.

nextStopTime
TYPE: 32 bit unsigned
This variable holds the value of the localTime counter corresponding to the end of the next grant.

opcode_rx
This variable is defined in 77.2.2.3.

registered
This variable is defined in 77.3.3.2.

stopTime
This variable is defined in 77.2.2.3.

syncTime
This variable is defined in 77.3.3.2.

transmitAllowed
This variable is defined in 77.2.2.3.

77.3.5.3 Functions

empty(list)

This function is use to check whether the list is empty. When there are no elements queued in the list, the function returns true. Otherwise, a value of false is returned.

confirmDiscovery(data)

This function is used to check whether the current Discovery Window is open for the given ONU (TRUE) or not (FALSE). This function returns values as shown in Table 77–1.

Table 77–1—Operation of the confirmDiscovery(data) function

OLT Discovery Information: Discovery Window		ONU Tx capability		confirmDiscovery(data) returns
1G	**10G**	**1G**	**10G**	
X	1	0	1	TRUE
1	X	1	0	TRUE
0	1	1	0	FALSE
1	0	0	1	FALSE
0	0	X	X	FALSE[a]

[a] These particular values for the Discovery Window fields should not be normally generated by the OLT.

InsertInOrder(sorted_list, inserted_element)

This function is used to queue an element inside a sorted list. The queuing order is sorted. In the condition that the list is full the element may be discarded. The length of the list is dynamic and it's maximum size equals the value advertised during registration as maximum number of pending grants.

IsBroadcast(grant)

This function is used to check whether its argument represents a broadcast grant, i.e., grant given to multiple ONUs. This is determined by the destination MAC address of the corresponding GATE message. The function returns the value true when MAC address is a global assigned MAC Control address as defined in Annex 31B, and false otherwise.

PeekHead(sorted_list)

This function is used to check the content of a sorted list. It returns the element at the head of the list without dequeuing the element.

Random(r)

This function is used to compute a random integer number uniformly distributed between 0 and r. The randomly generated number is then returned by the function.

RemoveHead(sorted_list)

This function is used to dequeue an element from the head of a sorted list. The return value of the function is the dequeued element.

77.3.5.4 Timers

gntWinTmr

This timer is used to wait for the event signaling the end of a grant window.
VALUE: The timer value is dynamically set according to the signaled grant length.

gate_periodic_timer

The OLT is required to generate GATE MPCPDUs with a periodicity of less than gate_timeout value. This timer counts down time remaining before a forced generation of a GATE message in the OLT.

mpcp_timer

This timer is defined in 77.3.3.4.

rndDlyTmr

This timer is used to measure a random delay inside the discovery window. The purpose of the delay is to a priori reduce the probability of transmission overlap during the registration process, and thus lowering the expectancy of registration time in the PON.
VALUE: A random value less than the net discovery window size less the REGISTER_REQ MPCPDU frame size less the idle period and laser turn on and off delays less the preamble size less the IFG size. The timer value is set dynamically based on the parameters passed from the client.

77.3.5.5 Messages

MA_DATA.request (DA, SA, m_sdu)

The service primitive is defined in 2.3.2.

MA_CONTROL.request(DA, GATE, grant_number, start[4], length[4], force_report[4])

This service primitive is defined in 77.3.3.5.

MA_CONTROL.indication(GATE, start, length, force_report, discovery, status)

This service primitive issued by the Gate Process at the ONU to notify the MAC Control client and higher layers that a grant is pending. This primitive is invoked multiple times when a single GATE message arrives with multiple grants. It is also generated at the start and end of each grant as it becomes active. This primitive uses the following parameters:

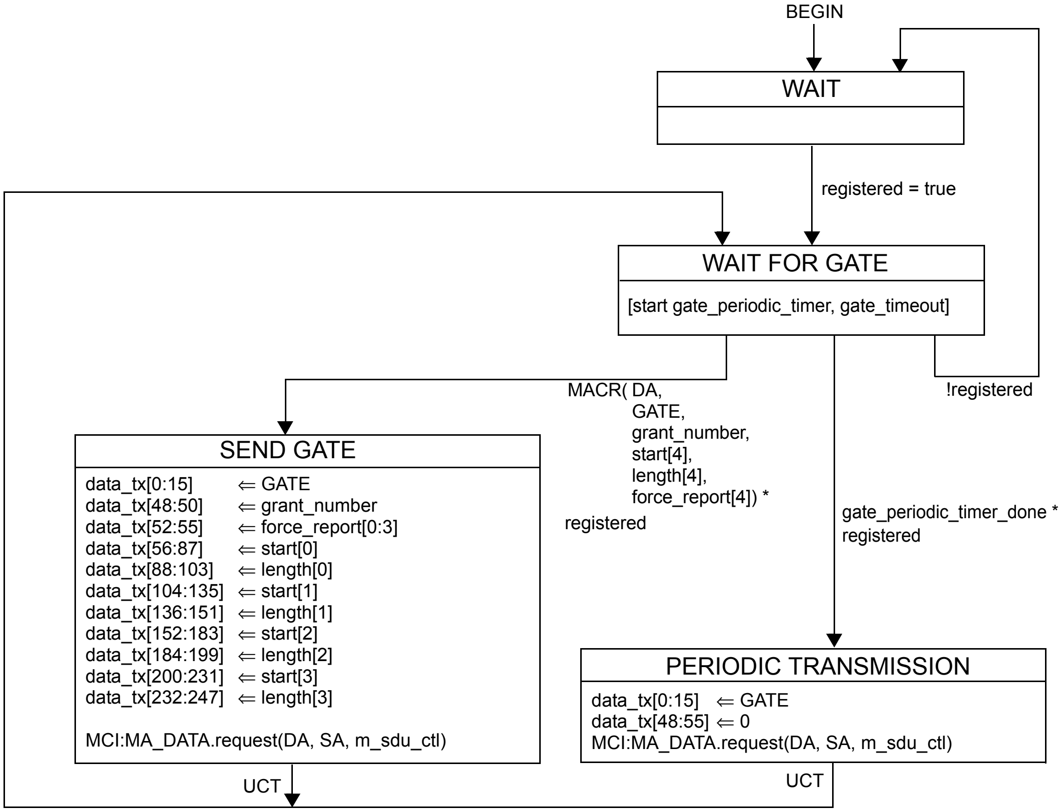
GATE:	Opcode for GATE MPCPDU as defined in Table 31A–1.
start:	start time of the grant. This parameter is not present when the parameter *status* value is equal to *deactive*.
length:	Length of the grant. This parameter is not present when the parameter *status* value is equal to *deactive*.
force_report:	Flags indicating whether a REPORT message should be transmitted in this grant. This parameter is not present when the parameter *status* value is equal to *deactive*.
discovery:	This parameter holds the value true when the grant is to be used for the discovery process, and false otherwise. This parameter is not present when the parameter *status* value is equal to *deactive*.
status:	This parameter takes the value *arrive* on grant reception, *active* when a grant becomes active, and *deactive* at the end of a grant.

Opcode-specific function(opcode)

Functions exported from opcode specific blocks that are invoked on the arrival of a MAC Control message of the appropriate opcode.

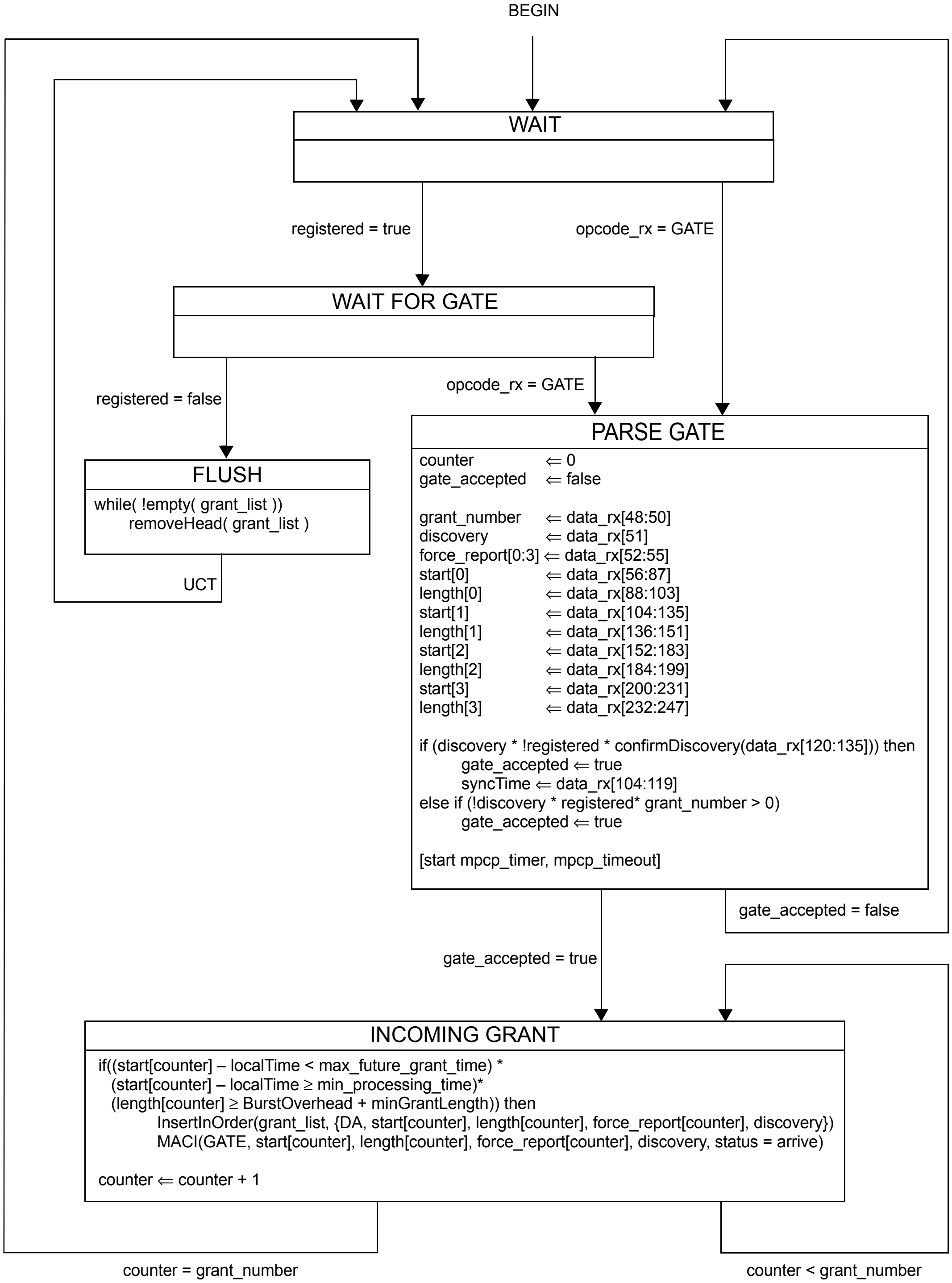
77.3.5.6 State diagrams

The gating process in the OLT shall implement the Gate processing state diagram as shown in Figure 77–28. The gating process in the ONU shall implement the Gate processing state diagram as shown in Figure 77–29 and Figure 77–30. Instantiation of state diagrams as described is performed for all Multipoint MAC Control instances.



Instances of MAC data service interface:
MCI=interface to MAC Control multiplexer

Figure 77–28—Gate Processing state diagram at OLT



```
FLUSH
while( !empty( grant_list ))
      removeHead( grant_list )
```

```
PARSE GATE
counter            ⇐ 0
gate_accepted      ⇐ false

grant_number       ⇐ data_rx[48:50]
discovery          ⇐ data_rx[51]
force_report[0:3]  ⇐ data_rx[52:55]
start[0]           ⇐ data_rx[56:87]
length[0]          ⇐ data_rx[88:103]
start[1]           ⇐ data_rx[104:135]
length[1]          ⇐ data_rx[136:151]
start[2]           ⇐ data_rx[152:183]
length[2]          ⇐ data_rx[184:199]
start[3]           ⇐ data_rx[200:231]
length[3]          ⇐ data_rx[232:247]

if (discovery * !registered * confirmDiscovery(data_rx[120:135])) then
        gate_accepted ⇐ true
        syncTime ⇐ data_rx[104:119]
else if (!discovery * registered* grant_number > 0)
        gate_accepted ⇐ true

[start mpcp_timer, mpcp_timeout]
```

```
INCOMING GRANT
if((start[counter] – localTime < max_future_grant_time) *
   (start[counter] – localTime ≥ min_processing_time)*
   (length[counter] ≥ BurstOverhead + minGrantLength)) then
          InsertInOrder(grant_list, {DA, start[counter], length[counter], force_report[counter], discovery})
          MACI(GATE, start[counter], length[counter], force_report[counter], discovery, status = arrive)

counter ⇐ counter + 1
```

Figure 77–29—Gate Processing ONU Programing state diagram

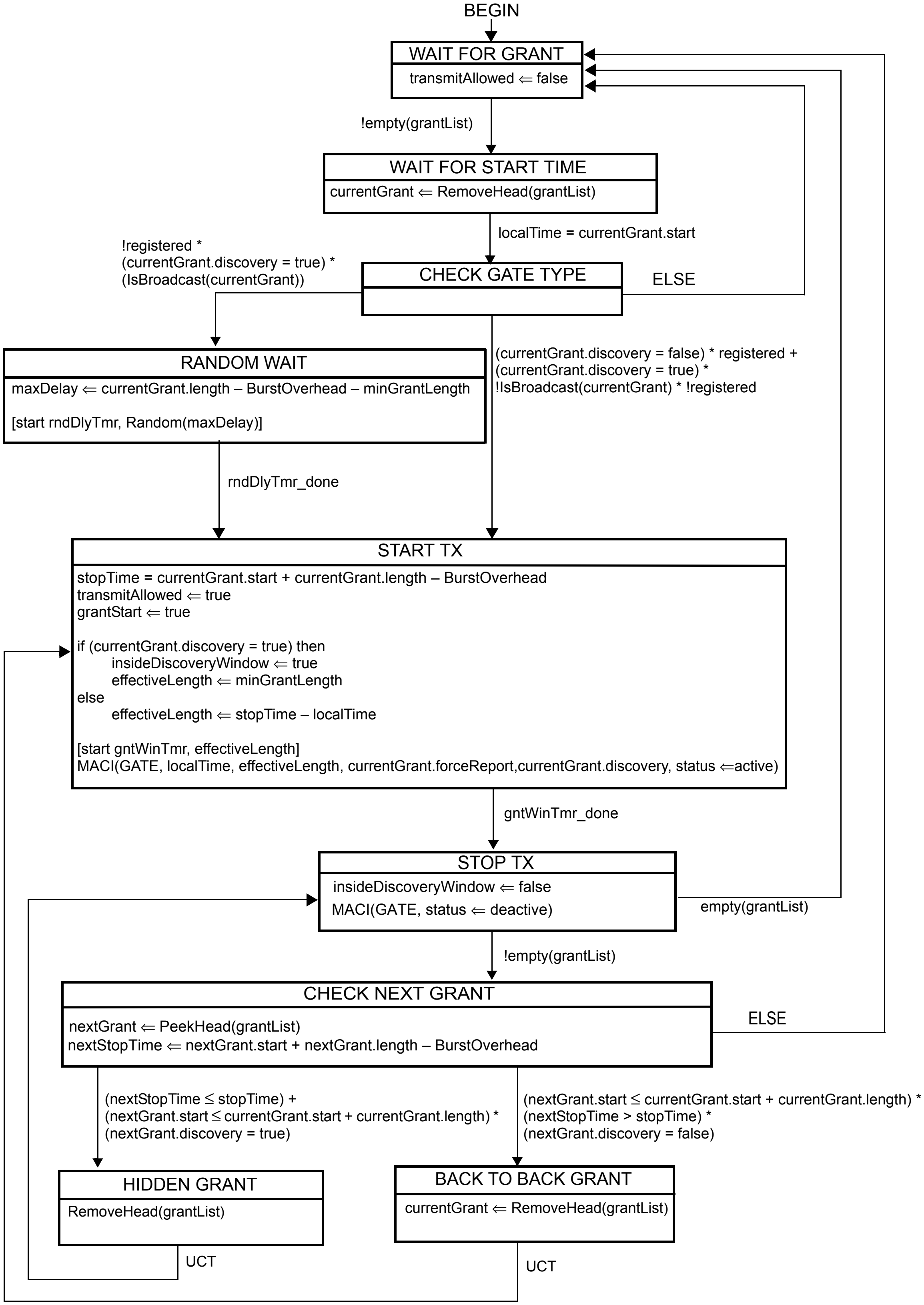


Figure 77–30—Gate Processing ONU Activation state diagram

77.3.6 MPCPDU structure and encoding

The MPCPDU structure shall be as shown in Figure 77–31, and is further defined in the following definitions:

a) Destination Address (DA). The DA in MPCPDU is the MAC Control Multicast address as specified in the annexes to Clause 31, or the individual MAC address associated with the port to which the MPCPDU is destined.
b) Source Address (SA). The SA in MPCPDU is the individual MAC address associated with the port through which the MPCPDU is transmitted. For MPCPDUs originating at the OLT end, this can be the address any of the individual MACs. These MACs may all share a single unicast address, as explained in 77.1.2.
c) Length/Type. The Length/Type in MPCPDUs carries the MAC_Control_Type field value as specified in 31.4.1.3.
d) Opcode. The opcode identifies the specific MPCPDU being encapsulated. Values are defined in Table 31A–1.
e) Timestamp. The timestamp field conveys the content of the localTime register at the time of transmission of the MPCPDUs. This field is 32 bits long and counts time in units of time_quanta.
f) Data/Reserved/PAD. These 40 octets are used for the payload of the MPCPDUs. When not used they would be filled with zeros on transmission, and be ignored on reception.
g) FCS. This field is the Frame Check Sequence, typically generated by the underlying MAC.
Based on the MAC instance used to generate the specific MPCPDU, the appropriate LLID shall be generated by the RS.

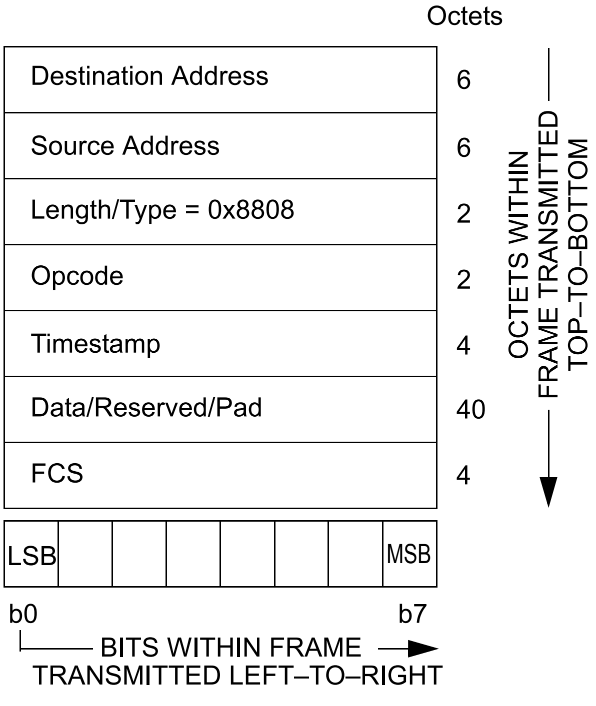


Figure 77–31—Generic MPCPDU

77.3.6.1 GATE description

The purpose of GATE message is to grant transmission windows to ONUs for both discovery messages and normal transmission. Up to four grants can be included in a single GATE message. The number of grants can also be set to zero for using the GATE message as an MPCP keep alive from OLT to the ONU.

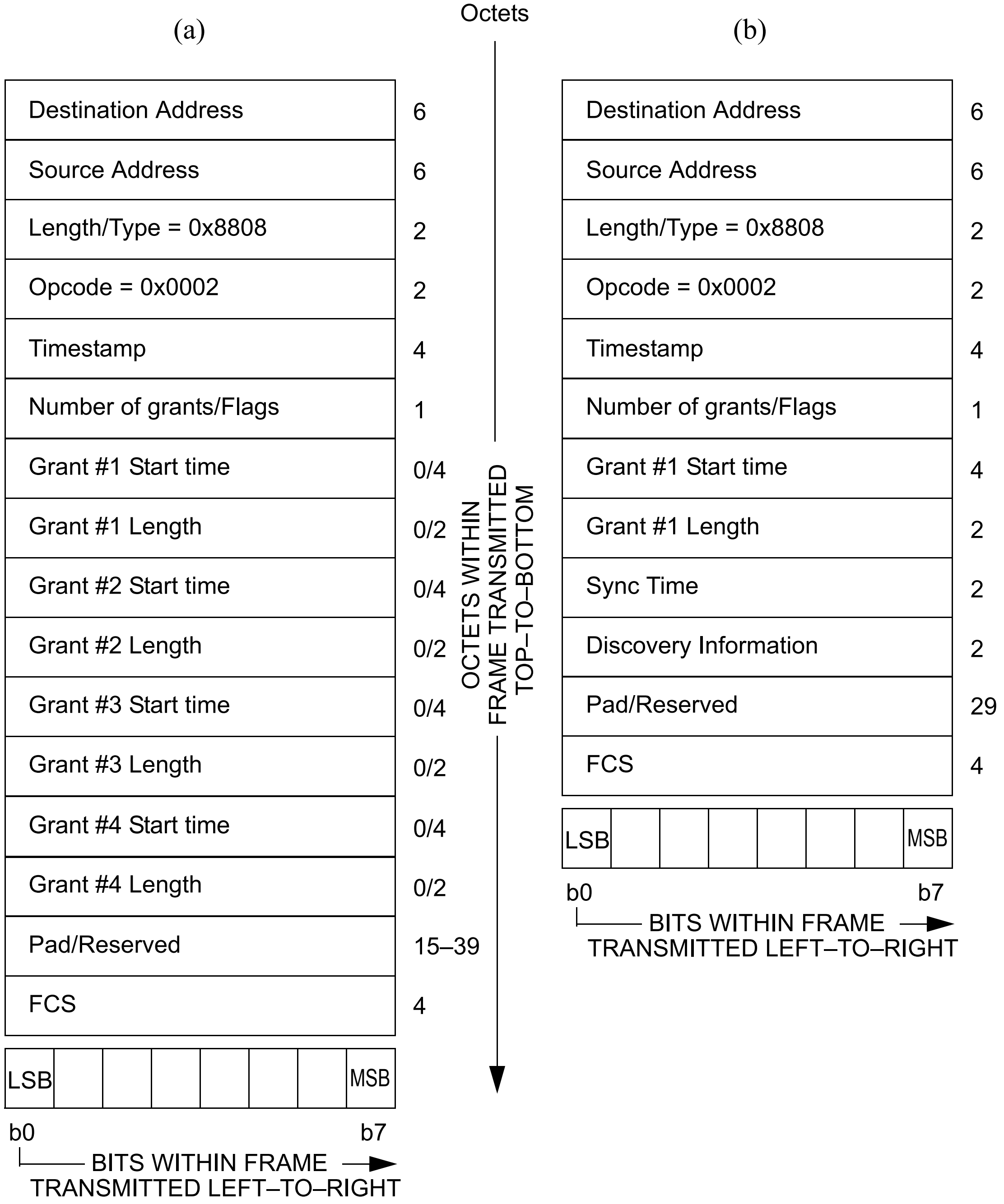


Figure 77–32—GATE MPCPDU: (a) normal GATE MPCPDU, (b) discovery GATE MPCPDU

The GATE MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the GATE MPCPDU is 0x0002.
b) Flags. This is an 8 bit flag register that holds the following flags: As presented in Table 77–2, the Number of grants field contains the number of grants, composed of valid Length, Start Time pairs in this MPCPDU. This is a number between 0 and 4.

   NOTE—When Number of grants is set to 0, sole purpose of message is conveying of timestamp to ONU.

   The Discovery flag field indicates that the signaled grants would be used for the discovery process, in which case a single grant shall be issued in the GATE message.

   The Force Report flag fields ask the ONU to issue a REPORT message related to the corresponding grant number at the corresponding transmission opportunity indicated in this GATE.

Table 77–2—GATE MPCPDU Number of grants/flags fields

Bit	Flag field	Values
0–2	Number of grants	0 – 4
3	Discovery	0 – Normal GATE 1 – Discovery GATE
4	Force Report Grant 1	0 – No action required 1 – A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 1
5	Force Report Grant 2	0 – No action required 1 – A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 2
6	Force Report Grant3	0 – No action required 1 – A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 3
7	Force Report Grant 4	0 – No action required 1 – A REPORT frame should be issued at the corresponding transmission opportunity indicated in Grant 4

c) Grant #n Start Time. This 32 bit unsigned field represents the start time of the grant. The start time is compared to the local clock, to correlate the start of the grant. Transmitted values shall satisfy the condition Grant #n Start Time < Grant #n+1 Start Time for consecutive grants within the same GATE MPCPDU.
d) Grant #n Length. This 16 bit unsigned field represents the length of the grant. The length is counted in 1 time_quantum increments. There are 4 Grants that are possibly packed into the GATE MPCPDU. The laserOnTime, syncTime, laserOffTime, two initial Idle blocks, FEC parity overhead, and burst terminator sequence (composed of three END_BURST_DELIMITER blocks) are included in and thus consume part of the Grant #n length.
e) Sync Time. This is an unsigned 16 bit value signifying the required synchronization time of the OLT receiver. The ONU calculates the effective grant length by subtracting the syncTime, laserOnTime, laserOffTime and END_BURST_DELIMITER from the grant length it received from the OLT. The value is counted in 1 time_quantum increments. The advertised value includes synchronization requirement on all receiver elements including PMD, PMA and PCS. This field is present only when the GATE is a discovery GATE, as signaled by the Discovery flag and is not present otherwise.
f) Discovery Information. This is a 16 bit flag register. This field is present only when the GATE is a discovery GATE, as signaled by the Discovery flag and is not present otherwise. Table 77–3 presents the internal structure of the Discovery Information flag field.
g) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception. The size of this field depends on the used Grant #n Length/Start Time entry-pairs as well as the presence of the Sync Time and Discovery Information fields, and varies in length from 15–39 accordingly.

The GATE MPCPDU shall be generated by a MAC Control instance mapped to an active ONU, and as such shall be marked with a unicast type of LLID, except when the MPCPDU is a discovery GATE, as indicated by the Discovery flag being set to true. For the discovery procedure, a MAC Control instance is mapped to all ONUs, and therefore, the discovery GATE MPCPDU is marked with the appropriate broadcast LLID (see 77.3.2.3).

Table 77–3—GATE MPCPDU discovery information fields

Bit	Flag field	Values
0	OLT is 1G upstream capable	0 – OLT does not support 1 Gb/s reception 1 – OLT supports 1 Gb/s reception
1	OLT is 10G upstream capable	0 – OLT does not support 10 Gb/s reception 1 – OLT supports 10 Gb/s reception
2–3	Reserved	Ignored on reception
4	OLT is opening 1G discovery window	0 – OLT cannot receive 1 Gb/s data in this window 1 – OLT can receive 1 Gb/s data in this window
5	OLT is opening 10G discovery window	0 – OLT cannot receive 10 Gb/s data in this window 1 – OLT can receive 10 Gb/s data in this window
6–15	Reserved	Ignored on reception

77.3.6.2 REPORT description

REPORT messages have several functionalities. Time stamp in each REPORT message is used for round trip (RTT) calculation. In the REPORT messages ONUs indicate the upstream bandwidth needs they request per IEEE 802.1Q priority queue. REPORT messages are also used as keep–alives from ONU to OLT. ONUs issue REPORT messages periodically in order to maintain link health at the OLT as defined in 77.3.4. In addition, the OLT may specifically request a REPORT message.

The REPORT MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the REPORT MPCPDU is 0x0003.
b) Number of Queue Sets. This field specifies the number of requests in the REPORT message. A REPORT frame may hold multiple sets of Report bitmap and Queue #n as specified in the Number of Queue Sets field.
c) Report bitmap. This is an 8 bit flag register that indicates which queues are represented in this REPORT MPCPDU—see Table 77–4.

Table 77–4—REPORT MPCPDU Report bitmap fields

Bit	Flag field	Values
0	Queue 0	0 – queue 0 report is not present; 1 – queue 0 report is present
1	Queue 1	0 – queue 1 report is not present; 1 – queue 1 report is present
2	Queue 2	0 – queue 2 report is not present; 1 – queue 2 report is present
3	Queue 3	0 – queue 3 report is not present; 1 – queue 3 report is present
4	Queue 4	0 – queue 4 report is not present; 1 – queue 4 report is present
5	Queue 5	0 – queue 5 report is not present; 1 – queue 5 report is present

Table 77–4—REPORT MPCPDU Report bitmap fields *(continued)*

Bit	Flag field	Values
6	Queue 6	0 – queue 6 report is not present; 1 – queue 6 report is present
7	Queue 7	0 – queue 7 report is not present; 1 – queue 7 report is present

d) Queue #n Report. This value represents the length of queue #n at time of REPORT message generation. The reported length shall be adjusted and rounded up to the nearest time_quantum to account for the necessary inter–frame spacing and preamble. FEC parity overhead is not included in the reported length. The Queue #n Report field is an unsigned 16 bit integer representing the transmission request in units of time_quanta. This field is present only when the corresponding flag in the Report bitmap is set.

e) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception. The size of this field depends on the used Queue Report entries, and accordingly varies in length from 0 to 39.

The REPORT MPCPDU shall be generated by a MAC Control instance mapped to an active ONU, and as such shall be marked with a unicast type of LLID.

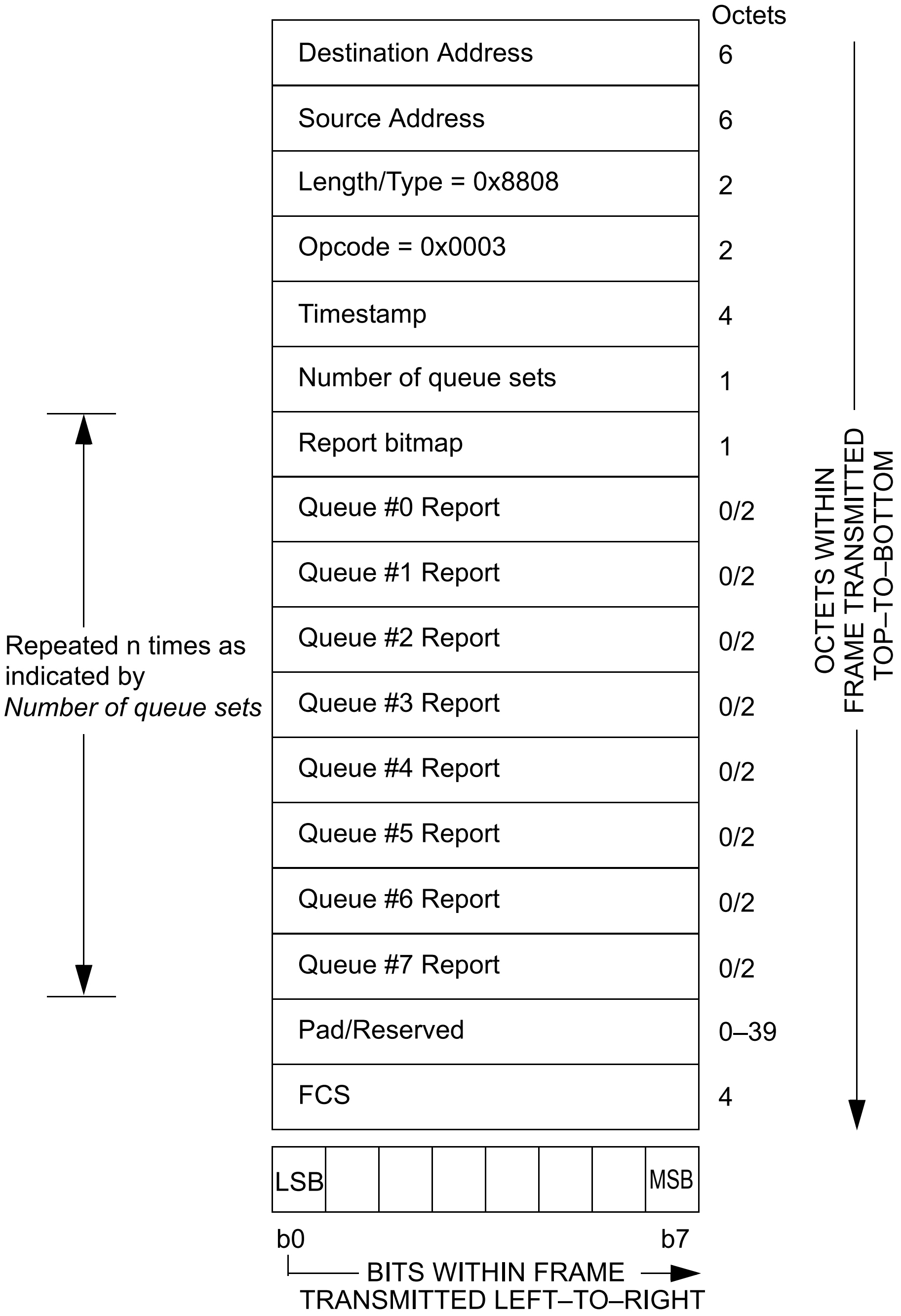


Figure 77–33—REPORT MPCPDU

77.3.6.3 REGISTER_REQ description

The REGISTER_REQ MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the REGISTER_REQ MPCPDU is 0x0004.
b) Flags. This is an 8 bit flag register that indicates special requirements for the registration, as presented in Table 77–5.

Table 77–5—REGISTER_REQ MPCPDU Flags fields

Value	Indication	Comment
0	Reserved	Ignored on reception.
1	Register	Registration attempt for ONU.
2	Reserved	Ignored on reception.
3	Deregister	This is a request to deregister the ONU. Subsequently, the MAC is deallocated and the LLID may be reused.
4–255	Reserved	Ignored on reception.

c) Pending grants. This is an unsigned 8 bit value signifying the maximum number of future grants the ONU is configured to buffer. The OLT should not grant the ONU more than this maximum number of Pending grants vectors comprised of {start, length, force_report, discovery} into the future.
d) Discovery Information. This is a 16 bit flag register. Table 77–6 presents the structure of the Discovery Information flag.

Table 77–6—REGISTER_REQ MPCPDU Discovery Information Fields

Bit	Flag field	Values
0	ONU is 1G upstream capable	0 – ONU transmitter is not capable of 1 Gb/s 1 – ONU transmitter is capable of 1 Gb/s
1	ONU is 10G upstream capable	0 – ONU transmitter is not capable of 10 Gb/s 1 – ONU transmitter is capable of 10 Gb/s
2–3	Reserved	Ignored on reception
4	1G registration attempt	0 – 1 Gb/s registration is not attempted 1 – 1 Gb/s registration is attempted
5	10G registration attempt	0 – 10 Gb/s registration is not attempted 1 – 10 Gb/s registration is attempted
6–15	Reserved	Ignored on reception

e) Laser On Time. This field is 1 octet long and carries the Laser On Time characteristic for the given ONU transmitter. The value is expressed in the units of time_quanta.
f) Laser Off Time. This field is 1 octet long and carries the Laser Off Time characteristic for the given ONU transmitter. The value is expressed in the units of time_quanta.
g) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception.

The REGISTER_REQ MPCPDU shall be generated by a MAC Control instance mapped to an undiscovered ONU, and as such shall be marked with a broadcast type of LLID (77.3.2.3).

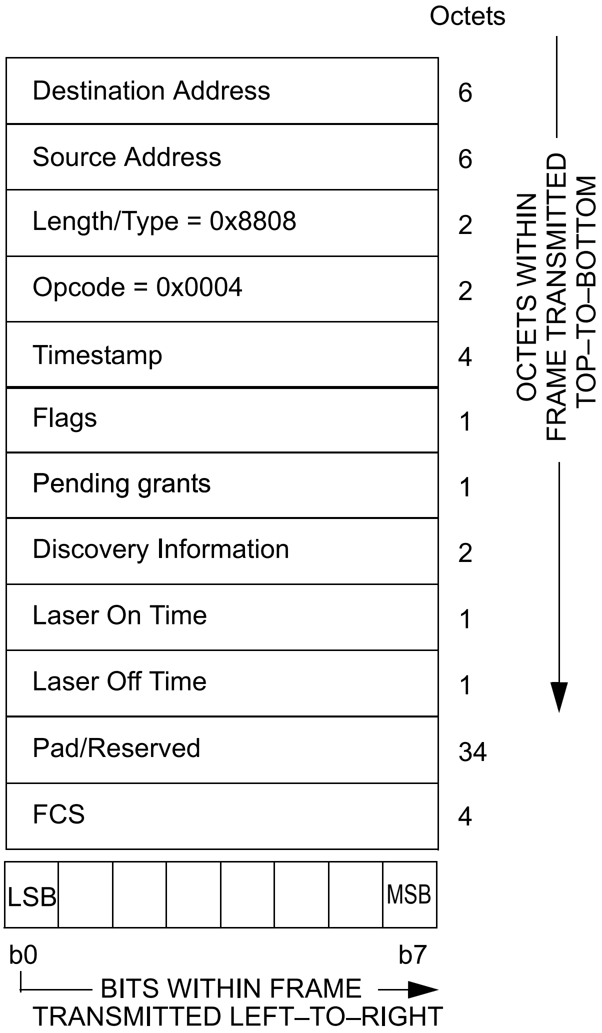


Figure 77–34—REGISTER_REQ MPCPDU

77.3.6.4 REGISTER description

The REGISTER MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) DA. The destination address used shall be an individual MAC address.
b) Opcode. The opcode for the REGISTER MPCPDU is 0x0005.
c) Assigned Port. This field holds a 16 bit unsigned value reflecting the LLID of the port assigned following registration.
d) Flags. this is an 8 bit flag register that indicates special requirements for the registration, as presented in Table 77–7.
e) Sync Time. This is an unsigned 16 bit value signifying the required synchronization time of the OLT receiver. The ONU calculates the effective grant length by subtracting the syncTime, laserOnTime, laserOffTime, and END_BURST_DELIMITER from the grant length it received from the OLT. The value is counted in 1 time_quantum increments. The advertised value includes synchronization requirement on all receiver elements including PMD, PMA, and PCS.

Table 77–7—REGISTER MPCPDU Flags field

Value	Indication	Comment
0	Reserved	Ignored on reception.
1	Reregister	The ONU is explicitly asked to re-register.
2	Deregister	This is a request to deallocate the port and free the LLID. Subsequently, the MAC is deallocated.
3	Ack	The requested registration is successful.
4	Nack	The requested registration attempt is denied by the MAC Control Client.
5–255	Reserved	Ignored on reception.

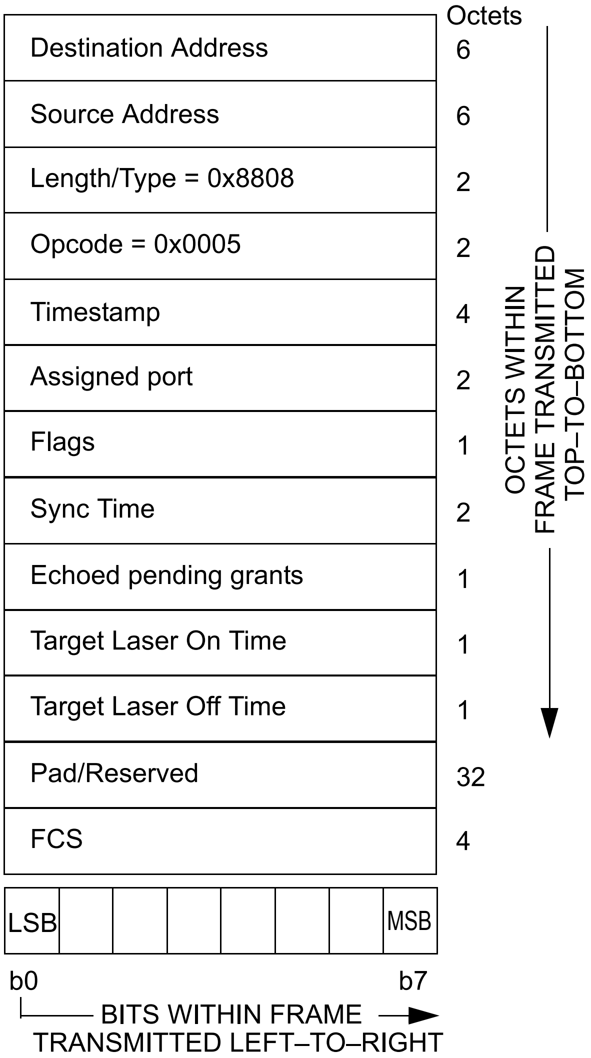


Figure 77–35—REGISTER MPCPDU

f) Echoed pending grants. This is an unsigned 8 bit value signifying the number of future grants the ONU may buffer before activating. The OLT should not grant the ONU more than this number of grants into the future.
g) Target Laser On Time. This is an unsigned 8 bit value, expressed in the units of time_quanta, signifying the Laser On Time for the given ONU transmitter. This value may be different from Laser On Time delivered by the ONU in the REGISTER_REQ MPCPDU during the Discovery process. The ONU updates the local laserOnTime variable per state diagram in Figure 77–23.
h) Target Laser Off Time. This is an unsigned 8 bit value, expressed in the units of time_quanta, signifying the Laser Off Time for the given ONU transmitter. This value may be different from Laser Off Time delivered by the ONU in the REGISTER_REQ MPCPDU during the Discovery process. The ONU updates the local laserOffTime variable per state diagram in Figure 77–23.
i) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored on reception.

The REGISTER MPCPDU shall be generated by a MAC Control instance mapped to all ONUs and such frame is marked by the broadcast LLID (77.3.2.3).

77.3.6.5 REGISTER_ACK description

The REGISTER_ACK MPCPDU is an instantiation of the Generic MPCPDU, and is further defined using the following definitions:

a) Opcode. The opcode for the REGISTER_ACK MPCPDU is 0x0006.
b) Flags. This is an 8 bit flag register that indicates special requirements for the registration, as presented in Table 77–8.
c) Echoed assigned port. This field holds a 16 bit unsigned value reflecting the LLID for the port assigned following registration.
d) Echoed Sync Time. This is an unsigned 16 bit value echoing the required synchronization time of the OLT receiver as previously advertised (77.3.6.4).
e) Pad/Reserved. This is an empty field that is transmitted as zeros, and ignored at reception.

Table 77–8—REGISTER_ACK MPCPDU Flags fields

Value	Indication	Comment
0	Nack	The requested registration attempt is denied by the MAC Control Client.
1	Ack	The registration process is successfully acknowledged.
2–255	Reserved	Ignored on reception.

The REGISTER_ACK MPCPDU shall be generated by a MAC Control instance mapped to an active ONU, and as such shall be marked with a unicast type of LLID.

77.4 Discovery Process in dual-rate systems

The enhancements introduced to the Clause 77 discovery process for EPONs facilitate the coexistence of 10G–EPON with 1G–EPON.

77.4.1 OLT speed-specific discovery

The discovery GATE MPCPDU is defined in Clause 64 for 1 Gb/s operation and in Clause 77 for 10 Gb/s operation. An additional field (Discovery Information field) was added to the 10 Gb/s discovery GATE MPCPDU. This field allows the OLT to relay speed-specific information regarding the discovery window to the different ONUs that may coexist in the same PON. The OLT has the ability to transmit common discovery GATE MPCPDUs on both the 1 Gb/s transmit path and 10 Gb/s transmit path, or it can send

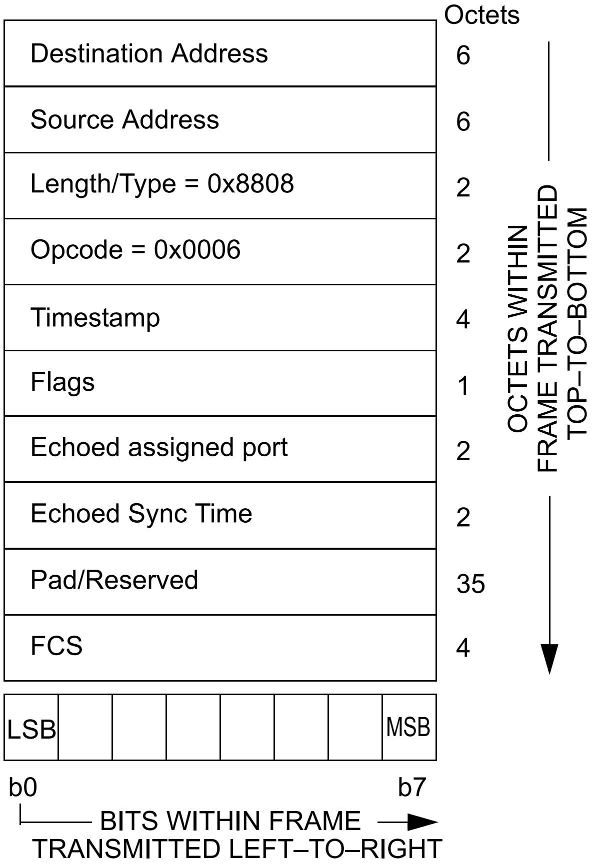


Figure 77–36—REGISTER_ACK MPCPDU

completely separate and independent GATE messages on these different paths. For each discovery window, the OLT is capable of opening windows for individual speeds or multiple speeds.

These different combinations allow the OLT MAC Control Client to open a number of discovery windows for all of the different ONU types. Table 77–9 shows the different types of windows that are possible, along with the necessary LLID and discovery information that also needs to be present in the discovery GATE MPCPDUs. For some combinations, it may be desirable for the OLT MAC Control Client to open overlapping discovery windows. It may do so by sending one discovery GATE MPCPDU on the 1 Gb/s downstream channel and a similar discovery GATE MPCPDU on the 10 Gb/s downstream channel; both discovery GATE MPCPDUs having the same Start Time value.

Figure 77–37 shows the three primary combinations of discovery windows and the different types of REGISTER_REQ MPCPDUs that may be received during the window. Figure 77–37(a) shows reception of messages from 1 Gb/s and 10/1 Gb/s ONUs. Figure 77–37(b) shows reception of messages from 10 Gb/s ONUs. Figure 77–37(c) shows reception of messages from all types of ONUs.

77.4.2 ONU speed-specific registration

A 1G–EPON ONU receives only discovery GATE messages transmitted by the OLT in the 1 Gb/s broadcast channel. Operation and registration of these ONUs is specified in Clause 64.

A 10/1G–EPON ONU is only capable of receiving discovery GATE MPCPDU transmitted by the OLT in the 10 Gb/s broadcast channel. These messages are parsed, and if a 1 Gb/s discovery window is opened, the ONU may attempt to register in the EPON.

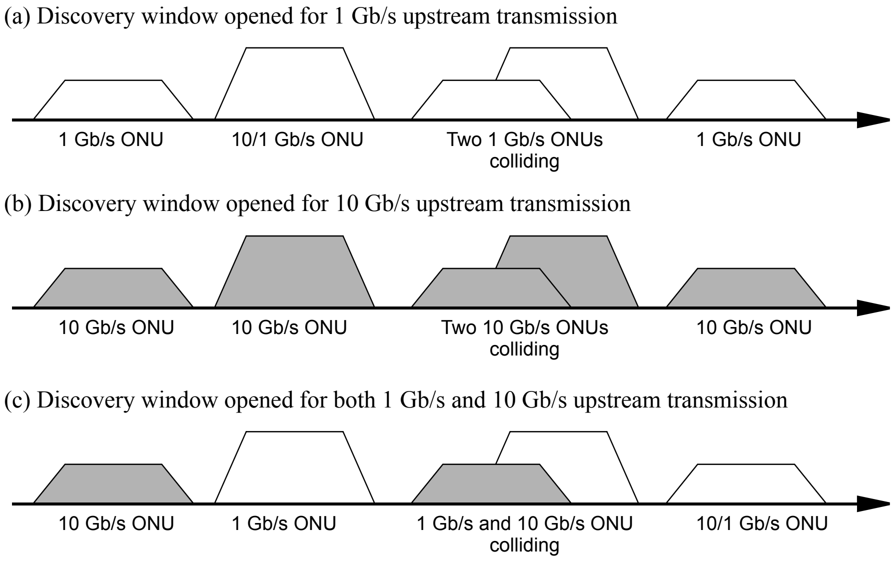


Figure 77–37—Combinations of REGISTER_REQ MPCPDUs during discovery window for 10G–EPON and 1G–EPON coexisting in the same PON

Table 77–9—Discovery GATE MPCPDUs for all ONU types

ONU types targeted by discovery GATE MPCPDU	LLID of discovery GATE(s)	Discovery information			
		Upstream capable		Discovery window	
		1G	10G	1G	10G
1G–EPON	0x7FFF	No Discovery Information field present			
10/1G–EPON	0x7FFE	1	0	1	0
1G–EPON and 10/1G–EPON	0x7FFF[a]	No Discovery Information field present			
	0x7FFE[a]	1	0	1	0
10/10G–EPON	0x7FFE	0	1	0	1
10/1G–EPON and 10/10G–EPON	0x7FFE	1	1	1	1
1G–EPON, 10/1G–EPON, and 10/10G–EPON	0x7FFF[a]	No Discovery Information field present			
	0x7FFE[a]	1	1	1	1

[a] Two discovery GATE MPCPDUs are transmitted in two separate downstream broadcast channels: one with the LLID of 0x7FFF transmitted in the 1 Gb/s downstream broadcast channel and another one the LLID of 0x7FFE transmitted in the 10 Gb/s downstream broadcast channel.

A 10/10G–EPON ONU is only capable of receiving discovery GATE MPCPDU transmitted by the OLT in the 10 Gb/s broadcast channel. These messages are parsed, and if a 10 Gb/s discovery window is opened, the ONU may attempt to register in the EPON.

A dual speed ONU capable of 10/1G–EPON operation or 10/10G–EPON operation is also only capable of receiving discovery GATE MPCPDU transmitted by the OLT in the 10 Gb/s broadcast channel. These messages need to be parsed, and the ONU makes the registration decision based on the available information. The ONU should attempt to register during the discovery window announced as supporting the highest speed common to both the OLT and ONU. Table 77–10 shows the action the ONU should take based on the ONU transmit capabilities and the received discovery information.

Table 77–10—ONU action during discovery window

OLT Discovery information				**ONU Tx capability**		**ONU action**
Upstream capable		**Discovery window**				
1G	**10G**	**1G**	**10G**	**1G**	**10G**	
1	0	1	0	1	X	Attempt 1G registration
1	X	1	X	1	0	Attempt 1G registration
X	1	X	1	X	1	Attempt 10G registration
1	1	0	1	1	0	Wait for 1G discovery window
1	1	1	0	X	1	Wait for 10G discovery window

The ONU generates the REGISTER_REQ MPCPDU with the same LLID as the discovery GATE MPCPDU it responds to, i.e., 1G–EPON ONU (per Clause 64) use LLID 0x7FFF, while the 10G–EPON ONUs use LLID 0x7FFE.

77.5 Protocol implementation conformance statement (PICS) proforma for Clause 77, Multipoint MAC Control[34]

77.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 77 Multipoint MAC Control, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

77.5.2 Identification

77.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

77.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Clause 77, Multipoint MAC Control
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[34] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

77.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*OLT	OLT functionality	77.1	Device supports functionality required for OLT	O/1	Yes [ ] No [ ]
*ONU	ONU functionality	77.1	Device supports functionality required for ONU	O/1	Yes [ ] No [ ]

77.5.4 PICS proforma tables for Multipoint MAC Control

77.5.4.1 Compatibility considerations

Item	Feature	Subclause	Value/Comment	Status	Support
CC1	Delay through MAC	77.3.2.4	Maximum delay variation of 1 time_quantum	M	Yes [ ]
CC2	OLT grant time delays	77.3.2.4	Not grant nearer than 1024 time_quanta into the future	OLT:M	Yes [ ]
CC3	ONU processing delays	77.3.2.4	Process all messages in less than 1024 time_quanta	ONU:M	Yes [ ]
CC4	OLT grant issuance	77.3.2.4	Not grant more than one message every 1024 time_quanta to a single ONU	OLT:M	Yes [ ]

77.5.4.2 Multipoint MAC Control

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	OLT localTime	77.2.2.2	Track transmit clock	OLT:M	Yes [ ]
OM2	ONU localTime	77.2.2.2	Track receive clock	ONU:M	Yes [ ]
OM3	Random wait for transmitting REGISTER_REQ messages	77.3.3	Shorter than length of discovery window	ONU:M	Yes [ ]
OM4	Periodic report generation	77.3.4	Reports are generated periodically	ONU:M	Yes [ ]
OM5	Periodic granting	77.3.4	Grants are issued periodically	OLT:M	Yes [ ]
OM6	Issuing of grants	77.3.5	Not issue more than maximum supported grants	OLT:M	Yes [ ]

77.5.4.3 State diagrams

Item	Feature	Subclause	Value/Comment	Status	Support
SM1	Multipoint Transmission Control	77.2.2.7	Meets the requirements of Figure 77–10	M	Yes [ ]
SM2	OLT Control Parser	77.2.2.7	Meets the requirements of Figure 77–11	M	Yes [ ]
SM3	ONU Control Parser	77.2.2.7	Meets the requirements of Figure 77–12	M	Yes [ ]
SM4	OLT Control Multiplexer	77.2.2.7	Meets the requirements of Figure 77–13	OLT:M	Yes [ ]
SM5	ONU Control Multiplexer	77.2.2.7	Meets the requirements of Figure 77–14	OLT:M	Yes [ ]
SM6	Discovery Processing OLT Window Setup	77.3.3.6	Meets the requirements of Figure 77–19	OLT:M	Yes [ ]
SM7	Discovery Processing OLT Process Requests	77.3.3.6	Meets the requirements of Figure 77–20	OLT:M	Yes [ ]
SM8	Discovery Processing OLT Register	77.3.3.6	Meets the requirements of Figure 77–21	ONU:M	Yes [ ]
SM9	Discovery Processing OLT Final Registration	77.3.3.6	Meets the requirements of Figure 77–22	OLT:M	Yes [ ]
SM10	Discovery Processing ONU Registration	77.3.3.6	Meets the requirements of Figure 77–23	ONU:M	Yes [ ]
SM11	Report Processing at OLT	77.3.4.6	Meets the requirements of Figure 77–25	OLT:M	Yes [ ]
SM12	Report Processing at ONU	77.3.4.6	Meets the requirements of Figure 77–26	ONU:M	Yes [ ]
SM13	Gate Processing at OLT	77.3.5.6	Meets the requirements of Figure 77–28	OLT:M	Yes [ ]
SM14	Gate Processing at ONU	77.3.5.6	Meets the requirements of Figure 77–29	ONU:M	Yes [ ]
SM15	Gate Processing ONU Activation	77.3.5.6	Meets the requirements of Figure 77–30	ONU:M	Yes [ ]

77.5.4.4 MPCP

Item	Feature	Subclause	Value/Comment	Status	Support
MP1	MPCPDU structure	77.3.6	As in Figure 77–31	M	Yes [ ]
MP2	LLID for MPCPDU	77.3.6	RS generates LLID for MPCPDU	M	Yes [ ]
MP3	Grants during discovery	77.3.6.1	Single grant in GATE message during discovery	OLT:M	Yes [ ]
MP4	Grant start time	77.3.6.1	Grants within one GATE MPCPDU are sorted by their Start time values	OLT:M	Yes [ ]
MP5	GATE generation	77.3.6.1	GATE generated for active ONU except during discovery	OLT:M	Yes [ ]
MP6	GATE LLID	77.3.6.1	Unicast LLID except for discovery	OLT:M	Yes [ ]
MP7	REPORT issuing	77.3.6.2	Issues REPORT periodically	ONU:M	Yes [ ]
MP8	REPORT generation	77.3.6.2	Generated by active ONU	ONU:M	Yes [ ]
MP9	REPORT generation	77.3.6.2	REPORT Queue #n length rounding	ONU:M	Yes [ ]
MP10	REPORT LLID	77.3.6.2	REPORT has unicast LLID	ONU:M	Yes [ ]
MP11	REGISTER_REQ generation	77.3.6.3	Generated by undiscovered ONU	ONU:M	Yes [ ]
MP12	REGISTER_REQ LLID	77.3.6.3	Use broadcast LLID	ONU:M	Yes [ ]
MP13	REGISTER DA address	77.3.6.4	Use individual MAC address	OLT:M	Yes [ ]
MP14	REGISTER generation	77.3.6.4	Generated for all ONUs	OLT:M	Yes [ ]
MP15	REGISTER_ACK generation	77.3.6.5	Generated by active ONU	ONU:M	Yes [ ]
MP16	REGISTER_ACK LLID	77.3.6.5	Use unicast LLID	ONU:M	Yes [ ]

Annex 57A

(normative)

Requirements for support of Slow Protocols

57A.1 Introduction and rationale

There are two distinct classes of protocols used to control various aspects of the operation of IEEE 802.3 devices. They are as follows:

a) Protocols such as the MAC Control PAUSE operation (Annex 31B) that need to process and respond to PDUs rapidly in order to avoid performance degradation. These are likely to be implemented as embedded hardware functions, making it relatively unlikely that existing equipment could be easily upgraded to support additional such protocols.

NOTE—This consideration was one of the contributing factors in the decision to use a separate group MAC address to support LACP and the Marker protocol, rather than re-using the group MAC address currently used for PAUSE frames.

b) Protocols such as LACP, with less stringent frequency and latency requirements. These may be implemented in software, with a reasonable expectation that existing equipment be upgradeable to support additional such protocols, depending upon the approach taken in the original implementation.

In order to place some realistic bounds upon the demands that might be placed upon such a protocol implementation, this annex defines the characteristics of this class of protocols and identifies some of the behaviors that an extensible implementation needs to exhibit.

57A.2 Slow Protocol transmission characteristics

Protocols that make use of the addressing and protocol identification mechanisms identified in this annex are subject to the following constraints:

a) The number of frames transmitted in any one-second period per Slow Protocol subtype shall not exceed aSlowProtocolFrameLimit (see 30.3.1.1.38).
b) The maximum number of Slow Protocols subtypes is 10.
c) The MAC Client data generated by any of these protocols shall be no larger than maxBasicDataSize (see 4.2.7.1). It is recommended that the maximum length for a Slow Protocol frame be limited to 128 octets.

The effect of these restrictions is to restrict the bandwidth consumed and performance demanded by this set of protocols; by default the maximum traffic loading that would result is 100 maximum length frames per second per point-to-point link and 100 maximum length frames per ONU for point-to-multipoint topologies.

57A.3 Addressing

The Slow_Protocols_Multicast address has been allocated exclusively for use by Slow Protocols PDUs; its value is identified in Table 57A–1.

Table 57A–1—Slow_Protocols_Multicast address

Name	Value
Slow_Protocols_Multicast address	01-80-C2-00-00-02

NOTE 1—This address is within the range reserved by IEEE Std 802.1D for link-constrained protocols. As such, frames sent to this address will not be forwarded by conformant MAC Bridges; its use is restricted to a single link.

NOTE 2—Although the two currently existing Slow Protocols (i.e., LACP and the Marker protocol) always use this MAC address as the destination address in transmitted PDUs, this may not be true for all Slow Protocols. In some yet-to-be-defined protocol, unicast addressing may be appropriate and necessary. Rather, the requirement is that this address not be used by any protocols that are not Slow Protocols.

57A.4 Protocol identification

All Slow Protocols use type interpretation of the Length/Type field, and use the Slow_Protocols_Type value as the primary means of protocol identification; its value is shown in Table 57A–2.

Table 57A–2—Slow_Protocols_Type value

Name	Value
Slow_Protocols_Type	88-09

The first octet of the MAC Client data following the Length/Type field is a protocol subtype identifier that distinguishes between different Slow Protocols. Table 57A–3 identifies the semantics of this subtype.

Table 57A–3—Slow Protocols subtypes

Protocol Subtype value	Protocol name
0	Unused—Illegal value
1	Link Aggregation Control Protocol (LACP)
2	Link Aggregation—Marker Protocol
3	Operations, Administration, and Maintenance (OAM)
4	Reserved for future use
5	Reserved for future use
6	Reserved for future use
7	Reserved for future use
8	Reserved for future use
9	Reserved for future use
10	Organization Specific Slow Protcol (OSSP)
11–255	Unused—Illegal values

NOTE—Although this mechanism is defined as part of an IEEE 802.3 standard, it is the intent that the reserved code points in this table will be made available to protocols defined by other working groups within IEEE 802, should this mechanism be appropriate for their use.

57A.5 Handling of Slow Protocol frames

Any received MAC frame that carries the Slow_Protocols_Type field value is assumed to be a Slow Protocol frame. An implementation that claims conformance to this standard shall handle all Slow Protocol frames as follows:

a) Discard any Slow Protocol frame that carries an illegal value of Protocol Subtype (see Table 57A–3). Such frames shall not be passed to the MAC Client.

b) Pass any Slow Protocol frames that carry Protocol Subtype values that identify supported Slow Protocols to the protocol entity for the identified Slow Protocol.

c) Pass any Slow Protocol frames that carry Protocol Subtype values that identify unsupported Slow Protocols to the MAC Client.

NOTE—The intent of these rules is twofold. First, they rigidly enforce the maximum number of Slow Protocols, ensuring that early implementations of this mechanism do not become invalidated as a result of "scope creep." Second, they make it clear that the appropriate thing to do in any embedded frame parsing mechanism is to pass frames destined for unsupported protocols up to the MAC Client rather than discarding them, thus allowing for the possibility that, in soft configurable systems, the MAC Client might be enhanced in the future in order to support protocols that were not implemented in the hardware.

57A.6 Protocol implementation conformance statement (PICS) proforma for Annex 57A, Requirements for support of Slow Protocols[35]

57A.6.1 Introduction

The supplier of an implementation that is claimed to conform to Annex 57A shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

57A.6.2 Identification

57A.6.2.1 Implementation identification

Supplier (Note 1)	
Contact point for inquiries about the PICS (Note 1)	
Implementation Name(s) and Version(s) (Notes 1 and 3)	
Other information necessary for full identification—e.g., name(s) and version(s) of machines and/or operating system names (Note 2)	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

57A.6.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 57A, Requirements for support of Slow Protocols.
Identification of amendments and corrigenda to the PICS proforma that have been completed as part of the PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21: the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[35] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

57A.6.2.3 Transmission characteristics

Item	Feature	Subclause	Value/Comment	Status	Support
SP1	Transmission rate	57A.2	Max 10 frames in any one-second period	M	Yes [ ]
SP2	Data field	57A.2	No larger than maxBasicDataSize (see 4.2.7.1)	M	Yes [ ]

57A.6.2.4 Frame handling

Item	Feature	Subclause	Value/Comment	Status	Support
FH1	Handling of Slow Protocol frames	57A.5	As specified in 57A.5	M	Yes [ ]

Annex 57B

(normative)

Organization specific slow protocol (OSSP)

The organization specific slow protocol (OSSP) provides a standardized means for organizations to define their own slow protocols outside the scope of this standard. The requirements defined in Annex 57A apply to these slow protocols.

57B.1 Transmission and representation of octets

An organization specific slow protocol data unit (OSSPDU) comprises an integral number of octets. The bits in each octet are numbered from 0 to 7, where 0 is the least significant bit. When consecutive octets are used to represent a numerical value, the most significant octet is transmitted first, followed by successively less significant octets.

57B.1.1 OSSPDU frame structure

The OSSPDU frame structure shall be as depicted in Figure 57B–1. In this figure:

a) Octets are transmitted from top to bottom.
b) Within an octet, bits are shown with bit 0 to the left and bit 7 to the right, and are transmitted from left to right.
c) When consecutive octets are used to represent a binary number, the octet transmitted first has the more significant value.
d) When consecutive octets are used to represent a MAC address, the least significant bit of the first octet is assigned the value of the first bit of the MAC address, the next most significant bit the value of the second bit of the MAC address, and so on through the eighth bit. Similarly the least significant through most significant bits of the second octet are assigned the value of the ninth through seventeenth bits of the MAC address, and so on for all the octets of the MAC address.
e) OSSPDUs are at least minFrameSize in length.

A OSSPDU shall have the following fields:

f) *Destination Address (DA).* The DA in OSSPDUs is the Slow_Protocols_Multicast address. Its use and encoding are specified in Annex 57A.
g) *Source Address (SA).* The SA in OSSPDUs is the individual MAC address associated with the port through which the OSSPDU is transmitted.
h) *Length/Type.* The Length/Type in OSSPDUs carries the Slow_Protocols_Type field value specified in 57A.4.
i) *Subtype.* The Subtype field identifies the specific Slow Protocol being encapsulated. OSSPDUs carry the Subtype value 0x0A as specified in Annex 57A.
j) *Organizationally Unique Identifier (OUI) or Company ID (CID).* The OUI/CID field contains the OUI or CID to identify the Organization Specific Data. The bit/octet ordering of the OUI/CID field within an OSSPDU is identical to the bit/octet ordering of the OUI portion of the DA/SA.
k) *Organization Specific Data*. The format and function of the Organization Specific Data field is dependent on the value of the OUI/CID field and is beyond the scope of this standard.
l) *FCS.* This field is the Frame Check Sequence, typically generated by the underlying MAC.

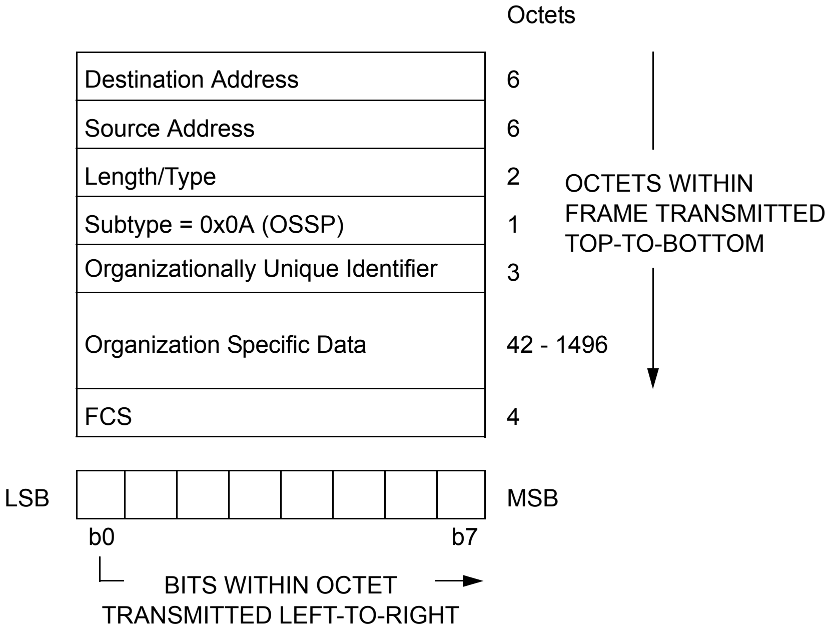

Figure 57B–1—OSSPDU structure

57B.2 Protocol implementation conformance statement (PICS) proforma for Annex 57B, Organization specific slow protocol (OSSP)[36]

57B.2.1 Introduction

The supplier of an implementation that is claimed to conform to Annex 57B shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

57B.2.2 Identification

57B.2.2.1 Implementation identification

Supplier (Note 1)	
Contact point for inquiries about the PICS (Note 1)	
Implementation Name(s) and Version(s) (Notes 1 and 3)	
Other information necessary for full identification—e.g., name(s) and version(s) of machines and/or operating system names (Note 2)	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

57B.2.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 57B, Organization specific slow protocol (OSSP).
Identification of amendments and corrigenda to the PICS proforma that have been completed as part of the PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21: the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	

Date of Statement	

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[36] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

57B.2.2.3 OSSPDU structure

Item	Feature	Subclause	Value/Comment	Status	Support
OS1	Organization Specific Protocol Data Unit (OSSPDU) frame structure	57B.1.1	As shown in Figure 57B–1 and as described	M	Yes [ ]

Annex 58A

(informative)

Frame-based testing

The use of the frame-based test patterns described in Clause 58, Clause 59, and Clause 60 provides for the most general testing of the external interfaces. They combine patterns appropriate for testing the desired parameters with a flexible frame structure that allows the test pattern to be passed through a compliant system. However, the frame-based nature of the patterns may cause difficulties with some bit oriented test systems if care is not taken.

The concern is that streams of data that are passed through a system under test may have their inter-frame gap altered by rate control mechanisms. This changes the bit sequence, even in the presence of no errors, and causes difficulties with bit sequence oriented test systems. There are several methods of addressing this issue. The solutions fall roughly into the following three categories:

a) Error detection internal to the equipment under test
b) Use of frame-based test equipment
c) Synchronized systems

An example of the first type of test where the internal error detection would be used is a receiver sensitivity test. The input pattern may be generated by any method, including a bit oriented serial pattern generator or a frame-based pattern generator. Errored frames would be rejected internal to the system under test based on FCS errors. This type of test has the advantage of testing all of the components of an input interface. The error count may be made by accessing the error counters internal to the system under test.

The number of bit errors may be assumed to be the same as the number of frame errors to a 90% confidence level as long as frame error ratio is less than 0.2. The bit error ratio may be determined by dividing the frame error ratio by the number of bits in the test frame that are used in the computation of the FCS.

If the internal error counters are not accessible, the test frames may be passed to an output port and the number of received frames may the counted. Any missing frames may be assumed to have had errors. The frame count may be made by conventional frame-based test equipment. The missing frames render the use of bit stream oriented test equipment inappropriate.

When testing transmitter outputs, frames may be passed to the port under test from another port in the system under test. In this case, loss of frames within the system is not expected and testing may be done using a bit oriented test system by making the system synchronous. This may be done by recovering the clock from the output under test and using this as a clock source for the input. If there are no variable delays in the system under test, such as variable queuing delays, the input data stream will be reproduced in the output and conventional Bit Error Ratio Testing (BERT) systems may be used. In the case of 100BASE-X, the output bit stream may be inverted.

Two frame-based alternatives avoid the need for synchronization. The first is to use a frame-based tester for both the pattern generation and the error detection. The optical signal will need to be received by an optical receiver with the proper characteristics for the specific test. The processed data stream would then be sent to the frame-based receiver to determine possible frame errors.

Another method would be to use a bit oriented test system suitable for burst mode operation. This type of tester will examine only the frame contents for errors. Two methods are used for determining the frame contents. An external gating signal may be used. This must be triggered by the data source and include any latency associated with the system under test. Alternately, the test set may recognize the frame boundaries in the incoming data stream.

As the behavior above the MAC is not specified by this standard, the system under test might not be able to forward, return or respond to incoming frames at line rate. Diluting the frame rate is thought to be acceptable for 1000BASE-X but for 100BASE-X testing, groups of 12 frames should be kept together. A system might emit additional frames from a port and may need to be configured so that it does not.

NOTE—Users are advised to take care that the system under test is not connected to a network in service.

Annex 61A

(informative)

EFM Copper examples

61A.1 Purpose and scope

The purpose of this informative annex is to provide practical examples of the use of

a) Aggregation Discovery, for aggregated operation of 10PASS-TS PHYs (Clause 62) or 2BASE-TL PHYs (Clause 63); see 61A.2.
b) 64/65-octet encapsulation, as specified in 61.3.3; see 61A.3.

61A.2 Aggregation Discovery example

An example procedure for PME aggregation discovery is described for system components as shown in Figure 61A–1, connected as in Figure 61A–2. Additional information on example discovery transactions are shown in Figure 61A–3. An example procedure for discovering this connectivity follows:

a) -O system writes remote_discovery_register to value *alpha* (*alpha* may be any 48-bit value, but would benefit from being locally unique e.g. MAC address) using PME-1.
b) -O system reads remote_discovery_register for all other PMEs.
c) -O system discovers that PME-2, PME-6 and PME-7 are associated with the same remote MAC device as PME-1.
d) -O system writes remote_discovery_register to value *alpha* using PME-3— the next non-associated PME.
e) -O system reads remote_discovery_register for all other PMEs.
f) -O system expects that PME-1, PME-2, PME-3, PME-6 and PME-7 will already be written to value *alpha*.
g) -O system discovers that no other PME is associated with the same remote MAC device as PME-3.
h) -O system writes remote_discovery_register to value *alpha* using PME-4—the next non-associated PME.
i) -O system reads remote_discovery_register for all other PMEs.
j) -O system expects that PME-1, PME-2, PME-3, PME-4, PME-6 and PME-7 will already be written to value *alpha*.
k) -O system discovers that PME-5, PME-9 and PME-11 are associated with the same remote MAC device as PME-4.
l) This procedure repeats for all of the PMEs connected to -O system.

An alternate example procedure for discovering this connectivity uses two different 48-bit values:

m) -O system writes remote_discovery_register to value *alpha* (*alpha* may be any 48-bit value, but would benefit from being locally unique e.g. MAC address) using PME-1.
n) -O system reads remote_discovery_register for all other PMEs.
o) -O system discovers that PME-2, PME-6 and PME-7 are associated with the same remote MAC device as PME-1.
p) -O system rewrites remote_discovery_register to value *beta* (*beta* may be any 48-bit value, different to *alpha*) using PME-1.
q) -O system writes remote_discovery_register to value *alpha* using PME-3— the next non-associated PME.

r) -O system reads remote_discovery_register for all other PMEs.
s) -O system discovers that no other PME is associated with the same remote MAC device as PME-3.
t) -O system rewrites remote_discovery_register to value *beta* using PME-3.
u) -O system writes remote_discovery_register to value *alpha* using PME-4—the next non-associated PME.
v) -O system reads remote_discovery_register for all other PMEs.
w) -O system discovers that PME-5, PME-9 and PME-11 are associated with the same remote MAC device as PME-4.
x) -O system rewrites remote_discovery_register to value *beta* using PME-4.
y) This procedure repeats for all of the PMEs connected to -O system.

NOTE— This procedure can be expanded at the -O end to provide up to 32 unique alpha values. The -O end would then write a different alpha value on each port and then read all remote_discovery_register. Since the write operation is an atomic write, only one alpha value for each remote PCS will be written. All other subsequent write operations on that PCS will fail.

Observe also that a large and complex -O system may perform multiple discovery operations in parallel by using multiple unique 48-bit values for writing the remote_discovery_register.

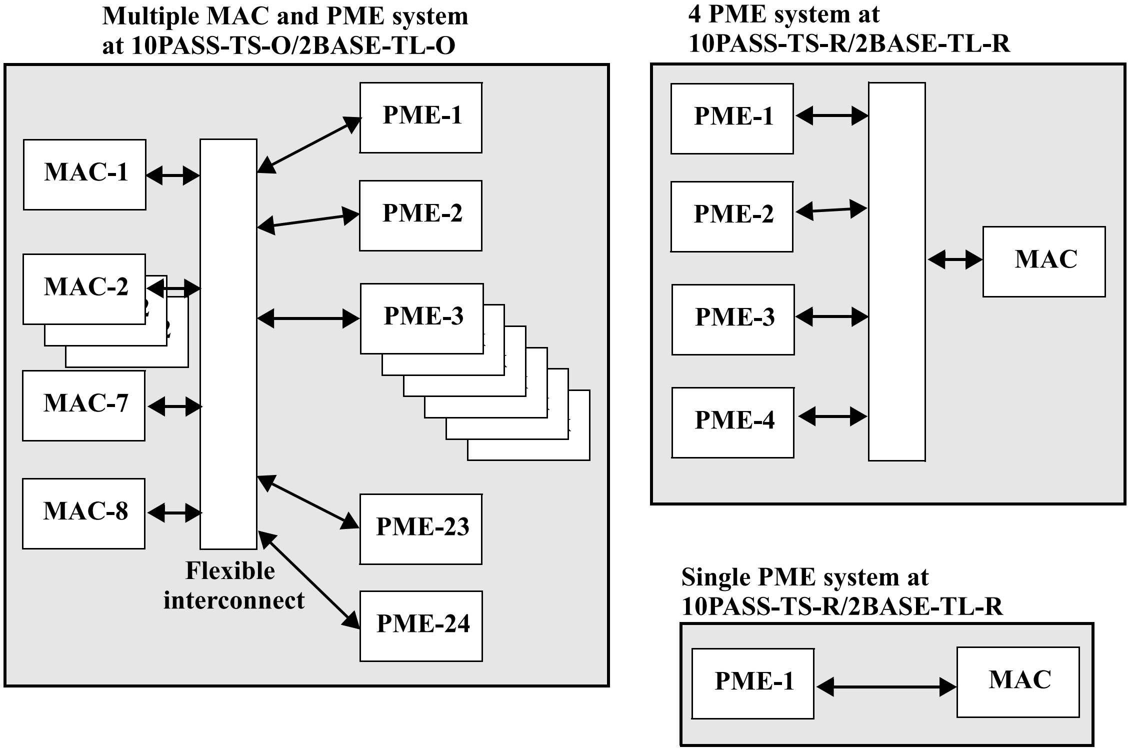

Figure 61A–1—Example systems for discovery

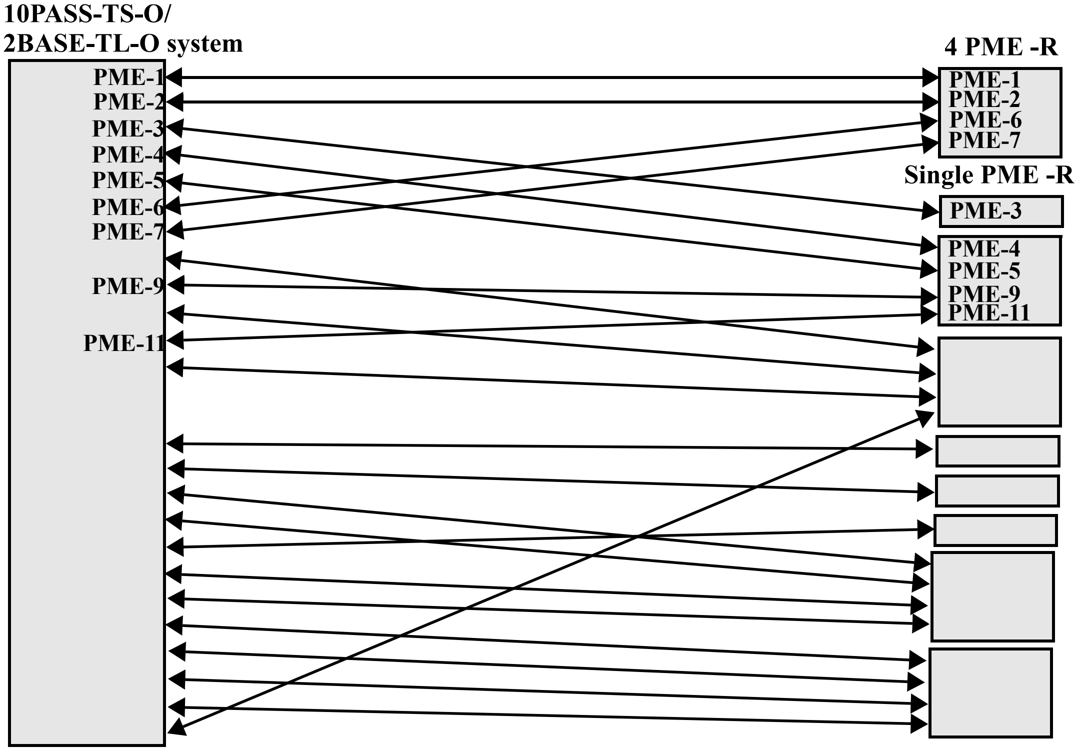

Figure 61A–2—System connectivity for discovery example

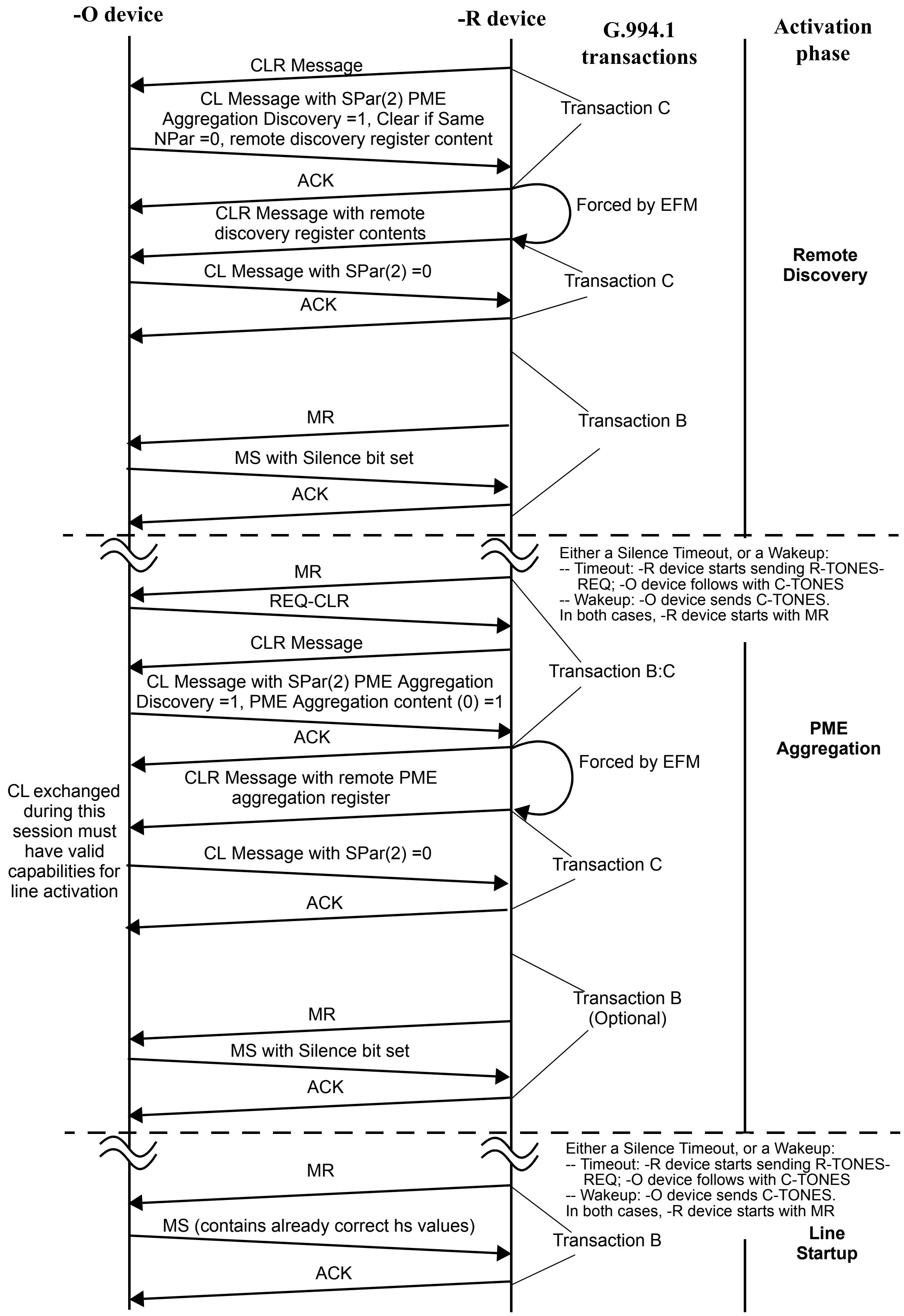

Figure 61A–3—Example activation sequence example

61A.3 Example of 64/65-octet encapsulation

The code below [Equation (61A–1)] consists of an example “C” implementation of the 64/65-octet encapsulation specified in 61.3.3.

NOTE—The example implementation operates under the assumption that the receiver is synchronized at all times.

```
/*
*   802.3ah (EFM) 2BASE-TL (SHDSL) TC Transmitter simulator from 61.2.3
*/

#include <stdio.h>

/* test frame data */
char p0[] = {0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
 0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
 0x10, 0x11, 0x12, 0x13, 0x14, 0x15, 0x16, 0x17,
 0x18, 0x19, 0x1a, 0x1b, 0x1c, 0x1d, 0x1e, 0x1f,
 0x20, 0x21, 0x22, 0x23, 0x24, 0x25, 0x26, 0x27,
 0x28, 0x29, 0x2a, 0x2b, 0x2c, 0x2d, 0x2e, 0x2f,
 0x30, 0x31, 0x32, 0x33, 0x34, 0x35, 0x36, 0x37,
 0x38, 0x39, 0x3a, 0x3b, 0x3c, 0x3d, 0x3e, 0x3f};

char p1[] = {0x40, 0x41, 0x42, 0x43, 0x44, 0x45, 0x46, 0x47,
 0x48, 0x49, 0x4a, 0x4b, 0x4c, 0x4d, 0x4e, 0x4f,
 0x50, 0x51, 0x52, 0x53, 0x54, 0x55, 0x56, 0x57,
 0x58, 0x59, 0x5a, 0x5b, 0x5c, 0x5d, 0x5e, 0x5f,
 0x60, 0x61, 0x62, 0x63, 0x64, 0x65, 0x66, 0x67,
 0x68, 0x69, 0x6a, 0x6b, 0x6c, 0x6d, 0x6e, 0x6f,
 0x70, 0x71, 0x72, 0x73, 0x74, 0x75, 0x76, 0x77,
 0x78, 0x79, 0x7a, 0x7b, 0x7c, 0x7d, 0x7e, 0x7f,
 0x80, 0x81, 0x82, 0x83, 0x84, 0x85, 0x86, 0x87,
 0x88, 0x89, 0x8a, 0x8b, 0x8c, 0x8d, 0x8e, 0x8f};

char p2[] = {0x65, 0x43, 0x21};

#define NUM_CODEWORDS 14    /* number of 65 byte EFM codewords to transmit */

/*
* Define a list of user frames to transmit
*  NOTE: This list defines the set of test cases to transmit.
*/

struct frame {
 int  startingByteNum;    /* byte position at which frame is available to send */
 int  length;             /* number of bytes in ethernet frame */
 char *theBytes;          /* pointer to ethernet frame bytes */
} FrameList[] = {      /* To test: */
 {200, 64, p0},   /* vanilla frame, scrambler, C(k), crc */
 {389, 64, p0},   /* all data sync byte, sync splitting S/data/crc */
 {465, 50, p1},   /* end frame & start new frame in same codeword, C(0) */
 {530,  3, p2},   /* align small frame to span sync byte */
 {650, 64, p0},   /* S following sync byte */
 {700, 55, p1},   /* back-to-back frames, sync byte within crc */
 {0,0,0}          /* end test */
};

/* constants as per TC spec */

#define CODEWORD_BYTE_COUNT     65
#define SYNC_ALL_DATA           0x0f     /* all data sync byte */
#define SYNC_NOT_ALL_DATA       0xf0     /* not all data sync byte */
#define START_OF_FRAME_BYTE     0x50     /* start data byte */
#define IDLE_BYTE               0x00     /* idle data byte */
#define EFM_CRC_POLY 0x82f63b78  /* X**28 + X**27 + X**26 + X**25 + X**23 +
 X**22 + X**20 + X**19 + X**18 + X**14 +
 X**13 + X**11 + X**10 + X**09 + X**08 +
 X**06 + X**00  (lsb is x**31) */

/* the EFM TC crc accumulator */
unsigned long CrcAccum;

void EfmCrcReset(void) {
 CrcAccum = 0xffffffff;
}

void EfmCrc(unsigned char TheByte) {
```

```
 int i;
 /* for all the bits in TheByte, lsb first */
 for( i=0; i<8; i++) {
     /* xor the lsb of TheByte with the x**31 of CrcAccum */
     int FeedBack = 0x01 & (CrcAccum ^ TheByte);
     TheByte  = TheByte  >> 1;
     CrcAccum = CrcAccum >> 1;
     if(FeedBack) {
         CrcAccum = CrcAccum ^ EFM_CRC_POLY;
     }
 }
}

/* run with an argument to get test tags in output, else just the numbers */
main(int argc, char * argv[])
{
 int   ByteNum;
 int   UserFrameIndex   = 0;
 int   HaveUserFrame    = 0;
 int   FrameBytesToGo   = 0;
 char *FrameBytePointer = 0;
 int   NeedCZero        = 0;
 int   b;
 char  Foo[50];

 for(ByteNum=0; ByteNum < (CODEWORD_BYTE_COUNT * NUM_CODEWORDS) ; ByteNum++) {
     unsigned char ByteToSend;
     int BytesLeftInCodeword = CODEWORD_BYTE_COUNT - (ByteNum % CODEWORD_BYTE_COUNT);
     char *FrameTag = 0;
     /* decide what I'm doing */
     switch(ByteNum % CODEWORD_BYTE_COUNT) {
         case 0: /* output start of a codeword */
             if(FrameBytesToGo >= (CODEWORD_BYTE_COUNT-1)) {
                 /* 64 or more bytes to go, send an all data codeword */
                 ByteToSend = SYNC_ALL_DATA;
                 FrameTag = "CODEWORD START (all data)";
             } else {
                 ByteToSend = SYNC_NOT_ALL_DATA;
                 FrameTag = "CODEWORD START (not all data)";
                 if( ByteNum == 0) FrameTag = "EFM bitstream reading right to left.";
             }
             break;
         case 1: /* if a C(k) byte is needed */
             if((FrameBytesToGo && (FrameBytesToGo < (CODEWORD_BYTE_COUNT-1))) ||
NeedCZero) {
                 int kVal = FrameBytesToGo;
                 /* output a C(k) */
                 ByteToSend = 0x10 + kVal;
                 /* calculate even parity */
                 for(b=0x40; b; b=b>>1) {
                 if(ByteToSend & b) {
                     ByteToSend ^= 0x80;
                 }
             }
             NeedCZero = 0;
             /* display C(k) with decimal k */
             sprintf(Foo,"    C(%d)",kVal);
             FrameTag = Foo;
             break;
         }
         /* else fall into default case */
         default:
             /* if I'm
             *   not sending a frame and
             *   there are more to send, and
             *   it's time to start (next frame is available), and
             *   the frame is not too short to start now (including S and crc bytes)
             */
             if(   (FrameBytesToGo == 0)
             && (FrameList[UserFrameIndex].length != 0)
             && (ByteNum >= FrameList[UserFrameIndex].startingByteNum)
             && ((FrameList[UserFrameIndex].length+5) >= BytesLeftInCodeword) )
             {
                 /* then start a new frame */
                 FrameTag = "  Start Frame";
                 ByteToSend = START_OF_FRAME_BYTE;
                 FrameBytesToGo = FrameList[UserFrameIndex].length + 4;
                 FrameBytePointer = FrameList[UserFrameIndex].theBytes;
                 UserFrameIndex++;
                 EfmCrcReset();
             } else if(FrameBytesToGo) {
```

```
             /* else if inside a frame then handle outputting
              * a data byte (or the crc to go with it) */
             switch(FrameBytesToGo) {
             case 4: /* send first crc byte */
                FrameTag = "    First Crc Byte";
                ByteToSend = 0xff & ~CrcAccum;
                break;
             case 3:
                ByteToSend = 0xff & ~(CrcAccum >> 8);
                break;
             case 2:
                ByteToSend = 0xff & ~(CrcAccum >> 16);
                break;
             case 1: /* send last crc byte */
                FrameTag = "    Last Crc Byte";
                ByteToSend = 0xff & ~(CrcAccum >> 24);
                /* if crc ends just before sync byte,
                 * prepare to send C(0) byte */
                if (ByteNum % CODEWORD_BYTE_COUNT == 64) {
                NeedCZero = 1;
                }
                break;
             default: /* just send next data byte and update crc */
                ByteToSend = (unsigned char)*FrameBytePointer++;
                /* calculate CRC on data (61.2.3.3) */
                EfmCrc(ByteToSend);
                break;
             }
          FrameBytesToGo--;
       } else {
          /* else just output an idle byte */
          ByteToSend = IDLE_BYTE;
       }
    }
    /* output the byte (msb on left) (transmission order is right to left)*/
    printf("%05.5d: %02.2X ", ByteNum, ByteToSend);
    for(b=0x80; b; b = b >> 1) {
       if(ByteToSend & b) {
          printf("1");
       } else {
          printf("0");
       }
    }
    if((argc > 1) && FrameTag) {
       printf("    ;%s", FrameTag);
    }
    printf("\n");
 }
 return(0);
}
```

(61A–1)

The following data represents a valid data stream generated by the 64/65-octet encapsulation function (read left-to-right, then top-to-bottom).

```
F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 F0 00 00 00 00 50 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16
17 18 19 1A 1B 1C 1D 1E 1F 20 21 22 23 24 25 26 27 28 29 2A 2B 2C 2D 2E 2F 30 31 32 33 34 35 36
37 38 39 3A F0 99 3B 3C 3D 3E 3F EB 36 6D FB 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 50 0F 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 18
19 1A 1B 1C 1D 1E 1F 20 21 22 23 24 25 26 27 28 29 2A 2B 2C 2D 2E 2F 30 31 32 33 34 35 36 37 38
39 3A 3B 3C 3D 3E 3F F0 14 EB 36 6D FB 00 00 00 00 50 40 41 42 43 44 45 46 47 48 49 4A 4B 4C 4D
4E 4F 50 51 52 53 54 55 56 57 58 59 5A 5B 5C 5D 5E 5F 60 61 62 63 64 65 66 67 68 69 6A 6B 6C 6D
6E 6F 70 71 55 A6 27 CE F0 90 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 50 65 43 21 93 8D FC 64 F0 90 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 F0 50 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13
14 15 16 17 18 19 1A 1B 1C 1D 1E 1F 20 21 22 23 24 25 26 27 28 29 2A 2B 2C 2D 2E 2F 30 31 32 33
34 35 36 37 38 39 3A 3B 3C 3D 3E F0 95 3F EB 36 6D FB 50 40 41 42 43 44 45 46 47 48 49 4A 4B 4C
4D 4E 4F 50 51 52 53 54 55 56 57 58 59 5A 5B 5C 5D 5E 5F 60 61 62 63 64 65 66 67 68 69 6A 6B 6C
6D 6E 6F 70 71 72 73 74 75 76 16 7C F0 12 07 58 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

```
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

Annex 61B

(normative)

Handshake codepoints for 2BASE-TL and 10PASS-TS

61B.1 Purpose and scope

This annex contains the G.994.1 “standard information field” codepoints to be used by 2BASE-TL and 10PASS-TS in the procedures described in 61.4.

61B.2 Level-1 S field codepoints for 2BASE-TL and 10PASS-TS

The Npar(1) codepoints common to 2BASE-TL and 10PASS-TS are specified in Table 10 of G.994.1.

The SPar(1) codepoints to be used by 2BASE-TL and 10PASS-TS transceivers are specified in ITU-T Recommendation G.994.1. The EFM-specific codepoints are shown in Table 61B–1 for information only.

Table 61B–1—Standard information field — SPar(1) coding – Octet 4

Bits								
8	7	6	5	4	3	2	1	SPar(1)s – Octet 4
x	x	1	x	x	x	x	x	2BASE-TL
x	1	x	x	x	x	x	x	10PASS-TS
x	0	0	0	0	0	0	0	No parameters in this octet

61B.3 Codepoints for 2BASE-TL

61B.3.1 Level-2 S field codepoints for 2BASE-TL

Table 61B–2 through Table 61B–5 contain the level-2 codepoints specific to 2BASE-TL.

To support a wide range of data rates and multiple encodings, this section introduces a new way to encode data rates in G.994.1 code points. This method of encoding rates is used for both the PMMS rates and the training rates. Data rates are encoded as a set of ranges, where each range is expressed as a 3-tuple (minimum, maximum, step). The 3-tuple represents all rates of the form (m + ks)(64 kb/s) where m is the minimum value, s is the step value, and k is the set of all integers greater than or equal to zero such that m+ks is less than or equal to the maximum value. Thus, for example, the 3-tuple (40, 70, 10) represents the rates (40)(64 kb/s), (50)(64 kb/s), (60)(64 kb/s), and (70)(64 kb/s).

Each data rate parameter can be expressed as a set of between 1 to 8 ranges, where the supported rates are the union of those supported by the individual ranges. Thus, for example, the 3-tuples (20,30,4), (40,70,10) represent the rates (20)(64 kb/s), (24)(64 kb/s), (28)(64 kb/s), (40)(64 kb/s), (50)(64 kb/s), (60)(64 kb/s), and (70)(64 kb/s). If all bits of the extended base data rate minimum and maximum are set to zero, then those rates are not supported for line probe. If only one range of rates is required, then only the octets associated with (min1,max1,step1) shall be sent.

Also, in many cases, the values in the data range 3-tuple can be less than or equal to 89 (representing the maximum data rate of 5696 kb/s supported by 2BASE-TL). When using G.994.1 code point representation, only 6 bits are available for the value of an NPar(3). To support numbers greater than 63, the value must be split across multiple octets. When encoding a data range using G.994.1, 4 octets are used, where the first octet contains the highest order bit from each of the values in the 3-tuple.

The following definition is added to the G.994.1 code point definitions in 6.4.1 of G.991.2 for the support of the extended data rates specified in this subclause.

Extended Base Data Rate These octets are used to specify payload rates, as follows:

- The PMMS octets indicate rates for line probing segments. Note that while PMMS uses 2-PAM modulation, the PMMS symbol rates are specified assuming 32 TC-PAM encoding, so the PMMS symbol rate (in kbaud) would be equal to the (payload data rate (kb/s) + 8 kb/s)/4. Valid values for minimum and maximum shall be between 4 and 89, inclusive, and valid values for step shall be between 1 and 89, inclusive. The variables j_5 and j_6 associated with the PMMS rates shall be independent, and shall range from 2 to 8, inclusive. If only one range of rates is required, then only the octets associated with (min1,max1,step1) shall be sent. If more than one range of rates is required, then j_5*4 and j_6*4 correspond to the number of octets sent.
- The training parameter octets indicate extended payload data rates supported.
- In CLR, upstream training parameters indicate which data mode rates the 2BASE-TL-R is capable of transmitting and downstream training parameters indicate which data mode rates the 2BASE-TL-R is capable of receiving. If the optional line probe is used, the receiver training parameters will be further limited by the probe results. Valid values for minimum and maximum shall be between 3 and 60, inclusive, for 16-TCPAM and between 12 and 89, inclusive, for 32-TCPAM. Valid values for step shall be between 1 and 89, inclusive. The variables j_1, j_2, j_3, and j_4 associated with the training rates shall be independent, and shall range from 2 to 8, inclusive. If only one range of rates is required, then only the octets associated with (min1,max1,step1) shall be sent. If more than one range of rates is required, then j_1*4, j_2*4, j_3*4, and j_4*4 correspond to the number of octets sent.
- In CL, downstream training parameters indicate which data mode rates the 2BASE-TL-O is capable of transmitting and upstream training parameters indicate which data mode rates the 2BASE-TL-O is capable of receiving. Valid values for minimum and maximum shall be between 3 and 60, inclusive, for 16-TCPAM and between 12 and 89, inclusive, for 32-TCPAM. Valid values for step shall be between 1 and 89, inclusive. The variables j_1, j_2, j_3, and j_4 associated with the training rates shall be independent, and shall range from 2 to 8, inclusive. If only one range of rates is required, then only the octets associated with (min1,max1,step1) shall be sent. If more than one range of rates is required, then j_1*4, j_2*4, j_3*4, and j_4*4 correspond to the number of octets sent. If optional line probe is used, the receiver training parameters will be further limited by the probe results.
- Data rate selections shall be specified in MP and MS messages by setting the maximum and minimum rates to the same value.

Table 61B–2—Standard information field – 2BASE-TL NPar(2) coding – Octet 1

Bits								
8	7	6	5	4	3	2	1	**2BASE-TL NPar(2)s – Octet 1**
x	x	x	x	x	x	x	1	2BASE-TL Training mode[a]
x	x	x	x	x	x	1	x	2BASE-TL PMMS mode[a]
x	x	x	x	x	1	x	x	2BASE-TL G.991.2 Annex A Operation
x	x	x	x	1	x	x	x	2BASE-TL G.991.2 Annex B Operation
x	x	x	1	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	0	0	0	0	0	0	No parameters in this octet

[a] Only one of these bits shall be set at any given time.

Table 61B–3—Standard information field – 2BASE-TL NPar(2) coding – Octet 2

Bits								
8	7	6	5	4	3	2	1	2BASE-TL NPar(2)s – Octet 2
x	x	x	x	x	x	x	1	Regenerator silent period[a,b]
x	x	x	x	x	x	1	x	SRU[b]
x	x	x	x	x	1	x	x	Diagnostic Mode[b]
x	x	x	x	1	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	1	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	0	0	0	0	0	0	No parameters in this octet

[a] This bit shall be set to 0_b if the 2BASE-TL PMMS mode NPar(2) bit is set to 1_b or the 2BASE-TL Training mode NPar(2) bit is set to 1_b.

[b] The specification and use of regenerators is outside the scope of this standard.

Table 61B–4—Standard information field – 2BASE-TL SPar(2) coding – Octet 1

Bits								
8	7	6	5	4	3	2	1	2BASE-TL SPar(2)s – Octet 1
x	x	x	x	x	x	x	1	2BASE-TL Downstream training parameters
x	x	x	x	x	x	1	x	2BASE-TL Downstream training rates - 16-TCPAM
x	x	x	x	x	1	x	x	2BASE-TL Downstream training rates - 32-TCPAM
x	x	x	x	1	x	x	x	2BASE-TL Upstream training parameters
x	x	x	1	x	x	x	x	2BASE-TL Upstream training rates - 16-TCPAM
x	x	1	x	x	x	x	x	2BASE-TL Upstream training rates - 32-TCPAM
x	x	0	0	0	0	0	0	No parameters in this octet

61B.3.2 Level-3 S field codepoints for 2BASE-TL

61B.3.2.1 Training parameter codepoints

Tables 61B–6 through 61B–39 contain the level-3 codepoints specific to 2BASE-TL training parameters.

Table 61B–5—Standard information field – 2BASE-TL SPar(2) coding – Octet 2

Bits								
8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2BASE-TL SPar(2)s – Octet 2**
x	x	x	x	x	x	x	1	2BASE-TL Downstream PMMS parameters
x	x	x	x	x	x	1	x	2BASE-TL Downstream PMMS rates
x	x	x	x	x	1	x	x	2BASE-TL Upstream PMMS parameters
x	x	x	x	1	x	x	x	2BASE-TL Upstream PMMS rates
x	x	x	1	x	x	x	x	2BASE-TL Downstream framing parameters
x	x	1	x	x	x	x	x	2BASE-TL Upstream framing parameters
x	x	0	0	0	0	0	0	No parameters in this octet

Table 61B–6—Standard information field – 2BASE-TL - Downstream training parameters - NPar(3) coding – Octet 1

Bits								
8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2BASE-TL downstream training NPar(3)s – Octet 1**
x	x	0	x	x	x	x	x	Downstream PBO (dB) (bits 5–1 × 1.0 dB)
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3

Table 61B–7—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM- NPar(3) coding – Octet 1

Bits								
8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2BASE-TL downstream training rate - 16-TCPAM NPar(3)s – Octet 1**
x	x						x	Downstream base data rate -16-TCPAM Minimum 1 (bit 7)
x	x					x		Downstream base data rate -16-TCPAM Maximum 1 (bit 7)
x	x				x			Downstream base data rate -16-TCPAM Step 1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–8—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM- NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	**2BASE-TL downstream training rate - 16-TCPAM NPar(3)s – Octet 2**
x	x	x	x	x	x	x	x	Downstream base data rate -16-TCPAM Minimum 1 (bit 1–6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–9—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	**2BASE-TL downstream training rate - 16-TCPAM NPar(3)s – Octet 3**
x	x	x	x	x	x	x	x	Downstream base data rate -16-TCPAM Maximum 1 (bit 1–6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–10—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM - NPar(3) coding – Octet 4

Bits 8	7	6	5	4	3	2	1	**2BASE-TL downstream training rate - 16-TCPAM NPar(3)s Octet 4**
x	x	x	x	x	x	x	x	Downstream base data rate -16-TCPAM Step 1 (bit 1–6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–11—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM- NPar(3) coding – Octet j_1*4-3

Bits 8	7	6	5	4	3	2	1	**2BASE-TL downstream training rate - 16-TCPAM NPar(3)s – Octet j_1*4-3**
x	x						x	Extended Downstream base data rate -16-TCPAM Minimum j_1 (bit 7)
x	x					x		Extended Downstream base data rate -16-TCPAM Maximum j_1 (bit 7)
x	x				x			Extended Downstream base data rate -16-TCPAM Step j_1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–12—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM- NPar(3) coding – Octet j_1*4-2

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 16-TCPAM NPar(3)s – Octet j_1*4-2
x	x	x	x	x	x	x	x	Extended Downstream base data rate -16-TCPAM Minimum j_1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–13—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM - NPar(3) coding – Octet j_1*4-1

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 16-TCPAM NPar(3)s – Octet j_1*4-1
x	x	x	x	x	x	x	x	Extended Downstream base data rate -16-TCPAM Maximum j_1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–14—Standard information field – 2BASE-TL - Downstream training rate - 16-TCPAM - NPar(3) coding – Octet j_1*4

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 16-TCPAM NPar(3)s Octet j_1*4
x	x	x	x	x	x	x	x	Extended Downstream base data rate -16-TCPAM Step j_1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–15—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM- NPar(3) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s – Octet 1
x	x						x	Downstream base data rate -32-TCPAM Minimum 1 (bit 7)
x	x					x		Downstream base data rate -32-TCPAM Maximum 1 (bit 7)
x	x				x			Downstream base data rate -32-TCPAM Step 1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–16—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM- NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s – Octet 2
x	x	x	x	x	x	x	x	Downstream base data rate -32-TCPAM Minimum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–17—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s – Octet 3
x	x	x	x	x	x	x	x	Downstream base data rate -32-TCPAM Maximum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–18—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM - NPar(3) coding – Octet 4

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s Octet 4
x	x	x	x	x	x	x	x	Downstream base data rate -32-TCPAM Step 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–19—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM- NPar(3) coding – Octet j_2*4-3

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s – Octet j_2*4-3
x	x						x	Extended Downstream base data rate - 32-TCPAM Minimum j_2 (bit 7)
x	x					x		Extended Downstream base data rate - 32-TCPAM Maximum j_2 (bit 7)
x	x				x			Extended Downstream base data rate - 32-TCPAM Step j_2 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–20—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM- NPar(3) coding – Octet j_2*4-2

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s – Octet j_2*4-2
x	x	x	x	x	x	x	x	Extended Downstream base data rate - 32-TCPAM Minimum j_2 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–21—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM - NPar(3) coding – Octet j_2*4-1

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s – Octet j_2*4-1
x	x	x	x	x	x	x	x	Extended Downstream base data rate - 32-TCPAM Maximum j_2 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–22—Standard information field – 2BASE-TL - Downstream training rate - 32-TCPAM - NPar(3) coding – Octet j_2*4

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream training rate - 32-TCPAM NPar(3)s Octet j_2*4
x	x	x	x	x	x	x	x	Extended Downstream base data rate - 32-TCPAM Step j_2 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–23—Standard information field – 2BASE-TL - Upstream training parameters - NPar(3) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training NPar(3)s – Octet 1
x	x	0	x	x	x	x	x	Upstream PBO (dB) (bits 5-1 × 1.0 dB)
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3

Table 61B–24—Standard information field – 2BASE-TL - upstream training rate - 16-TCPAM-NPar(3) coding – Octet 1

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s – Octet 1
x	x						x	Upstream base data rate -16-TCPAM Minimum 1 (bit 7)
x	x					x		Upstream base data rate -16-TCPAM Maximum 1 (bit 7)
x	x				x			Upstream base data rate -16-TCPAM Step 1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–25—Standard information field – 2BASE-TL - upstream training rate - 16-TCPAM-NPar(3) coding – Octet 2

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s – Octet 2
x	x	x	x	x	x	x	x	Upstream base data rate -16-TCPAM Minimum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–26—Standard information field – 2BASE-TL - upstream training rate - 16-TCPAM - NPar(3) coding – Octet 3

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s – Octet 3
x	x	x	x	x	x	x	x	Upstream base data rate -16-TCPAM Maximum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–27—Standard information field – 2BASE-TL - Upstream training rate - 16-TCPAM - NPar(3) coding – Octet 4

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s Octet 4
x	x	x	x	x	x	x	x	Upstream base data rate -16-TCPAM Step 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–28—Standard information field – 2BASE-TL - Upstream training rate - 16-TCPAM-NPar(3) coding – Octet j_3*4-3

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s – Octet j_3*4-3
x	x						x	Extended Upstream base data rate - 16-TCPAM Minimum j_3 (bit 7)
x	x					x		Extended Upstream base data rate -16-TCPAM Maximum j_3 (bit 7)
x	x				x			Extended Upstream base data rate -16-TCPAM Step j_3 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE 802.3

Table 61B–29—Standard information field – 2BASE-TL - Upstream training rate - 16-TCPAM-NPar(3) coding – Octet j_3*4-2

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s – Octet j_3*4-2
x	x	x	x	x	x	x	x	Extended Upstream base data rate -16-TCPAM Minimum j_3 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–30—Standard information field – 2BASE-TL - Upstream training rate - 16-TCPAM - NPar(3) coding – Octet j_3*4-1

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s – Octet j_3*4-1
x	x	x	x	x	x	x	x	Extended Upstream base data rate -16-TCPAM Maximum j_3 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–31—Standard information field – 2BASE-TL - Upstream training rate - 16-TCPAM - NPar(3) coding – Octet j_3*4

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 16-TCPAM NPar(3)s Octet j_3*4
x	x	x	x	x	x	x	x	Extended Upstream base data rate -16-TCPAM Step j_3 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–32—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM-NPar(3) coding – Octet 1

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s – Octet 1
x	x						x	Upstream base data rate -32-TCPAM Minimum 1 (bit 7)
x	x					x		Upstream base data rate -32-TCPAM Maximum 1 (bit 7)
x	x				x			Upstream base data rate -32-TCPAM Step 1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–33—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM-NPar(3) coding – Octet 2

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s – Octet 2
x	x	x	x	x	x	x	x	Upstream base data rate -32-TCPAM Minimum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–34—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM - NPar(3) coding – Octet 3

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s – Octet 3
x	x	x	x	x	x	x	x	Upstream base data rate -32-TCPAM Maximum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–35—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM - NPar(3) coding – Octet 4

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s Octet 4
x	x	x	x	x	x	x	x	Upstream base data rate -32-TCPAM Step 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–36—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM-NPar(3) coding – Octet j_4*4-3

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s – Octet j_4*4-3
x	x						x	Extended Upstream base data rate - 32-TCPAM Minimum j_4 (bit 7)
x	x					x		Extended Upstream base data rate - 32-TCPAM Maximum j_4 (bit 7)
x	x				x			Extended Upstream base data rate - 32-TCPAM Step j_4 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–37—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM-NPar(3) coding – Octet j_4*4-2

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s – Octet j_4*4-2
x	x	x	x	x	x	x	x	Extended Upstream base data rate - 32-TCPAM Minimum j_4 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–38—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM - NPar(3) coding – Octet j_4*4-1

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s – Octet j_4*4-1
x	x	x	x	x	x	x	x	Extended Upstream base data rate -32-TCPAM Maximum j_4 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–39—Standard information field – 2BASE-TL - Upstream training rate - 32-TCPAM - NPar(3) coding – Octet j_4*4

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream training rate - 32-TCPAM NPar(3)s Octet j_4*4
x	x	x	x	x	x	x	x	Extended Upstream base data rate -32-TCPAM Step j_4 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

61B.3.2.2 PMMS parameter codepoints

Tables 61B–40 through 61B–67 contain the level-3 codepoints specific to 2BASE-TL PMMS parameters.

Table 61B–40—Standard information field – 2BASE-TL - Downstream PMMS parameters - NPar(3) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 1
x	x	0	x	x	x	x	x	Downstream PBO (dB) (bits 5-1 × 1.0 dB)
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3

Table 61B–41—Standard information field – 2BASE-TL - Downstream PMMS parameters - NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 2
x	x	0	0	0	0	0	0	Downstream PMMS duration unspecified by terminal
x	x	x	x	x	x	x	x	Downstream PMMS duration (bits 6-1 x 50 ms)
x	x	1	1	1	1	1	1	Reserved for allocation by IEEE Std 802.3

Table 61B–42—Standard information field – 2BASE-TL - Downstream PMMS parameters - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 3
x	x	0	0	0	x	x	x	Downstream PMMS scrambler polynomial Index (i2, i1, i0)

Table 61B–43—Standard information field – 2BASE-TL - Downstream PMMS parameters - NPar(3) coding – Octet 4

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 4
x	x	1	x	x	x	x	x	Worst-case PMMS target margin (dB) (bits 5-1 × 1.0 dB - 10 dB)
x	x	0	0	0	0	0	0	Worst-case PMMS target margin unspecified by terminal (values of bits 6-1 from 1 to 31 reserved for allocation by IEEE Std 802.3)

Table 61B–44—Standard information field – 2BASE-TL - Downstream PMMS parameters - NPar(3) coding – Octet 5

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 5
x	x	1	x	x	x	x	x	Current-condition PMMS target margin (dB) (bits 5-1 × 1.0 dB - 10 dB)
x	x	0	0	0	0	0	0	Current-condition PMMS target margin unspecified by terminal (values of bits 6-1 from 1 to 31 reserved for allocation by IEEE Std 802.3)

Table 61B–45—Standard information field – 2BASE-TL - Downstream PMMS parameters - NPar(3) coding – Octet 6

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 6
x	x	x	x	x	x	x	1	Reserved for allocation by IEEE Std 802.3
x	x	x	x	x	x	1	x	Transmit Silence
x	x	x	x	x	1	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	x	1	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	1	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	0	0	0	0	0	0	No parameters in this octet

Table 61B–46—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet 1
x	x						x	Downstream base data rate- 32-TCPAM Minimum 1 (bit 7)
						x		Downstream base data rate- 32-TCPAM Maximum 1 (bit 7)
x	x				x			Downstream base data rate- 32-TCPAM Step 1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEEStd 802.3

Table 61B–47—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS rates NPar(3)s – Octet 2
x	x	x	x	x	x	x	x	Downstream base data rate- 32-TCPAM Minimum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–48—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS rates NPar(3)s – Octet 3
x	x	x	x	x	x	x	x	Downstream base data rate- 32-TCPAM Maximum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–49—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet 4

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s Octet 6
x	x	x	x	x	x	x	x	Downstream base data rate- 32-TCPAM Step 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–50—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet j_5*4-3

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s – Octet j_5*4-3
x	x						x	Downstream base data rate- 32-TCPAM Minimum j_5 (bit 7)
x	x					x		Downstream base data rate- 32-TCPAM Maximum j_5 (bit 7)
x	x				x			Downstream base data rate- 32-TCPAM Step j_5 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–51—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet j_5*4-2

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS rates NPar(3)s – Octet j_5*4-2
x	x	x	x	x	x	x	x	Downstream base data rate- 32-TCPAM Minimum j_5 (bit 1-6)[a]

[a]Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–52—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet j_5*4-1

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS rates NPar(3)s – Octet j_5*4-1
x	x	x	x	x	x	x	x	Downstream base data rate- 32-TCPAM Maximum j_5 (bit 1-6)[a]

[a]Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–53—Standard information field – 2BASE-TL - Downstream PMMS rates - NPar(3) coding – Octet j_5*4

Bits 8	7	6	5	4	3	2	1	2BASE-TL downstream PMMS NPar(3)s Octet j_5*4
x	x	x	x	x	x	x	x	Downstream base data rate- 32-TCPAM Step j_5 (bit 1-6)[a]

[a]Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–54—Standard information field – 2BASE-TL - Upstream PMMS parameters - NPar(3) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 1
x	x	0	x	x	x	x	x	Upstream PBO (dB) (bits 5-1 × 1.0 dB)
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3

Table 61B–55—Standard information field – 2BASE-TL - Upstream PMMS parameters - NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 2
x	x	0	0	0	0	0	0	Upstream PMMS duration unspecified by terminal
x	x	x	x	x	x	x	x	Upstream PMMS duration (bits 6-1 × 50 ms)
x	x	1	1	1	1	1	1	Reserved for allocation by IEEE Std 802.3

Table 61B–56—Standard information field – 2BASE-TL - Upstream PMMS parameters - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 3
x	x	0	0	0	x	x	x	Upstream PMMS scrambler polynomial Index (i2, i1, i0)

Table 61B–57—Standard information field – 2BASE-TL - Upstream PMMS parameters - NPar(3) coding – Octet 4

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 4
x	x	1	x	x	x	x	x	Worst-case PMMS target margin (dB) (bits 5-1 × 1.0 dB - 10 dB)
x	x	0	0	0	0	0	0	Worst-case PMMS target margin unspecified by terminal (values of bits 6-1 from 1 to 31 reserved for allocation by IEEE Std 802.3)

Table 61B–58—Standard information field – 2BASE-TL - Upstream PMMS parameters - NPar(3) coding – Octet 5

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 5
x	x	1	x	x	x	x	x	Current-condition PMMS target margin (dB) (bits 5-1 × 1.0 dB – 10 dB)
x	x	0	0	0	0	0	0	Current-condition PMMS target margin unspecified by terminal (values of bits 6-1 from 1 to 31 reserved for allocation by IEEE Std 802.3)

Table 61B–59—Standard information field – 2BASE-TL - Upstream PMMS parameters - NPar(3) coding – Octet 6

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 6
x	x	x	x	x	x	x	1	Reserved for allocation by IEEE Std 802.3
x	x	x	x	x	x	1	x	Transmit Silence
x	x	x	x	x	1	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	x	1	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	1	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	1	x	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	0	0	0	0	0	0	No parameters in this octet

Table 61B–60—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s – Octet 1
x	x						x	Upstream base data rate- 32-TCPAM Minimum 1 (bit 7)
x	x					x		Upstream base data rate- 32-TCPAM Maximum 1 (bit 7)
x	x				x			Upstream base data rate- 32-TCPAM Step 1 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–61—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS rates NPar(3)s – Octet 2
x	x	x	x	x	x	x	x	Upstream base data rate- 32-TCPAM Minimum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–62—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS rates NPar(3)s – Octet 3
x	x	x	x	x	x	x	x	Upstream base data rate- 32-TCPAM Maximum 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–63—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet 4

Bits 8	7	6	5	4	3	2	1	2BASE-TL upstream PMMS NPar(3)s Octet 6
x	x	x	x	x	x	x	x	Upstream base data rate- 32-TCPAM Step 1 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–64—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet j_6*4-3

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream PMMS NPar(3)s – Octet j_6*4-3
x	x						x	Upstream base data rate- 32-TCPAM Minimum j_6 (bit 7)
x	x					x		Upstream base data rate- 32-TCPAM Maximum j_6 (bit 7)
x	x				x			Upstream base data rate- 32-TCPAM Step j_6 (bit 7)
x	x	x	x	x				Reserved for allocation by IEEE Std 802.3

Table 61B–65—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet j_6*4-2

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream PMMS rates NPar(3)s – Octet j_6*4-2
x	x	x	x	x	x	x	x	Upstream base data rate- 32-TCPAM Minimum j_6 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–66—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet j_6*4-1

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream PMMS rates NPar(3)s – Octet j_6*4-1
x	x	x	x	x	x	x	x	Upstream base data rate- 32-TCPAM Maximum j_6 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

Table 61B–67—Standard information field – 2BASE-TL - Upstream PMMS rates - NPar(3) coding – Octet j_6*4

Bits 8	 7	 6	 5	 4	 3	 2	 1	2BASE-TL upstream PMMS NPar(3)s Octet j_6*4
x	x	x	x	x	x	x	x	Upstream base data rate- 32-TCPAM Step j_6 (bit 1-6)[a]

[a] Note that the rates are determined by combining (bit 7) and the 6-bits in this octet to create a 7-bit number.

61B.3.2.3 Framing parameter codepoints

Tables 61B–68 through 61B–73 contain the level-3 codepoints specific to 2BASE-TL framing parameters.

Table 61B–68—Standard information field – 2BASE-TL - Downstream framing parameters - NPar(3) coding – Octet 1

Bits								2BASE-TL Downstream framing NPar(3)s – Octet 1
8	7	6	5	4	3	2	1	
x	x					x	x	Sync Word (bits 14 and 13)
x	x			x	x			Stuff Bits (bits 1 to 2)
		x	x					Reserved for allocation by IEEE Std 802.3

Table 61B–69—Standard information field – 2BASE-TL - Downstream framing parameters - NPar(3) coding – Octet 2

Bits								2BASE-TL Downstream framing NPar(3)s – Octet 2
8	7	6	5	4	3	2	1	
x	x	x	x	x	x	x	x	Sync Word (bits 12 to 7)

Table 61B–70—Standard information field – 2BASE-TL - Downstream framing parameters - NPar(3) coding – Octet 3

Bits								2BASE-TL Downstream framing NPar(3)s – Octet 3
8	7	6	5	4	3	2	1	
x	x	x	x	x	x	x	x	Sync Word (bits 6 to 1)

Table 61B–71—Standard information field – 2BASE-TL - Upstream framing parameters - NPar(3) coding – Octet 1

Bits								2BASE-TL Upstream framing NPar(3)s – Octet 1
8	7	6	5	4	3	2	1	
x	x					x	x	Sync Word (bits 14 and 13)
x	x			x	x			Stuff Bits (bits 1 to 2)
		x	x					Reserved for allocation by IEEE Std 802.3

Table 61B–72—Standard information field – 2BASE-TL - Upstream framing parameters - NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	2BASE-TL Upstream framing NPar(3)s – Octet 2
x	x	x	x	x	x	x	x	Sync Word (bits 12 to 7)

Table 61B–73—Standard information field – 2BASE-TL - Upstream framing parameters - NPar(3) coding – Octet 3

Bits 8	7	6	5	4	3	2	1	2BASE-TL Upstream framing NPar(3)s – Octet 3
x	x	x	x	x	x	x	x	Sync Word (bits 6 to 1)

61B.4 Codepoints for 10PASS-TS

61B.4.1 Level-2 S field codepoints for 10PASS-TS

Table 61B–74 and Table 61B–75 contain the level-2 codepoints specific to 10PASS-TS.

Table 61B–74—Standard information field – 10PASS-TS NPar(2) coding – Octet 1

Bits 8	7	6	5	4	3	2	1	10PASS-TS NPar(2)s
x	x	x	x	x	x	x	1	Upstream use of 25–138 KHz band
x	x	x	x	x	x	1	x	Downstream use of 25–138 KHz band
x	x	x	x	x	1	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	x	1	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	x	1	x	x	x	x	Reserved for allocation by IEEE Std 802.3
x	x	1	x	x	x	x	x	G.997.1 - Clear EOC OAM
x	x	0	0	0	0	0	0	No parameters in this octet

Table 61B–75—Standard information field – 10PASS-TS SPar(2) coding – Octet 1

Bits								
8	7	6	5	4	3	2	1	10PASS-TS SPar(2)s
x	x	x	x	x	x	x	1	Reserved for allocation by IEEE Std 802.3
x	x	x	x	x	x	1	x	Used bands in upstream[a]
x	x	x	x	x	1	x	x	Used bands in downstream[a]
x	x	x	x	1	x	x	x	IDFT/DFT size
x	x	x	1	x	x	x	x	Initial length of CE
x	x	1	x	x	x	x	x	MCM RFI bands[a]
x	x	0	0	0	0	0	0	No parameters in this octet

[a] The length of the corresponding NPar(3) field is variable and is a multiple of 4 octets. The length depends on the total number of bands to be specified.

61B.4.2 Level-3 S field codepoints for 10PASS-TS

61B.4.2.1 Used bands in upstream codepoints

Tables 61B–76 through 61B–79 contain the level-3 codepoints specific to 10PASS-TS Used bands in upstream.

Table 61B–76—Standard information field – Used bands in upstream NPar(3) coding – Octet 4n-3 (n = 1, 2, 3, 4, 5)

Bits								
8	7	6	5	4	3	2	1	10PASS-TS Used bands in upstream NPar(3)s Octet 4n-3 (n = 1, 2, 3, 4, 5)
x	x	x	x	x	x	x	x	End tone index of band n (bits 7 to 12)[a]

[a] n is the band index, starting from 1.

Table 61B–77—Standard information field – Used bands in upstream NPar(3) coding – Octet 4n-2 (n = 1, 2, 3, 4, 5)

Bits								
8	7	6	5	4	3	2	1	10PASS-TS Used bands in upstream NPar(3)s Octet 4n-2 (n = 1, 2, 3, 4, 5)
x	x	x	x	x	x	x	x	End tone index of band n (bits 1 to 6)[a]

[a] n is the band index, starting from 1.

Table 61B–78—Standard information field – Used bands in upstream NPar(3) coding – Octet 4n-1 (n = 1, 2, 3, 4, 5)

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Used bands in upstream NPar(3)s Octet 4n-1 (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	Start tone index of band n (bits 7 to 12)[a]

[a] n is the band index, starting from 1.

Table 61B–79—Standard information field – Used bands in upstream NPar(3) coding – Octet 4n (n = 1, 2, 3, 4, 5)

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Used bands in upstream NPar(3)s Octet 4n (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	Start tone index of band n (bits 1 to 6)[a]

[a] n is the band index, starting from 1.

61B.4.2.2 Used bands in downstream codepoints

Table 61B–80 through Table 61B–83 contain the level-3 codepoints specific to 10PASS-TS Used bands in downstream.

Table 61B–80—Standard information field – Used bands in downstream NPar(3) coding – Octet 4n-3 (n = 1, 2, 3, 4, 5)

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Used bands in downstream NPar(3)s Octet 4n-3 (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	End tone index of band n (bits 7 to 12)[a]

[a] n is the band index, starting from 1.

Table 61B–81—Standard information field – Used bands in downstream NPar(3) coding – Octet 4n-2 (n = 1, 2, 3, 4, 5)

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Used bands in downstream NPar(3)s Octet 4n-2 (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	End tone index of band n (bits 1 to 6)[a]

[a] n is the band index, starting from 1.

Table 61B–82—Standard information field – Used bands in downstream NPar(3) coding – Octet 4n-1 (n = 1, 2, 3, 4, 5)

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Used bands in downstream NPar(3)s Octet 4n-1 (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	Start tone index of band n (bits 7 to 12)[a]

[a] n is the band index, starting from 1.

Table 61B–83—Standard information field – Used bands in downstream NPar(3) coding – Octet 4n (n = 1, 2, 3, 4, 5)

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Used bands in downstream NPar(3)s Octet 4n (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	Start tone index of band n (bits 1 to 6)[a]

[a] n is the band index, starting from 1.

61B.4.2.3 IDFT/DFT size codepoints

Table 61B–84 contains the level-3 codepoints specific to 10PASS-TS IDFT/DFT size.

Table 61B–84—Standard information field – IDFT/DFT size NPar(3) coding – Octet 1

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS IDFT/DFT size NPar(3)s Octet 1**
x	x	x	x	x	x	x	x	IDFT/DFT size (bits 6-1 × 256 points)

61B.4.2.4 Initial length of CE codepoints

Table 61B–85 through Table 61B–86 contain the level-3 codepoints specific to 10PASS-TS Initial length of CE.

Table 61B–85—Standard information field – Initial length of CE NPar(3) coding – Octet 1

Bits 8	 7	 6	 5	 4	 3	 2	 1	**10PASS-TS Initial length of CE NPar(3)s Octet 1**
x	x	0	0	x	x	x	x	Initial sample length of cyclic extension (bits 7 to 10)

Table 61B–86—Standard information field – Initial length of CE NPar(3) coding – Octet 2

Bits 8	7	6	5	4	3	2	1	10PASS-TS Initial length of CE NPar(3)s Octet 2
x	x	x	x	x	x	x	x	Initial sample length of cyclic extension (bits 6-1)

61B.4.2.5 MCM RFI band codepoints

Table 61B–87 through Table 61B–90 contain the level-3 codepoints specific to 10PASS-TS MCM RFI bands.

Table 61B–87—Standard information field – MCM RFI bands NPar(3) coding – Octet 4n-3 (n = 1, 2, 3, 4, 5)

Bits 8	7	6	5	4	3	2	1	10PASS-TS MCM RFI bands NPar(3)s Octet 4n-3 (n = 1, 2, 3, 4, 5)
x	x	x	x	x	x	x	x	End tone index of band n (bits 7 to 12)[a]

[a] n is the band index, starting from 1.

Table 61B–88—Standard information field – MCM RFI bands NPar(3) coding – Octet 4n-2 (n = 1, 2, 3, 4, 5)

Bits 8	7	6	5	4	3	2	1	10PASS-TS MCM RFI bands NPar(3)s Octet 4n-2 (n = 1, 2, 3, 4, 5)
x	x	x	x	x	x	x	x	End tone index of band n (bits 1 to 6)[a]

[a] n is the band index, starting from 1.

Table 61B–89—Standard information field – MCM RFI bands NPar(3) coding – Octet 4n-1 (n = 1, 2, 3, 4, 5)

Bits 8	7	6	5	4	3	2	1	10PASS-TS MCM RFI bands NPar(3)s Octet 4n-1 (n = 1, 2, 3, 4, 5)
x	x	x	x	x	x	x	x	Start tone index of band n (bits 7 to 12)[a]

[a] n is the band index, starting from 1.

Table 61B–90—Standard information field – MCM RFI bands NPar(3) coding – Octet 4n (n = 1, 2, 3, 4, 5)

Bits 8	7	6	5	4	3	2	1	**10PASS-TS MCM RFI bands NPar(3)s Octet 4n (n = 1, 2, 3, 4, 5)**
x	x	x	x	x	x	x	x	Start tone index of band n (bits 1 to 6)[a]

[a] n is the band index, starting from 1.

61B.5 Protocol implementation conformance statement (PICS) proforma for Annex 61B, Handshake codepoints for 2BASE-TL and 10PASS-TS[37]

61B.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Annex 61B, Handshake codepoints for 2BASE-TL and 10PASS-TS, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

61B.5.2 Identification

61B.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

61B.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 61B, Handshake codepoints for 2BASE-TL and 10PASS-TS.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

61B.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
HSCP	Handshake Codepoints	61B	The coding rules for 2BASE-TL handshake messages are implemented.	M	Yes [ ]

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[37] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

61B.5.4 2BASE-TL handshake coding rules

Item	Feature	Subclause	Value/Comment	Status	Support
HSCP-1	PMMS coding	61B.3.1	Values for min and max are between 4 and 89, inclusive.	M	Yes [ ]
HSCP-2	PMMS coding	61B.3.1	Valid values for step are between 1 and 89, inclusive.	M	Yes [ ]
HSCP-3	PMMS coding	61B.3.1	The variables j_5 and j_6 associated with the PMMS rates are independent, and range from 2 to 8, inclusive.	M	Yes [ ]
HSCP-4	PMMS coding	61B.3.1	If only one range of rates is required, then only the octets associated with (min1,max1,step1) are sent.	M	Yes [ ]
HSCP-5	CLR coding	61B.3.1	Valid values for minimum and maximum are between 3 and 60, inclusive, for 16-TCPAM and between 12 and 89, inclusive, for 32-TCPAM.	M	Yes [ ]
HSCP-6	CLR coding	61B.3.1	Valid values for step are between 1 and 89, inclusive.	M	Yes [ ]
HSCP-7	CLR coding	61B.3.1	The variables j_1, j_2, j_3 and j_4 associated with the training rates are independent, and range from 2 to 8, inclusive.	M	Yes [ ]
HSCP-8	CLR coding	61B.3.1	If only one range of rates is required, then only the octets associated with (min1,max1,step1) is sent. If more than one range of rates is required, then j_1*4, j_2*4, j_3*4 and j_4*4 correspond to the number of octets sent.	M	Yes [ ]
HSCP-9	CL coding	61B.3.1	Valid values for minimum and maximum are between 3 and 60, inclusive, for 16-TCPAM and between 12 and 89, inclusive, for 32-TCPAM.	M	Yes [ ]
HSCP-10	CL coding	61B.3.1	Valid values for step are between 1 and 89, inclusive.	M	Yes [ ]
HSCP-11	CL coding	61B.3.1	The variables j_1, j_2, j_3 and j_4 associated with the training rates are independent, and range from 2 to 8, inclusive.	M	Yes [ ]
HSCP-12	CL coding	61B.3.1	If only one range of rates is required, then only the octets associated with (min1,max1,step1) is sent. If more than one range of rates is required, then j_1*4, j_2*4, j_3*4 and j_4*4 correspond to the number of octets sent.	M	Yes [ ]
HSCP-13	SPar(2) coding	61B.3.1	Only one of the bits 2BASE-TL training mode and 2BASE-TL PMMS mode is set at any given time.	M	Yes [ ]
HSCP-14	SPar(2) coding	61B.3.1	The Regenerator silent period bit is set to 0_b if the 2BASE-TL PMMS mode NPar(2) bit is set to 1_b or the 2BASE-TL Training mode NPar(2) bit is set to 1_b.	M	Yes [ ]

Annex 62A

(normative)

PMD profiles for 10PASS-TS

62A.1 Introduction and rationale

Annex 62A defines the PMD profiles for 10PASS-TS. These profiles define the transmission characteristics of the PHY on the media. 10PASS-TS PHYs are required to operate across varying media quality, regulatory and noise environments.

The profiles defined in this clause have two purposes. The first is to describe a bounded set of operating modes that a party might choose from when implementing, integrating and installing 10PASS-TS equipment. 10PASS-TS PHYs are inherently flexible in their transmission capabilities. The possible combination of transmission parameters are nearly infinite. The defined profiles collect a small subset of these parameters into modes that work well in most deployments. For deployments that require an operating mode not defined in this Annex, profiles can be overridden by setting PHY PMD registers directly, via Clause 45 for example. Informative Annex 62C contains examples of such user-defined modes of operation.

The second purpose of profiles is to define a set of operating modes against which PHY performance compliance may be tested. The topic of performance compliance is addressed for 10PASS-TS in Annex 62B.

62A.2 Relationship to other clauses

Clause 30 describes how the selection of Annex 62A profiles is exported to a management entity.

Clause 45 registers describe an optional mechanism for configuring a 10PASS-TS PHY to use a particular profile. The register settings for each profile are contained in 62A.4.

62A.3 Profile definitions

The following sections define the mandatory profiles for 10PASS-TS operation, in terms of bandplan, PSD mask, UPBO Reference PSD, notching parameters and payload rate.

62A.3.1 Bandplan and PSD mask profiles

The spectral characteristics of 10PASS-TS communication on the copper medium are defined by a choice of bandplans and PSD Masks.

Each of 5 standard frequency bands (Band 0, D1, U1, D2, U2) used for 10PASS-TS communication are defined in a bandplan. 10PASS-TS PHYs operating in the same cable bundle should use the same bandplan to ensure spectral compatibility. Furthermore, the selection of bandplan may be governed by regional regulations that pertain to the deployment. While all 10PASS-TS PHYs may operate in any of the below bandplans, installers should be aware of any regulations that might restrict their choice of modes. Bandplan profiles specify the use of 2, 3, 4, or 5 standard frequency bands.

PSD Masks further define the spectral environment by specifying the maximum transmit power spectral density at a given frequency. Like bandplans, the PSD mask should be selected to be compatible with applicable regulations and to match other PHYs operating in the same cable bundle.

Profiles are defined here for various regulatory environments as well as for private installation. Additionally, operation with a bandplan or PSD mask not defined in this clause is supported by configuration through Clause 45 registers. All 10PASS-TS PHYs shall be capable of operating in all profiles listed in this clause. Profile definitions are listed in Table 62A-1.

.

Table 62A-1—Bandplan and PSD Mask Profiles

Profile Number	PSD Mask	Band Assignment[a]	Bandplan
1	T1.424 FTTCab.M1	x/D/U/D/U	G.993.1 Bandplan A
2	T1.424 FTTEx.M1		
3	T1.424 FTTCab.M2		
4	T1.424 FTTEx.M2		
5	T1.424 FTTCab.M1	D/D/U/D/U	
6	T1.424 FTTEx.M1		
7	T1.424 FTTCab.M2		
8	T1.424 FTTEx.M2		
9	T1.424 FTTCab.M1	U/D/U/D/x	
10	T1.424 FTTEx.M1		
11	T1.424 FTTCab.M2		
12	T1.424 FTTEx.M2		
13	TS1 101 270-1 Pcab.M1.A	x/D/U/D/U	G.993.1 Bandplan B
14	TS1 101 270-1 Pcab.M1.B		
15	TS1 101 270-1 Pex.P1.M1		
16	TS1 101 270-1 Pex.P2.M1		
17	TS1 101 270-1 Pcab.M2		
18	TS1 101 270-1 Pex.P1.M2		
19	TS1 101 270-1 Pex.P2.M2		
20	TS1 101 270-1 Pcab.M1.A	U/D/U/D/x	
21	TS1 101 270-1 Pcab.M1.B		
22	TS1 101 270-1 Pex.P1.M1		
23	TS1 101 270-1 Pex.P2.M1		
24	TS1 101 270-1 Pcab.M2		
25	TS1 101 270-1 Pex.P1.M2		
26	TS1 101 270-1 Pex.P2.M2		
27	G.993.1 F.1.2.1 (VDSL over POTS)	x/D/U/D/U	G.993.1 Annex F
28	G.993.1 F.1.2.2 (VDSL over TCM-ISDN)		
29	G.993.1 F.1.2.3 (PSD reduction)		
30	T1.424 FTTCab.M1 (extended)	x/D/U/D/U/D	G.993.1 Annex A[b]

[a] For each band in the bandplan, the Band Assignment indicates the use or direction of communication for that band. U=upstream, D=downstream, x=band is unused. Bands are listed in this order: 0/1/2/3/4.

[b] This profile uses a 5th band (12 MHz—16.5 MHz) for downstream transmission at –60 dBm/Hz.

62A.3.2 Bandplan definitions

The management entity should load the appropriate Clause 45 registers according to the bandplan specified by the selected profile. 62A.4 contains examples of the use of Clause 45 registers for the purpose of setting profiles.

The VDSL bandplans defined in ITU-T Recommendation G.993.1 shall be supported by all 10PASS-TS PMDs. These bandplans are represented for information in Table 62A-2.

Table 62A-2—Bandplans defined by ITU-T Recommendation G.993.1

Plan	Band 0 (optional) US/DS	Band D1	Band U1	Band D2	Band U2
Bandplan A (formerly Plan 998)	25 kHz – 138 kHz	138 kHz – 3.75 MHz	3.75 Mhz – 5.2 MHz	5.2 MHz – 8.5 MHz	8.5 MHz – 12 MHz
Bandplan B (formerly Plan 997)	25 kHz – 138 kHz	138 kHz – 3.0 MHz	3.0 MHz – 5.1 MHz	5.2 MHz – 7.05 MHz	7.05 MHz – 12 MHz
Bandplan C[a]	25 kHz – 138 kHz	138 kHz – 2.5MHz	2.5 MHz – 3.75 MHz	3.75 MHz – *Fx*	*Fx* – 12MHz
Annex F[b],[c]	25 kHz – 138 kHz	138 kHz – 3.75 MHz	3.75 Mhz – 5.2 MHz	5.2 MHz – 8.5 MHz	8.5 MHz – 12 MHz

[a] Bandplan C is characterized by a variable split frequency between band D2 and band U2, represented as "*Fx*". 10PASS-TS shall support operation in Bandplan C for $Fx = 3750\ \text{kHz} + n \times 250\ \text{kHz}$, where $0 \le n \le 33$.

[b] Subsets composed of at least one downstream band and one upstream band among D1, U1, D2 and U2 may be implemented.

[c] Band 1D starts at 640 kHz when operating in the frequency region above TCM-ISDN DSL band. Band 1D starts at 1.104 MHz when operating with PSD reduction function in the frequency region below 1.104 Mhz.

62A.3.3 PSD mask definitions

The management entity should load the appropriate Clause 45 registers according to the PSD Mask specified by the selected profile. 62A.4 contains examples of the use of Clause 45 registers for the purpose of setting profiles.

The VDSL PSD Masks defined in ITU-T Recommendation G.993.1, T1.424 and ETSI TS 101 270-1 shall be supported by all 10PASS-TS PMDs.

NOTE—The reference documents in which the PSD Masks are specified also specify the relationship between PSD Mask and PSD template, and the appropriate method to assess compliance with a PSD Mask or a PSD template.

62A.3.4 UPBO Reference PSD Profiles

Upstream Power Back-Off (UPBO) is defined in 62.3.4.1. Its operation requires the specification of a Reference PSD, by means of which the 10PASS-TS-R calculates the maximum upstream transmit PSD. Different UPBO Reference PSDs have been standardized in T1.424 and ETSI TS 101 270-1, as shown in Table 62A-3. 10PASS-TS implementations shall support all UPBO Reference PSDs listed in Table 62A-3. The 10PASS-TS PHY shall additionally allow a profile value of "0" to be selected, which indicates that UPBO is to be disabled.

62A.3.5 Band Notch Profiles

In certain deployments, 10PASS-TS operation may interfere with nearby amateur radio equipment. The Band Notch profiles specify notches that 10PASS-TS PHYs shall add to their transmit PSDs when selected.

Table 62A-3—UPBO Reference PSD Profiles
(*f* is in MHz, the PSD level is in dBm/Hz)

#	Reference PSD			1U	2U
1	T1.424	Noise A	M1	$-60-22.00\sqrt{f}$	$-60-17.18\sqrt{f}$
2			M2	$-53-24.47\sqrt{f}$	$-54-18.93\sqrt{f}$
3		Noise F	M1	$-60-18.54\sqrt{f}$	$-60-16.865\sqrt{f}$
4			M2	$-53-21.19\sqrt{f}$	$-54-18.69\sqrt{f}$
5	ETSI TS 101 270-1	Noise A&B		$-47.3-28.01\sqrt{f}$	$-54-19.22\sqrt{f}$
6		Noise C		$-47.3-21.14\sqrt{f}$	$-54-16.29\sqrt{f}$
7		Noise D		$-47.3-26.21\sqrt{f}$	$-54-17.36\sqrt{f}$
8		Noise E		$-47.3-27.27\sqrt{f}$	$-54-18.1\sqrt{f}$
9		Noise F		$-47.3-19.77\sqrt{f}$	$-54-15.77\sqrt{f}$

When a notch is activated, the transmitter shall reduce its PSD to less than –80 dBm/Hz in the frequencies of the notch. More than one notch may be activated at one time.

All Band Notches specified in the following standards shall be supported:
a) ITU-T Recommendation G.993.1 Annex F, Table F-5
b) T1.424, Clause 15
c) ETSI TS1 101 270 subclause 9.3.3.6.1

The Band Notch Profiles are listed for information in Table 62A-4. This table includes notches that are above 12MHz, that are therefore outside the scope of this standard.

Table 62A-4—Band Notch Profile definitions

Band Notch Profile	Specification			Start Frequency (MHz)	End Frequency (MHz)
	ITU-T Rec. G.993.1	T1.424	TS 101 270-1		
1	Table F-5 #01	—	—	1.810	1.825
2	Table 6-2	Table 15-1	Table 17	1.810	2.000
3	Table F-5 #02	—	—	1.9075	1.9125
4	Table F-5 #03	—	—	3.500	3.575
5	Table 6-2	—	Table 17	3.500	3.800
6	—	Table 15-1	—	3.500	4.000
7	Table F-5 #04	—	—	3.747	3.754
8	Table F-5 #05	—	—	3.791	3.805
9	Table 6-2	—	Table 17	7.000	7.100
10	Table F-5 #06	Table 15-1	—	7.000	7.300
11	Table 6-2	Table 15-1	Table 17	10.100	10.150
—	Table 6-2 Table F-5 #08	Table 15-1	Table 17	14.000	14.350
—	Table 6-2 Table F-5 #09	Table 15-1	Table 17	18.068	18.168
—	Table 6-2 Table F-5 #10	Table 15-1	Table 17	21.000	21.450
—	Table 6-2 Table F-5 #11	Table 15-1	Table 17	24.890	24.990
—	Table 6-2	—	Table 17	28.000	29.100
—	Table F-5 #12	Table 15-1	—	28.000	29.700

62A.3.6 Payload rate profiles

The Payload Rate Profile describes the payload bitrate as seen at the MII interface.

The Payload Rate Profile consists of a payload rate for each of the downstream and upstream directions. The profile is specified in the format Drate/Urate as the payload bitrate that the PHY link shall provide, where *Drate* and *Urate* are expressed in Mb/s. For example a Payload Rate Profile of 10/2.5 corresponds to a downstream payload rate of 10 Mb/s and an upstream payload rate of 2.5 Mb/s. *Drate* values of 2.5, 5, 7.5, 10, 12.5, 15, 25, 35, 50, 70, and 100 shall be supported where the loop environment, bandplan and PSD mask allow this. *Urate* values of 2.5, 5, 7.5, 10, 12.5, 15, 25, 35, and 50 shall be supported where the loop environment, bandplan and PSD mask allow this. This leads to a total of 9 symmetric and 90 asymmetric Payload Rate Profiles.

The selected Payload Rate Profile sets a target for the PHY’s operation. If the payload rates of the selected profile cannot be achieved based on the loop environment, bandplan and PSD mask, the PHY shall drop the link.

62A.3.7 Complete profiles

The complete PMD operation of the 10PASS-TS PHY can be selected by choosing one Bandplan and PSD Mask profile, one UPBO Reference PSD profile, one Payload Rate profile, and any number of Band Notch profiles.

62A.3.8 Default profile

A 10PASS-TS device that is not managed (i.e., no management functions are provided, or enabled) shall operate in the default profile and the default mode specified in this subclause and summarized in Table 62A-5.

Table 62A-5—Default profile and default mode settings

Profile / Setting	Value
Payload bitrate profile	10/10
Bandplan and PSD mask profile	#1
Band notch profiles	#2, #6, #10, and #11
UPBO reference PSD profile	#3
Reed-Solomon setting	(240, 224)
Interleaver setting	I=30, M=62

The default profile shall consist of the 10/10 payload bitrate profile, bandplan and PSD mask profile #1, band notch profiles #2, #6, #10, and #11 enabled, and UPBO reference PSD profile #3.

In addition, the default mode of 10PASS-TS implementations shall use Reed-Solomon setting (240, 224)[38], and interleaver setting I=30, M=62.

NOTE—The default profile may not be spectrally compatible to any particular regional requirement, nor may it be the optimal profile for a particular cable segement.

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[38] See 62.2.4.2.

62A.4 Register settings

Tables 62A-6 through 62A-8 contain the register settings required to implement the profiles described in this Annex. The referenced registers are defined in 45.2.

Table 62A-6 contains the MCM tone group definitions to be used in order to support the band plan profiles described in 62A.3.2. For each of the listed tone groups, the Tone Active and/or Tone Direction bits in the 10P MCM tone control parameter register shall be set according to the use indicated in the first column of the table.

Table 62A-6—MCM register settings implementing bandplan profiles

Band Allocation	Band Plan A 10P MCM Tone Group Register		Band Plan B 10P MCM Tone Group Register		Band Plan C 10P MCM Tone Group Register		Band Plan Ann. F 10P MCM Tone Group Register	
	lower	upper	lower	upper	lower	upper	lower	upper
0 (upstream, downstream or not used)	0007_{16}	$001F_{16}$	0007_{16}	$001F_{16}$	0007_{16}	$001F_{16}$	0007_{16}	$001F_{16}$
1D (downstream)	0021_{16}	0365_{16}	0021_{16}	$02B7_{16}$	0021_{16}	0243_{16}	0021_{16}	0365_{16}
1U (upstream)	0367_{16}	$04B5_{16}$	$02B9_{16}$	$049E_{16}$	0245_{16}	0365_{16}	0367_{16}	$04B5_{16}$
2D (downstream)	$04B7_{16}$	$07B2_{16}$	$04A0_{16}$	0662_{16}	0367_{16}	fx1[a]	$04B7_{16}$	$07B2_{16}$
2U (upstream)	$07B4_{16}$	$0ADE_{16}$	0664_{16}	$0ADE_{16}$	fx2[b]	$0ADE_{16}$	$07B4_{16}$	$0ADE_{16}$
3D (downstream)[c]	$0ADF_{16}$	$0EF2_{16}$	—	—	—	—	—	—

[a] Values for fx1 shall be in the range 0369_{16} to $0ADA_{16}$
[b] Values for fx2 shall be in the range (fx1 + 2) to $0ADE_{16}$
[c] Band 3D is only used in Band Plan and PSD Mask profile #30.

Unlike the other parameters governed by the profiles specified in the Annex, PSDs are typically defined by means of a functional expression, rather than a set of values. Transmit PSDs and Reference PSDs typically vary for each individual tone. A pseudo-C procedure for setting a PSD profile and a Reference PSD profile is shown in Equation (62A–1) below. It assumes the existence of the functions getPSDLevel(float frequencyInKHz) and getReferencePSD(float frequencyInKHz) specifying the transmit PSD and Reference PSD respectively, both expressed as a floating-point value in dBm/Hz. Registers are addressed by means of pointers ToneGroupRegister, ToneControlParameterRegister and ToneControlActionRegister.

```
for (int tone=0;tone<4096;tone++) {
 ToneGroupRegister[0] = tone;               // set lower bound of tone group
 ToneGroupRegister[1] = tone;               // set upper bound of tone group
                                            // to the same value
 short TxPSD = floor(4*(getPSDLevel(tone*4.3125)+100)) & 0x01FF;
                                            // convert to 9-bit value
 ToneControlParameterRegister[1] &= 0xFFFC; // clear first two bits of PSD level
 ToneControlParameterRegister[2] &= 0x01FF; // clear remaining 7 bits of PSD level
 ToneControlParameterRegister[1] |= TxPSD >> 7;// store first two bits of PSD level
 ToneControlParameterRegister[2] |= (TxPSD << 9) & 0xFE00;
                                            // store remaining 7 bits of PSD level
 short RefPSD = floor(4*(getReferencePSD(tone*4.3125)+100)) & 0x01FF;
                                            // convert to 9-bit value
 ToneControlParameterRegister[2] &= 0xFFE0; // clear Reference PSD level
 ToneControlParameterRegister[2] |= RefPSD; // store Reference PSD level
 *ToneControlActionRegister |= 0x0020;      // refresh contents of the selected
                                            // tones entries in table
}
*ToneControlActionRegister |= 0x0002;       // activates PSD level setting as in
                                            // ToneControlParameterRegister
*ToneControlActionRegister |= 0x0001;       // activates UPBO Ref. PSD level
                                            // setting as in
                                            // ToneControlParameterReg          (62A–1)
```

Functions specifying standard transmit PSDs can be found in the documents referenced in 62A.3.3. Functions specifying UPBO Reference PSDs can be found in Table 62A-3.

Table 62A-7 contains the MCM tone group definitions to be used in order to support the band notch profiles desribed in 62A.3.5. For each of the listed tone groups, the Tone Active bit in the 10P MCM tone control parameter register shall be cleared to activate the corresponding band notch.

Table 62A-7—MCM register settings implementing band notch profiles

Band Notch Profile	10P MCM Tone Group Register	
	lower	upper
1	$01A3_{16}$	$01A7_{16}$
2	$01A3_{16}$	$01D0_{16}$
3	$01B9_{16}$	$01BB_{16}$
4	$032B_{16}$	$033D_{16}$
5	$032B_{16}$	0371_{16}
6	$032B_{16}$	$03A0_{16}$
7	0364_{16}	0366_{16}
8	$036E_{16}$	0372_{16}
9	0656_{16}	$066E_{16}$
10	0656_{16}	$069D_{16}$
11	0925_{16}	0932_{16}

Table 62A-8 contains the MCM register settings for the payload rate profiles listed in 62A.3.6. When operating under a payload rate profile, the minimum and maximum data rates in the 10P MCM upstream/downstream data rate configuration registers shall be set to the same value.

Table 62A-8—MCM register settings implementing payload rate profiles

Profile (payload rate in Mb/s)	Downstream Data Rate Configuration Register setting (bits 15:0)	Upstream Data Rate Configuration Register setting (bits 15:0)
2.5	0027_{16}	0027_{16}
5	$004E_{16}$	$004E_{16}$
7.5	0075_{16}	0075_{16}
10	$009C_{16}$	$009C_{16}$
12.5	$00C3_{16}$	$00C3_{16}$
15	$00EA_{16}$	$00EA_{16}$
25	0186_{16}	0186_{16}
35	0222_{16}	0222_{16}
50	$030D_{16}$	$030D_{16}$
70	0445_{16}	no profile defined
100	$061A_{16}$	no profile defined

62A.5 Protocol implementation conformance statement (PICS) proforma for Annex 62A, PMD profiles for 10PASS-TS[39]

62A.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Annex 62A, PMD profiles for 10PASS-TS, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

62A.5.2 Identification

62A.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

62A.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 62A, PMD profiles for 10PASS-TS.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[39] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

62A.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
10PProf	PMD profiles for 10PASS-TS	Annex 62A	The PMD profiles listed in Annex 62A are supported.	10PASS-TS: M	Yes [ ]

62A.5.4 PICS proforma tables for PMD profiles for 10PASS-TS

Item	Feature	Subclause	Value/Comment	Status	Support
10PProf-1	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHYs is capable of operating in all profiles listed in this Clause.	M	Yes [ ]
10PProf-2	Bandplan and PSD mask profiles	62A.3.1	The VDSL bandplans defined in ITU-T Recommendation G.993.1 are supported.	M	Yes [ ]
10PProf-3	Bandplan and PSD mask profiles	62A.3.1	The VDSL PSD Masks defined in ITU-T Recommendation G.993.1, T1.424 and ETSI TS 101 270-1 are supported by all 10PASS-TS PMDs.	M	Yes [ ]
10PProf-4	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #1 as specified in Table 62A-1.	M	Yes [ ]
10PProf-5	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #2 as specified in Table 62A-1.	M	Yes [ ]
10PProf-6	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #3 as specified in Table 62A-1.	M	Yes [ ]
10PProf-7	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #4 as specified in Table 62A-1.	M	Yes [ ]
10PProf-8	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #5 as specified in Table 62A-1.	M	Yes [ ]
10PProf-9	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #6 as specified in Table 62A-1.	M	Yes [ ]
10PProf-10	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #7 as specified in Table 62A-1.	M	Yes [ ]
10PProf-11	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #8 as specified in Table 62A-1.	M	Yes [ ]
10PProf-12	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #9 as specified in Table 62A-1.	M	Yes [ ]
10PProf-13	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #10 as specified in Table 62A-1.	M	Yes [ ]

10PProf-14	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #11 as specified in Table 62A-1.	M	Yes [ ]
10PProf-15	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #12 as specified in Table 62A-1.	M	Yes [ ]
10PProf-16	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #13 as specified in Table 62A-1.	M	Yes [ ]
10PProf-17	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #14 as specified in Table 62A-1.	M	Yes [ ]
10PProf-18	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #15 as specified in Table 62A-1.	M	Yes [ ]
10PProf-19	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #16 as specified in Table 62A-1.	M	Yes [ ]
10PProf-20	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #17 as specified in Table 62A-1.	M	Yes [ ]
10PProf-21	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #18 as specified in Table 62A-1.	M	Yes [ ]
10PProf-22	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #19 as specified in Table 62A-1.	M	Yes [ ]
10PProf-23	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #20 as specified in Table 62A-1.	M	Yes [ ]
10PProf-24	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #21 as specified in Table 62A-1.	M	Yes [ ]
10PProf-25	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #22 as specified in Table 62A-1.	M	Yes [ ]
10PProf-26	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #23 as specified in Table 62A-1.	M	Yes [ ]
10PProf-27	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #24 as specified in Table 62A-1.	M	Yes [ ]
10PProf-28	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #25 as specified in Table 62A-1.	M	Yes [ ]
10PProf-29	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #26 as specified in Table 62A-1.	M	Yes [ ]
10PProf-30	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #27 as specified in Table 62A-1.	M	Yes [ ]

10PProf-31	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #28 as specified in Table 62A-1.	M	Yes [ ]
10PProf-32	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #29 as specified in Table 62A-1.	M	Yes [ ]
10PProf-33	Bandplan and PSD mask profiles	62A.3.1	The 10PASS-TS PHY is capable of operating in profile #30 as specified in Table 62A-1.	M	Yes [ ]
10PProf-34	UPBO Reference PSD Profiles	62A.3.4	The implementation supports all UPBO Reference PSDs listed in Table 62A-3.	M	Yes [ ]
10PProf-35	Band Notch Profiles	62A.3.5	The 10PASS-TS PHY adds the notches specified by the band notch profile to their transmit PSDs when selected.	M	Yes [ ]
10PProf-36	Band Notch Profiles	62A.3.5	When a notch is activated, the transmitter reduces its PSD to less than -80 dBm/Hz in the frequencies of the notch.	M	Yes [ ]
10PProf-37	Band Notch Profiles	62A.3.5	All Band Notches specified in the following standards are supported: -ITU-T Recommendation G.993.1 Annex F, Table F-5 -T1.424, Clause 15 -ETSI TS1 101 270 subclause 9.3.3.6.1	M	Yes [ ]
10PProf-38	Payload rate profiles	62A.3.6	Drate values of 2.5, 5, 7.5, 10, 12.5, 15, 25, 35, 50, 70, and 100 are supported where the loop environment, bandplan and PSD mask allow this.	M	Yes [ ]
10PProf-39	Payload rate profiles	62A.3.6	Urate values of 2.5, 5, 7.5, 10, 12.5, 15, 25, 35, and 50 are supported where the loop environment, bandplan and PSD mask allow this.	M	Yes [ ]
10PProf-40	Payload rate profiles	62A.3.6	If the payload rates of the selected profile cannot be achieved based on the loop environment, bandplan and PSD mask, the PHY drops the link.	M	Yes [ ]
10PProf-41	Default profile	62A.3.8	A 10PASS-TS device that is not managed operates in the default profile and the default mode specified in 62A.3.8 and summarized in Table 62A-5.	M	Yes [ ]

10PProf-42	Register settings	62A.4	For each of the listed tone groups, the Tone Active and/or Tone Direction bits in the 10P MCM tone control parameter register are set according to the use indicated in the first column of Table 62A-6.	M	Yes [ ]
10PProf-43	Register settings	62A.4	For each of the listed tone groups, the Tone Active bit in the 10P MCM tone control parameter register are cleared to activate the corresponding band notch.	M	Yes [ ]
10PProf-44	Register settings	62A.4	When operating under a payload rate profile, the minimum and maximum data rates in the 10P MCM upstream/downstream data rate configuration registers are set to the same value.	M	Yes [ ]

Annex 62B

(normative)

Performance guidelines for 10PASS-TS PMD profiles

62B.1 Introduction and rationale

Annex 62B defines performance guidelines for 10PASS-TS PMD profiles. The definition of these guidelines is challenging due to the varying nature of the access network. The access network has large variations in cable characteristics from region to region. In addition, the make-up of a cable can encompass multiple cable gauges and/or different configuration of bridged taps. Finally, services may vary from region to region creating different noise scenarios. Typically, deployment guidelines are a function of the telecommunications operator, which is operating a loop and the regional spectrum management policies, which govern deployment on that loop.

Given that one cannot test every possible combination of loop make-up and noise conditions, the performance guidelines are covered from two perspectives. Firstly, 62B.3 lists a suite of artificial tests crafted to test the 10PASS-TS PHYs under representative worst-case noise and loop conditions. Secondly, 62B.4 defines a deployment guideline rule which allows a service provider to determine whether a given loop will support a given profile.

62B.2 Relationship to other clauses

Annex 62A lists a set of PMD profiles for 10PASS-TS. Clause 30 describes how the selection of Annex 62A profiles is exported to a management entity. Clause 45 registers describe an optional mechanism for configuring a 10PASS-TS PHY to use a particular profile. The register settings for each profile are contained in 62A.4.

62B.3 Performance test cases

The performance test cases are derived from the standard definition of test loops in T1.424/Trial-Use, part 1, section 13.2, the noise models are defined in T1.424/Trial-Use, part 1, section 13.3 and the profiles are defined in 62A.3.1. In all cases the PHYs shall attain link in the specified profile in the presence of noise and impairments and maintain link with a Bit Error Ratio less than 10^{-7} with the noise raised by 6dB.

During the test the PHY shall meet the requirements of the bandplan, PSD and Upstream Power Back Off (where appropriate) specified. The control of the profile shall be through the Clause 30 MIB if supported. If the PHY under test includes any implementation options defined in the reference document (but out of scope for this standard) these options shall be disabled in such a manner as to render the behavior identical to implementations without such options.

If a PHY is capable of operating as both CO-subtype and CPE-subtype then both modes of operation shall be tested. If the PHY is capable of supporting PME aggregation then each PME shall be capable of passing the performance tests independently.

Table 62B-1 lists the performance test cases. The test loops are described in T1.424/Trial-Use, part 1, section 13.2. For tests using test loop “VDSL1” the table specifies which of the two cable types (TP1 or TP2) is used. The length value refers to the dimension “x”, “y”, “z”, “u” or “v” depending on the test loop. If “notch” is specified to be “on” then the RF notches specified in T1.424/Trial-Use, part 1, Annex 1 are applied as described in section 13.3.3. If “UPBO” is specified to be “on” then the Power Back Off specified in 62.3.4.1 is applied. The noise model applied will be noise model “A” or “F” as described in T1.424/Trial-Use, part 1, section 13.3.1.1 (also 13.3.1.4.2). The definition of self crosstalk is in section 13.3.1.4.1.

Table 62B-1—Test cases for 10PASS-TS

Test	Test Loop	L (m)	Profile	Payload Data Rate down/up (Mb/s)	Notch	UPBO	Noise Model[a]
1	TP1	750	13	10/10	—	5	AWGN
2	TP2	750	13	10/10	—	5	ETSI A
3	TP2	300	1	10/10	—	1	T1.424 A
4	TP2	200	16	50/50	—	—	AWGN
5	TP2	100	16	35/25	—	—	self
6	TP1	650	6	25/5	—	—	self
7	TP2	700	17	15/15	—	—	self
8	TP1	1000	8	15/2.5	—	—	self
9	TP2	400	4	12.5/12.5	—	—	self
10	TP2	750	4	7.5/7.5	—	—	self
11	TP2	1000	23	5/5	—	—	self
12	TP2	1200	23	2.5/2.5	—	—	self
13	TP2	150	16	50/50	2, 5, 9, 11	—	AWGN
14	TP2	100	16	35/25	2, 5, 9, 11	—	self
15	TP1	650	6	25/5	2, 6, 10, 11	—	self
16	TP2	600	17	15/15	2, 5, 9, 11	—	self
17	TP1	1000	8	15/2.5	2, 6, 10, 11	—	self
18	TP2	400	4	12.5/12.5	2, 6, 10, 11	—	self
19	TP2	750	4	7.5/7.5	2, 6, 10, 11	—	self
20	TP2	900	23	5/5	2, 5, 9, 11	—	self
21	TP2	1200	23	2.5/2.5	2, 5, 9, 11	—	self
22	TP2	150	30	100/25	—	—	AWGN

[a] “AWGN” means that only white gaussian noise at -140 dBm/Hz is present. “Self” means that the equivalent crosstalk generated by 20 10PASS-TS transceivers operating in the same mode (assuming the same loop length and the same UPBO configuration) as the device under test is present in addition to white gaussian noise at -140 dBm/Hz. “T1.424 A” means that alien crosstalk according to T1.424 Noise Model A is present in addition to white gaussian noise at –140 dBm/Hz. “ETSI A” means that alien crosstalk according to ETSI TS 101 270-1 Noise Model A is present in addition to white gaussian noise. Self crosstalk and alien crosstalk are not to be applied simultaneously.

62B.3.1 Additional tests

Additional testing to prove the requirements for link establishment, UPBO, burst noise immunity, link state and error reporting, etc. may be performed using any test scenarios from Table 62B-1.

62B.4 Deployment guidelines

The relationship between specific cable parameters and performance is complex and cannot be guaranteed. The performance tests described in section 62B.3 are designed to ensure that compliant PHYs will achieve a similar level of performance when applied in similar environments. The tests are designed to represent realistic worst case conditions but real world installations may sometimes experience worse performance for apparently similar conditions.

Annex A of ETSI TS1 101 270-1 (1999) contains some additional information regarding performance expectations related to cable parameters.

62B.5 Protocol implementation conformance statement (PICS) proforma for Annex 62B, Performance guidelines for 10PASS-TS PMD profiles[40]

62B.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Annex 62B, Performance guidelines for 10PASS-TS PMD profiles, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

62B.5.2 Identification

62B.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

62B.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 62B, Performance guidelines for 10PASS-TS PMD profiles.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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[40] *Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

62B.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
10PPerf	Performance guidelines for 10PASS-TS PMD profiles	Annex 62B	The performance guidelines listed in Annex 62B are supported.	10PASS-TS: M	Yes [ ]

62B.5.4 PICS proforma tables for Performance guidelines for 10PASS-TS PMD profiles

Item	Feature	Subclause	Value/Comment	Status	Support
10PPerf-1	Performance test cases	62B.3	In all cases the PHY attains link in the specified profile in the presence of noise and impairments and maintains link with a Bit Error Ratio less than 10^{-7} with the noise raised by 6dB.	M	Yes [ ]
10PPerf-2	Performance test cases	62B.3	During the test the PHY meets the requirements of the bandplan, PSD and Upstream Power Back Off specified.	M	Yes [ ]
10PPerf-3	Performance test cases	62B.3	The control of the profile is through the Clause 30 MIB if supported.	MDIO: M	Yes [ ] No [ ]
10PPerf-4	Performance test cases	62B.3	If the PHY under test includes any implementation options defined in the reference document these options are disabled in such a manner as to render the behavior identical to implementations without such options.	M	Yes [ ]
10PPerf-5	Performance test cases	62B.3	If a PHY is capable of operating as both CO-subtype and CPE-subtype then both modes of operation are tested.	M	Yes [ ]
10PPerf-6	Performance test cases	62B.3	If the PHY is capable of supporting PME aggregation then each PME is capable of passing the performance tests independently.	M	Yes [ ]

Annex 62C

(informative)

10PASS-TS Examples

62C.1 Introduction

Annex 62A contains profiles for deployment of 10PASS-TS in typical environments, as well as for testing purposes. Certain situations may require the full use of the 10PASS-TS PHY's flexibility, going beyond what is offered by the predefined profiles, in order to obtain optimal performance. Examples of such circumstances:

a) the 10PASS-TS system shares a cable bundle with a legacy system; the PSD mask can be configured to minimize crosstalk between 10PASS-TS and the legacy system
b) for a specific application, a particular symmetry ratio is required, which is not easily obtained with the standard band plans
c) the desired payload bit rates are beyond the ones that can be set by means of the standard payload rate profiles
d) other unanticipated situations

To use this flexibility, the 10PASS-TS equipment is configured by means of the appropriate Clause 45 registers. This Annex provides examples of such configurations.

62C.2 Bandplan configuration

Example situation: a user wishes to implement a custom bandplan for a 10PASS-TS deployment in a private network, in order to minimize near-end crosstalk to and from a certain legacy system.

Band plans can be configured by selecting any group of tones in the Tone Group register (45.2.1.38), and allocating them to either upstream or downstream by setting the tone direction bit to the appropriate value (0 = downstream, 1 = upstream) in the Tone Control Parameter register (45.2.1.39). This procedure is repeated until the desired number of frequency bands has been allocated. The new configuration is applied by writing binary 1 to the Change Tone Direction bit in the Tone Control Action register (45.2.1.40).

An example of a custom bandplan and PSD is shown in Figure 62C–1 (the solid line represents the upstream PSD, the dashed line represents the downstream PSD). The overall transmission power is assumed to be 14.5 dBm in either direction which is similar to the T1.424/Trial-Use M2 mask and SHDSL transmit power. The example defined here is such that it should meet VDSL compatibility requirements for up to 1524 m (5000 ft).

The example PSD was tested for spectral compatibility with existing VDSL systems using ITU-T Bandplan A (formerly known as plan 998). The spectral compatibility guideline was obtained by assuring that the new service will not disturb the guaranteed data rates for VDSL basis system as shown in Table 62C–1.

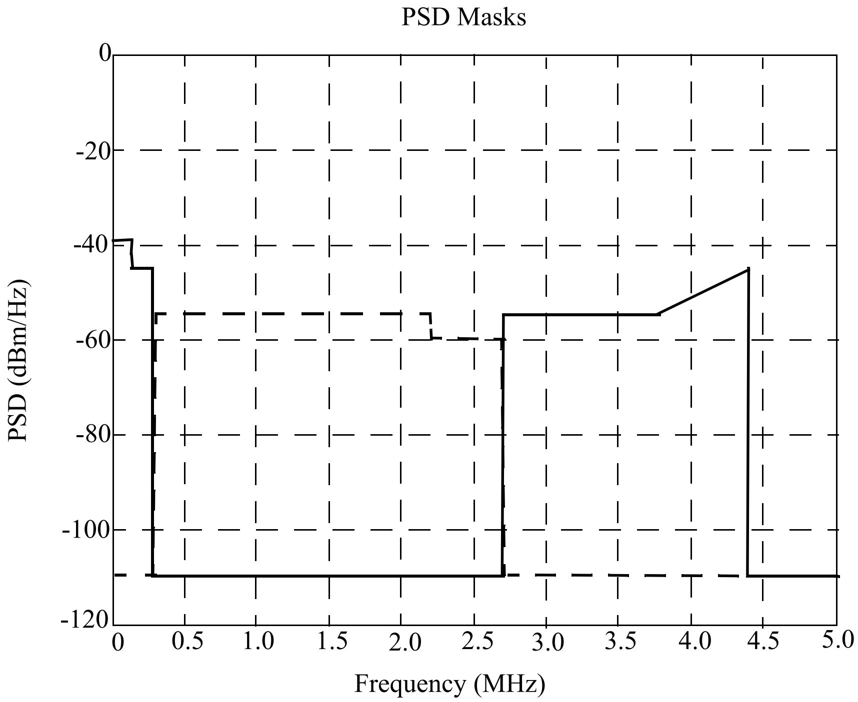

Figure 62C–1—Example PSD Masks for MCM 10PASS-TS

Table 62C–1—Required VDSL performance for spectral compatibility

Performance Level	Loop length (m)[a]	Upstream (Mb/s)	Downstream (Mb/s)
A	152.4	15.66	42.29
B	304.8	14.01	42.29
C	457.2	12.86	38.85
D	609.6	11.97	36.29
E	762.0	9.08	32.5
F	914.4	5.47	26.3
G	1066.8	3.66	22.12
H	1219.2	1.65	18.70
I	1371.6	0.42	15.40
J	1524.0	0.074	11.67

[a] NOTE—The performance requirements are taken from American National Standard T1.417, which specifies loop lengths in 500 ft (152.4 m) increments.

The results of the spectral compatibility analysis are shown in Figures 62C–1 through 62C–4.

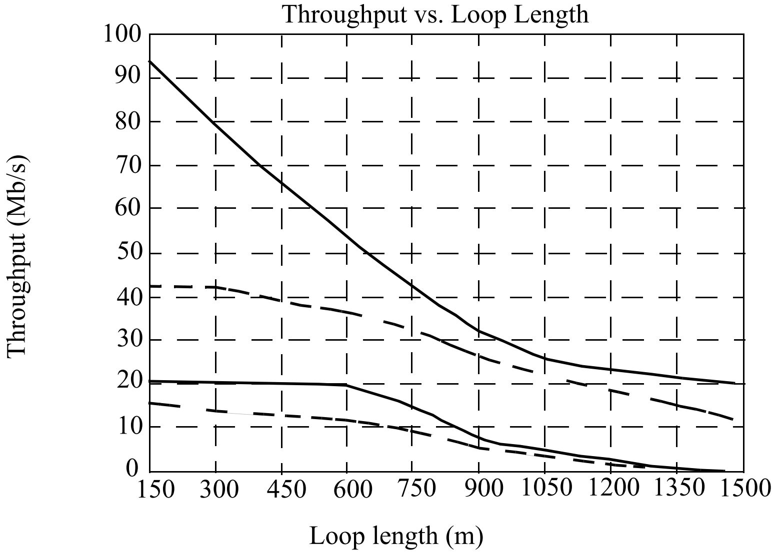

Figure 62C–2—Simulated performance of a VDSL system (using ITU-T Bandplan A) in the presence of 24 disturbers using the example PSD of this subclause.

NOTE—Dashed line = minimum VDSL performance required for spectral compatibility; solid line = simulated VDSL performance in presence of new disturbers.

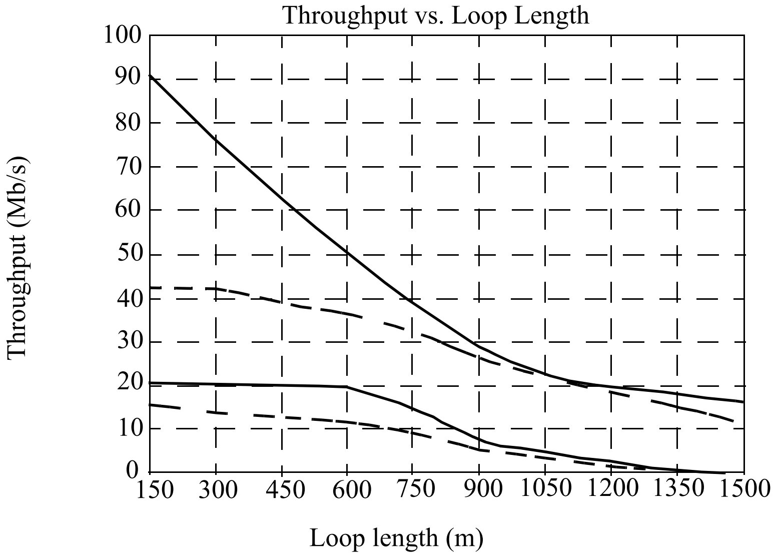

Figure 62C–3—Simulated performance of a VDSL system (using ITU-T Bandplan A) in the presence of 12 disturbers using the example PSD of this subclause and 12 disturbers using T1.417 mask SM9.

NOTE—Dashed line = minimum VDSL performance required for spectral compatibility; solid line = simulated VDSL performance in presence of new disturbers.

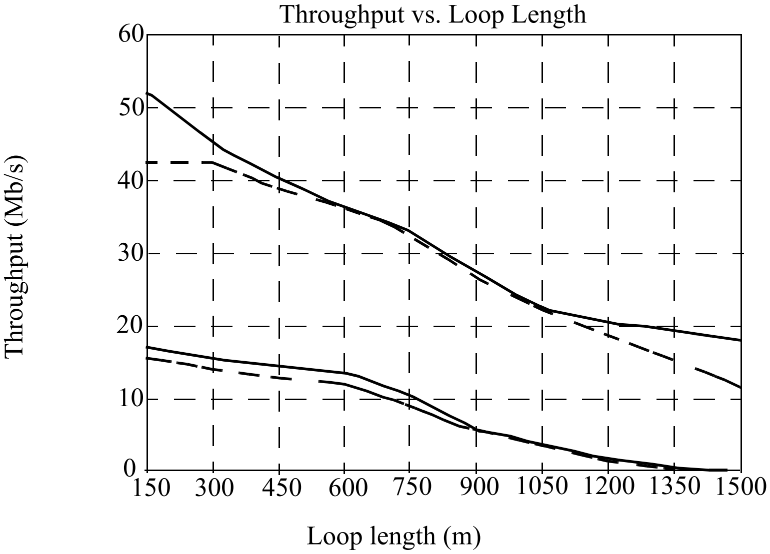

Figure 62C–4—Simulated performance of a VDSL system (using ITU-T Bandplan A) in the presence of 12 disturbers using the example PSD of this subclause and 12 disturbers using T1.417 mask SM6.

NOTE—Dashed line = minimum VDSL performance required for spectral compatibility; solid line = simulated VDSL performance in presence of new disturbers.

62C.2.1 Plan A with variable LF region

As an additional example, this subclause describes a modified version of ITU-T Bandplan A (formerly known as 998) with variable low-frequency region. Its target is to improve the reach of symmetric bitrates using 10PASS-TS or VDSL.

Plan A with variable LF region is shown in Figure 62C–5. The transition frequency between band 0 (used in upstream) and band 1D can be varied between 25 kHz and 490 kHz to boost the upstream channel bitrate. This principle is similar to the variable bandwidth capability of 2BASE-TL and SHDSL. A supporting PSD which observes spectral compatibility requirements is described in 62C.3.2.

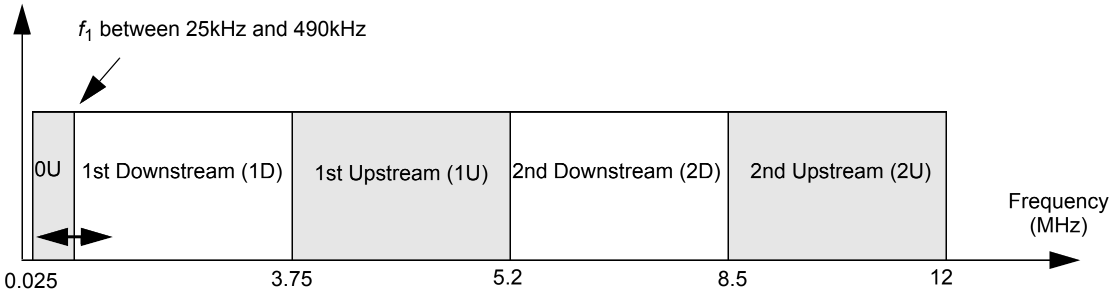

Figure 62C–5—Plan A with variable LF region

This family of bandplans can be implemented by assigning the appropriate tones to upstream and downstream, as shown in Table 62C–2.

Table 62C–2—Implementation of Plan A with variable LF region

Band	Tone Group
0 (upstream)	$6 \to \lfloor f_1 / (4.3125\text{kHz}) \rfloor$
1D (downstream)	$\lceil f_1 / (4.3125\text{kHz}) \rceil \to 869$
1U (upstream)	870 → 1205
2D (downstream)	1206 → 1970
2U (upstream)	1972 → 2782

62C.3 PSD mask configuration

62C.3.1 General procedure

Example situation: a mixed (transitional) deployment where certain subscribers are served with a 10PASS-TS line from a central office (longer lines), while others are served with a 10PASS-TS line from a cabinet (shorter lines). In order to guarantee high link quality for all subscribers, the transmit PSDs from the cabinet are reduced to mimic a longer line (downstream power back-off).

The properties of the different tones are configured by means of the Tone Group register (1.x.15:0; 1.x + 1.15:0, defined in 45.2.1.38). The 8-bit PSD Level field in the Tone Control Parameter register (45.2.1.39) is used to set the TX PSD level for the selected group of tones. Given the tone spacing of 4.3125 kHz, a very fine-grained PSD control is possible. To implement a gradual frequency-dependent power back-off, a narrow sliding window is defined in the Tone Group register; each time the window is moved towards higher frequencies, the allowed TX PSD for that frequency range is set. The new configuration is applied by writing binary 1 to the Change PSD Level bit in the Tone Control Action register (45.2.1.40). This approach is illustrated by the algorithm in Equation (62C–1).[41]

```
for (tone=0;tone<4096;tone+=16) {
 ToneGroupRegister[0] = tone;
 ToneGroupRegister[1] = tone+16;
 ToneControlParameterRegister[1] &= 0xFFFC; // clear first 2 bits
 ToneControlParameterRegister[2] &= 0x01FF; // clear last 7 bits
 ToneControlParameterRegister[1] |= TxPSD[tone] >> 7;
 ToneControlParameterRegister[2] |= (TxPSD[tone] << 9) & 0xFE00;
}
*ToneControlActionRegister |= 0x0002; // activate PSD level setting
```

(62C–1)

62C.3.2 PSD Masks for Plan A with variable LF region

As an additional example, this –subclause describes PSD masks for Plan A with variable LF region, as introduced in 62C.2.1.

In band 0 (up to f_1 between 25 kHz and 490 kHz), the PSD is limited to –50 dBm/Hz, as is the case for 2.32 Mb/s SHDSL.

The PSD in bands 1D, 1U, 2D and 2U is limited to comply with mask M2 as defined in T1.424.

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[41] Variables and pointers are used as described in 62A.4.

Annex 63A

(normative)

PMD Profiles for 2BASE-TL

63A.1 Introduction and rationale

Annex 63A defines the PMD profiles for 2BASE-TL. These profiles define the transmission characteristics of the PHY on the media. 2BASE-TL PHYs are required to operate across varying media quality, regulatory and noise environments. The profiles defined in this clause have two purposes.

The first is to describe a bounded set of operating modes that a party might choose from when implementing, integrating and installing 2BASE-TL equipment. 2BASE-TL PHYs are inherently flexible in their transmission capabilities. The defined profiles collect a subset of these parameters into modes that work well in most deployments. For deployments that require an operating mode not defined in this Annex, profiles can be overridden by setting PHY PMD registers directly, via Clause 45 for example.

The second purpose of the profiles is to define a set of operating modes against which PHY performance compliance may be tested. The topic of performance compliance is addressed for 2BASE-TL in Annex 63B.

63A.2 Relationship to other clauses

Clause 30 describes how the selection of Annex 63A profiles is exported to a management entity.

Clause 45 registers describe an optional mechanism for configuring a 2BASE-TL PHY to use a particular profile. The register settings for each profile are contained in 63A.4.

63A.3 Profile definitions

A 2BASE-TL profile is characterized by 4 parameters: data rate, power, constellation size and region. Different regions have different constraints on the PHY. ITU-T Recommendation G.991.2 distinguishes 3 regions and lists regional requirements in three annexes labeled A, B, C. Reference Annex A generally describes those specifications that are unique to SHDSL systems operating under conditions such as those typically encountered within the North American network; Reference Annex B, within European networks; and Reference Annex C, within networks with existing TCM-ISDN service.

The profiles of Table 63A–1 will generate a net data rate greater than 2 Mb/s at the MII interface on 1 to 4 pairs. Note that the profiles are defined on a single pair basis. The aggregation mechanism is specified in Clause 61. The data rate is the closest multiple of 64 kb/s greater than a net data rate of 2 Mb/s plus the corresponding 64/65-octet encapsulation overhead divided by the number of pairs. The line rate has an additional 8 kb/s of SHDSL overhead.

The default profile shall be profile #7 (Annex B).

Table 63A–1—2BASE-TL profiles

Profile #	Data rate per pair (kb/s)	Line rate per pair (kb/s)	Power (dBm)	Region	Constellation
1	5696	5704	13.5	Annex A sec. A.4.1	32-TCPAM
2	3072	3080	13.5	Annex A sec. A.4.1	32-TCPAM
3	2048	2056	13.5	Annex A sec. A.4.1	16-TCPAM
4	1024	1032	13.5	Annex A sec. A.4.1	16-TCPAM
5	704	712	13.5	Annex A sec. A.4.1	16-TCPAM
6	512	520	13.5	Annex A sec. A.4.1	16-TCPAM
7	5696	5704	14.5	Annex B sec. B.4.1	32-TCPAM
8	3072	3080	14.5	Annex B sec. B.4.1	32-TCPAM
9	2048	2056	14.5	Annex B sec. B.4.1	16-TCPAM
10	1024	1032	13.5	Annex B sec. B.4.1	16-TCPAM
11	704	712	13.5	Annex B sec. B.4.1	16-TCPAM
12	512	520	13.5	Annex B sec. B.4.1	16-TCPAM

63A.4 Register settings

This subclause contains Clause 45 register settings required to comply with the profiles defined in 63A.3. The 2B general parameter register (see 45.2.1.46) selects a region. The 2B PMD parameters register (see 45.2.1.47) selects values for data rate, power and constellation size. The 2B extended PMD parameters registers (see 45.2.1.61) define four additional data range sets to be used in conjunction with the 2B PMD parameters registers when additional PMD configuration detail is desired. Detailed register settings are shown in Table 63A–2.

Table 63A–2—2BASE-TL register settings

Profile #	2B general parameter register	2B PMD parameters register	
		1.81.15:0	1.82.15:0
1	0000_{16}	5959_{16}	0045_{16}
2	0000_{16}	3030_{16}	0045_{16}
3	0000_{16}	2020_{16}	0046_{16}
4	0000_{16}	1010_{16}	0046_{16}
5	0000_{16}	$0B0B_{16}$	0046_{16}
6	0000_{16}	0808_{16}	0046_{16}
7	0001_{16}	5959_{16}	$004D_{16}$
8	0001_{16}	3030_{16}	$004D_{16}$
9	0001_{16}	2020_{16}	$004E_{16}$
10	0001_{16}	1010_{16}	0046_{16}
11	0001_{16}	$0B0B_{16}$	0046_{16}
12	0001_{16}	0808_{16}	0046_{16}

63A.5 Protocol implementation conformance statement (PICS) proforma Annex 63A, PMD Profiles for 2BASE-TL[42]

63A.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Annex 63A, PMD Profiles for 2BASE-TL, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

63A.5.2 Identification

63A.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

63A.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 63A, 2BASE-TL PMD profiles.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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63A.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
2BProf	2BASE-TL PMD profiles	Annex 63A	The PMD profiles listed in Annex 63A are supported.	2BASE-TL: M	Yes [ ]

63A.5.4 PICS proforma tables for Performance guidelines for 2BASE-TL PMD profiles

Item	Feature	Subclause	Value/Comment	Status	Support
2BProf-1	Default Profile	63A.3	The default profile shall be profile #7.	M	Yes [ ]
2BProf-2	Register settings	63A.4	The register settings comply with Table 63A–2.	M	Yes [ ]
2BProf-3	Profiles	63A.3	A 2BASE-TL PHY supports all profiles listed in Table 63A–1.	M	Yes [ ]

Annex 63B

(normative)

Performance guidelines for 2BASE-TL PMD profiles

63B.1 Introduction and rationale

This annex defines performance guidelines for 2BASE-TL PMD profiles. The definition of those guidelines is challenging due to the varying nature of the access network. The access network has large variations in cable characteristics from region to region. In addition, the make-up of a cable can encompass multiple cable gauges and/or different configuration of bridged taps. Finally, services may vary from region to region creating different noise scenarios. Typically, deployment guidelines are a function of the telecommunications operator, which is operating a loop and the regional spectrum management policies, which govern deployment on that loop.

Given that one cannot test every possible combination of loop make-up and noise conditions, the performance guidelines are covered from two perspectives. Firstly, 63B.3 lists a suite of artificial tests crafted to test the 2BASE-TL PHYs under representative worst-case noise and loop conditions. Secondly, 63B.4 defines a deployment guideline rule which allows a service provider to determine whether a given loop will support a given profile.

63B.2 Relationship to other clauses

Annex 63A lists a set of PMD profiles for 2BASE-TL.

Clause 30 describes how the selection of Annex 63A profiles is exported to a management entity.

Clause 45 registers describe an optional mechanism for configuring a 2BASE-TL PHY to use a particular profile. The register settings for each profile are contained in 63A.4.

63B.3 Performance test cases.

The profiles associated with the 5696, 3072, 1024, 704 and 512 kb/s (profiles 1, 2, 4, 5, and 6) shall satisfy the tests described in Table 63B-1. The same test methodology defined in G.991.2 Annex A shall be applied. The test cases are numbered 57 to 78 to differentiate them from the existing tests 1 to 56 in Table A-1 of G.991.2. Profile 3 shall successfully pass the corresponding tests described in Table A-1 of G.991.2.

Table 63B-1—Additional tests for the Annex A data rate

Test	Test loop	L (km)	Test unit	Payload data rate (kb/s)	PSD	Interferer Combination	Required Margin (dB)
57	S	2.80	2BASE-TL-O	1024	symmetric	49-HDSL	5 + Δ*
58	BT1-C	2.47	2BASE-TL-O	1024	symmetric	49-SHDSL_768_sym	5 + Δ*
59	BT1-C	2.47	2BASE-TL-O	1024	symmetric	49-HDSL	5 + Δ*
60	S	2.83	2BASE-TL-R	1024	symmetric	49-HDSL	5 + Δ*
61	BT1-R	2.47	2BASE-TL-R	1024	symmetric	49-SHDSL_768_sym	5 + Δ*
62	BT1-R	2.47	2BASE-TL-R	1024	symmetric	49-HDSL	5 + Δ*

Table 63B-1—Additional tests for the Annex A data rate *(continued)*

Test	Test loop	L (km)	Test unit	Payload data rate (kb/s)	PSD	Interferer Combination	Required Margin (dB)
63	S	3.44	2BASE-TL-O	704	symmetric	49-HDSL	5 + Δ*
64	BT1-C	3.17	2BASE-TL-O	704	symmetric	49-SHDSL_768_sym	5 + Δ*
65	BT1-C	3.17	2BASE-TL-O	704	symmetric	49-HDSL	5 + Δ*
66	S	3.44	2BASE-TL-R	704	symmetric	49-HDSL	5 + Δ*
67	BT1-R	3.17	2BASE-TL-R	704	symmetric	49-SHDSL_768_sym	5 + Δ*
68	BT1-R	3.17	2BASE-TL-R	704	symmetric	49-HDSL	5 + Δ*
69	S	4.08	2BASE-TL-O	512	symmetric	49-HDSL	5 + Δ*
70	BT1-C	3.75	2BASE-TL-O	512	symmetric	49-SHDSL_768_sym	5 + Δ*
71	BT1-C	3.75	2BASE-TL-O	512	symmetric	49-HDSL	5 + Δ*
72	S	4.08	2BASE-TL-R	512	symmetric	49-HDSL	5 + Δ*
73	BT1-R	3.75	2BASE-TL-R	512	symmetric	49-SHDSL_768_sym	5 + Δ*
74	BT1-R	3.75	2BASE-TL-R	512	symmetric	49-HDSL	5 + Δ*
75	S	1.37	2BASE-TL-O	3072	symmetric	49-SHDSL_2304 (case 11)	5 + Δ*
76	S	1.37	2BASE-TL-R	3072	symmetric	49-SHDSL_2304 (case 11)	5 + Δ*
77	S	0.85	2BASE-TL-O	5696	symmetric	24-HDSL2+24-T1 (case 4)	5 + Δ*
78	S	0.85	2BASE-TL-R	5696	symmetric	24-HDSL2+24-T1 (case 14)	5 + Δ*

Profiles 7 and 8 shall be tested using tests B-1 to B-4 defined in Table 63B-2. The same test methodology defined in G.991.2 Annex B shall be applied. Profile 9, 10 and 12 shall be tested using the tests defined in Annex B of ITU-T Recommendation G.991.2. The loops defined in Annex B do not scale as well as the loops of Annex A because they are defined in terms of insertion loss at a given frequency (with a granularity of 0.5 dB), rather than a length in meters. The 704 kb/s data rate (profile 11) is expected to successfully pass the test associated with the 768 kb/s data rate. Therefore, for Annex B testing, the 704 kb/s data rate shall be tested using the 768 kb/s test.

Table 63B-2—Additional tests for the Annex B data rate

Test	Test loop	L (km)	Test unit	Payload data rate (kb/s)	PSD	Interferer Combination[a]	Required Margin (dB)
B-1	Loop 2	1.37	2BASE-TL-O	3072	symmetric	C2048sD2	5 + Δ*
B-2	Loop 2	1.37	2BASE-TL-R	3072	symmetric	R1536sB2	5 + Δ*
B-3	Loop 2	0.85	2BASE-TL-O	5696	symmetric	C2304sD2	5 + Δ*
B-4	Loop 2	0.85	2BASE-TL-R	5696	symmetric	R2048sA2	5 + Δ*

[a] The following nomenclature is used to describe Annex B noise shapes: ABBBCDE; where A is the Side (either C or R), BBB, the rate, C the PSD type (either ‘s’ for symmetric or ‘a’ for asymmetric), D the Noise type (A,B,C or D) and E, the loop number (from 1 to 7).

63B.4 Deployment Guidelines

The ITU-T G.991.2 defines an equivalent loop attenuation which can be used to determine whether a cable insertion loss function 1/H(f), can support a given profile associated with a nominal transmit signal power spectral density S(f). The loop attenuation should not be confused with another popular metric called the loop insertion loss at a given frequency. The latter specifies the insertion loss of the loop at a single frequency while the former weights the transmitted signal PSD and insertion loss of the loop over a frequency range corresponding to the transmitted signal bandwidth. The loop attenuation provides a more precise estimate of the loop capability to support a given data rate.

The SHDSL Loop Attenuation shall be defined as follows (section 9.5.5.7.5 of G.991.2):

$$LoopAtten_{SHDSL}(H) = \frac{2}{f_{\mathrm{Baud}}}\left(\begin{array}{l} \displaystyle\int_{0}^{\frac{f_{\mathrm{Baud}}}{2}} 10\log\left[\sum_{n=0}^{1} S(f-nf_{\mathrm{Baud}})\right]df - \\ \displaystyle\int_{0}^{\frac{f_{\mathrm{Baud}}}{2}} 10\log\left[\sum_{n=0}^{1} S(f-nf_{\mathrm{Baud}})\left|H(f-nf_{\mathrm{Baud}})\right|^{2}\right]df \end{array}\right) \tag{63B–1}$$

where f_{Baud} is the symbol rate, $1/H(f)$ is the insertion loss of the loop, and $S(f)$ is the nominal transmit PSD.

Table 63B-3 lists the maximum loop attenuation for a margin of 5 dB assuming the presence of 49 and 12 self-interferers for the profiles defined in Annex 63A. The 49 self-interferer case corresponds to a very conservative deployment reach.

Assuming a data rate of 2048 kb/s, the deployment reach for AWG24 gauge cable corresponds to 2.8 km for the 49-self number and 3.2 km for the 12-self number.

Table 63B-3—Loop attenuation guideline

Profile	Data rate (kb/s)	Maximum SHDSL Loop Attenuation for 49-self-interferers	Maximum SHDSL Loop Attenuation for 12-self-interferers
2 and 7	2048	24.0	27.7
3 and 8	1024	28.6	32.1
4 and 9	704	31.0	34.7
5 and 10	512	33.1	36.7

63B.5 Protocol implementation conformance statement (PICS) proforma for Annex 63B, Performance guidelines for 2BASE-TL PMD profiles[43]

63B.5.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Annex 63B, Performance guidelines for 2BASE-TL PMD profiles, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

63B.5.2 Identification

63B.5.2.1 Implementation identification

Supplier	
Contact point for inquiries about the PICS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification—e.g., names and versions for machines and/or operating systems; System Name(s)	
NOTE 1—Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirements for the identification. NOTE 2—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

63B.5.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3-2015, Annex 63B, Performance guidelines for 2BASE-TL PMD profiles.
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21, the answer Yes means that the implementation does not conform to IEEE Std 802.3-2015.)	
Date of Statement	

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63B.5.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
2BPerf	Performance guidelines for 2BASE-TL PMD profiles	Annex 63B	The performance guidelines listed in Annex 63B are supported.	2BASE-TL: M	Yes [ ]

63B.5.4 PICS proforma tables for Performance guidelines for 2BASE-TL PMD profiles

Item	Feature	Subclause	Value/Comment	Status	Support
2BPerf-1	Performance	63B.3	A 2BASE-TL PHY successfully passes the performance tests described in 63B.3.	M	Yes [ ]

Annex 67A

(informative)

Environmental characteristics for Ethernet subscriber access networks

67A.1 Introduction

The purpose of EFM and its distinction from traditional Ethernet networks, is that it specifies functionality required for the subscriber access network, i.e., public network access. Network design considerations for "public" access that may differ from traditional Ethernet LANs include the operations, administration and management (OAM) function, and the regulatory requirements, as well as the environmental factors that are addressed in this annex. This annex applies to Clause 56 through Clause 67 with particular relevance for Clause 58, Clause 59, and Clause 60.

The optical link is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling (such as shock and vibration). implementers are expected to indicate in their literature the operating environmental conditions to facilitate selection, installation, and maintenance, and may also give summary information on a product label. The normative specifications of this standard are understood to apply over the range of conditions defined by the implementer.

This informative annex provides information, to both the design engineer and the eventual user of specific product implementations, on the environmental factors to be considered when designing EFM network topologies. It is intended to record the assumptions used in developing the specifications contained in the normative specifications. The following sections give an example of likely deployment of the different Physical Layer types, followed by a discussion of temperature issues. Informative references may be found in Annex A.

It is believed that the most critical environmental factor on an Ethernet terminal will be temperature and that the most temperature sensitive element in a link is the semiconductor laser. The temperature sensitivity of these components may impact potential deployment scenarios if not considered. The remaining environmental factors (humidity, vibration, etc.) are not considered to be of such major importance and may be handled by conventional design practice. Therefore, the remainder of this annex addresses temperature.

67A.1.1 Terminal deployment scenarios

The terminal equipment of a link may or may not be in a weather-protected environment. 100BASE-LX10 and 1000BASE-LX10 links may be widely deployed with conventional building cabling for general purpose IT applications, as well as in Ethernet subscriber access applications. The other link types in Table 67A–1 are intended for Ethernet subscriber access applications. The table gives an example deployment scenario. Other scenarios are also supported by this standard, and may be deployed in significant numbers.

This example scenario places the customer premises equipment in a non-weather-protected position, e.g. the outside wall of a house, to allow ease of access for installation and maintenance. Where the premises is a large building such as a hotel, apartment block or office, a weather-protected space such as a basement within the building may be accessible enough.

It is expected that the physical format of the equipment at each end of the link will be different; however, this is outside the scope of the standard. The Physical Layer type (e.g., 2BASE-TL) and the PMD type (e.g., 1000BASE-PX20-U) are classifications of the signal on the line, and do not imply a temperature range or physical format.

Table 67A–1—Informative deployment examples

Head end (nearer the center of the network)	Customer premises (nearer the periphery of the network)
Weather-protected	**Not weather-protected or weather-protected**
100BASE-LX10	100BASE-LX10
100BASE-BX10-D	100BASE-BX10-U
1000BASE-LX10	1000BASE-LX10
1000BASE-BX10-D	1000BASE-BX10-U
1000BASE-PX10-D	1000BASE-PX10-U
1000BASE-PX20-D	1000BASE-PX20-U
10PASS-TS-O	10PASS-TS-R
2BASE-TL-O	2BASE-TL-R

67A.2 Temperature

Large portions of Ethernet subscriber access optical and copper links are expected to operate in environmental conditions consistent with the outside plant. However, it is recognized that the exact requirements for a particular deployment will vary greatly depending on the geographic location, system structure, and governing regulations. It is also recognized that portions of the network may be deployed in more benign and protected environments and that in some geographic location the outside environment may also be considered benign.

There are many factors. The temperatures in coastal regions are not usually extreme. Tropical regions are usually hot or hot and wet. The widest temperature swings are found in dry regions in the interior of large continents, e.g. central North America or central Asia. High altitude may reduce the efficacy of air cooling systems. To an extent, this is offset by the typically cooler air temperature at high altitude. Direct sunshine can add up to 1120 W/m^2 heating - see Table 1 of ETSI EN 300 019-1-3 [B27].

As a reference, Table 67A–2 shows the annual extreme air temperature values for the nine classes of climates from IEC 60721-2-1 [B37].

The climate is the basic determining factor in the component temperature. However, the temperature of the equipment using the component is significantly modified by a number of factors related to the location of the equipment. Some of these are:

- Is the equipment location weather-protected or non-weather-protected
- Is the building temperature controlled
- Are locations without temperature control subject to solar heating

Equipment temperatures for a number of locations from ETSI and Telcordia documents are shown in Table 67A–3.

An additional factor is the internal thermal design of the equipment using the optical component. The component temperature will be higher than the equipment ambient and the increase will be implementation dependant. For equipment with the complexity of EFM systems an internal temperature rise of 15 ºC to 20 ºC may be anticipated.

Table 67A–2—Informative listing of climate types

Type of climate	Low temperature (°C)	High temperature (°C)
Extremely cold (except the Central Antarctic)	–65	+32
Cold	–50	+32
Cold temperate	–33	+34
Warm temperate	–20	+35
Warm dry	–20	+40
Mild warm dry	–5	+40
Extremely warm dry	+3	+55
Warm damp	+5	+40
Warm damp, equable	+13	+35

Table 67A–3—Informative listing of equipment temperature ranges

Climate or location	Specified ambient temperature	Reference
Weather-protected		
Telecom control rooms	15 – 30°C	ETSI Class 3.6
Temperature controlled	5 – 40°C (–5 – 45°C with cooling failure)	ETSI Class 3.1
Controlled - long term	5 – 40°C (–5 – 50°C short term)	Telcordia GR-63 [B35]
Partly temperature-controlled	–5 – 45°C	ETSI Class 3.2
Not temperature-controlled	–25 – 55°C	ETSI Class 3.3
Sheltered locations	–40 – 40°C	ETSI Class 3.5
Extended/uncontrolled	–40 – 46°C (-40 to 65°C inside enclosure)	Telcordia GR-487 [B34], GR-468 [B33]
Sites with heat trap	–40 – 70°C	ETSI Class 3.4
Non-weather-protected		
Temperate	–33 – 40°C	ETSI Class 4.1
Extended	–45 – 45°C	ETSI Class 4.1E
Extremely cold	–65 – 35°C	ETSI Class 4.2L
Extremely warm dry	–20 – 55°C	ETSI Class 4.2H

67A.3 Temperature impact on optical components

Components are often commercially available in two grades, 0 to 70°C and –40 to 85°C, although optoelectronic components are also available in –20 or –10 to 85°C grade, depending on format. The GBIC MSA requires an operating temperature range of 0 to 50°C in moving air. Because of the varied physical format of equipment and components, the reader is advised to refer to specific product literature or multi source agreements for precise information.

The most temperature sensitive sub-component in an Ethernet terminal is expected to be the semiconductor laser, if for a fiber optic link. There are two categories of laser presently commonplace in the Physical Layers addressed here; Fabry-Perot (FP), a type of multi longitudinal mode (MLM) laser, and distributed feedback (DFB), a type of single longitudinal mode (SLM) laser.

Fabry-Perot lasers may have a temperature coefficient of wavelength around 0.45 nm/K, so the operating wavelength of a particular FP may vary by 55 nm over the range –40 to 85°C. The operating wavelength windows within this standard are generally 100 nm wide where FPs are anticipated, allowing adequate margin for manufacturing tolerances. To allow for the widest variety of implementation the spectral width is specified as a function of wavelength where appropriate. However, the requirement for low error ratios over substantial distances of fiber, as specified by transmitter and dispersion penalty (TDP), forces the implementer of 1000 Mb/s FP laser based implementations to pay careful attention to both wavelength and spectral width to avoid excessive mode partition noise. In practice, the full range of wavelengths in the standard is not actually available for use because at the temperature extremes the required spectral width would be too narrow. It can be seen that the wider the temperature range required, the more precisely the wavelength and spectral width must be contained to achieve a particular reach. This may have an impact on cost. This consideration would be expected to apply to 1000BASE-LX10, 1000BASE-BX10-U and 1000BASE-PX10-U.

Where the dispersion of the link or the wavelength limits are more demanding than can be met cost-effectively with FPs, DFBs may be used. They may have a temperature coefficient of wavelength under 0.1 nm/K and much narrower spectral widths than FPs. Because only a single longitudinal mode is present, a DFB does not suffer from mode partition noise. DFBs are generally more expensive than FPs. A DFB's lasing wavelength varies at 0.1 nm/K while its gain peak varies at around 0.45 nm/K. At extremes of temperature these two wavelengths are far apart and the laser may perform poorly. For this reason, DFBs for extended temperature range may be more expensive again. This consideration would be expected to apply to 1000BASE-BX10-D, 1000BASE-PX10-D, and 1000BASE-PX20.

67A.3.1 Component case temperature recommendations

67A.2 discussed the temperature progression from climate to equipment to component. 67A.3 discussed the impact of temperature, and particularly temperature range, on the design and cost of laser based optical components. In order to balance these two effects, contain costs, and yet cover the widest range of climates to allow access to the greatest markets the following recommendations are made.

Two component case temperature ranges, and by inference a third, are developed. These are defined as follows:

- Warm Extended: Intended for outdoor application in warmer climate locations.
- Cool Extended: Intended for outdoor applications in cooler climate locations.
- Universal Extended: (This is not a separate class, but is defined by simultaneously complying with the Warm and Cool Extended temperature ranges) This is a combination of the requirements for the Warm Extended and Cool Extended Classes and is intended for general outdoor applications in areas with wide seasonal variations or those designs intended for deployment in multiple geographic locations.

The recommended component case temperature ranges for these two classes are shown in Table 67A–4.

Table 67A–4—Component case temperature class recommendations

Class	Low temperature (°C)	High temperature (°C)
Warm extended	–5	+85
Cool extended	–40	+60
Universal extended	–40	+85

It will be noted that the recommendations of Table 67A–4 do not address the extremely cold climates of Table 67A–2 or the cold non-weather-protected equipment requirements of Table 67A–3. In these geographic locations it is common practice to avoid non-weather-protected locations for systems of EFM complexity and place the equipment indoors.

These temperature ranges are optional and conformance with these ranges is not required. This allows lower cost components to be had for those applications that require less extreme temperature ranges. This may be done by taking advantage of the reduced wavelength change to ease the central wavelength tolerance and spectral width requirements from the trade-off curves and more particularly, the TDP limit. This allows equipment and component suppliers, at their discretion, to develop systems and components that tolerate less severe environmental conditions that they view as suitable for their market as long as the PMD is consistent with the PICS proforma of the relevant clause. This limitation assures interoperability while allowing the equipment to be developed for specific markets. It is to be noted that the PMD specifications included in the optics Clause 58, Clause 59, and Clause 60 are based on a temperature range of –40 to 85°C in terms of the wavelength ranges and spectral widths defined.

Annex 69A

(normative)

Interference tolerance testing

69A.1 Introduction

A major problem in communicating across crowded backplanes is interference. The interfering signal can come from a variety of sources including:

a) Crosstalk from other data channels running the same kind of signals as the channel of interest. This type of interference is usually subdivided into:
   1) Far-end crosstalk (FEXT) coming from data traveling in the same general direction as the channel of interest.
   2) Near-end crosstalk (NEXT) originating from a channel with a transmitter near the receiver of the channel of interest.
b) Self interference caused by reflections due to impedance discontinuities, stubs, etc. This is a form of intersymbol interference (ISI) that is beyond what a reasonable equalizer can compensate.
c) Alien crosstalk which is defined to be interference from unrelated sources such as clocks, other kinds of data, power supply noise, etc.

For the channel to work, the receiver must be able to extract correct data from the lossy channel in the presences of interference. The ability of the receiver to extract data in the presence of interference is an important characteristic of the receiver and needs to be measured. This ability is called interference tolerance.

69A.2 Test setup

The interference tolerance test is performed with the setup shown in Figure 69A–1.

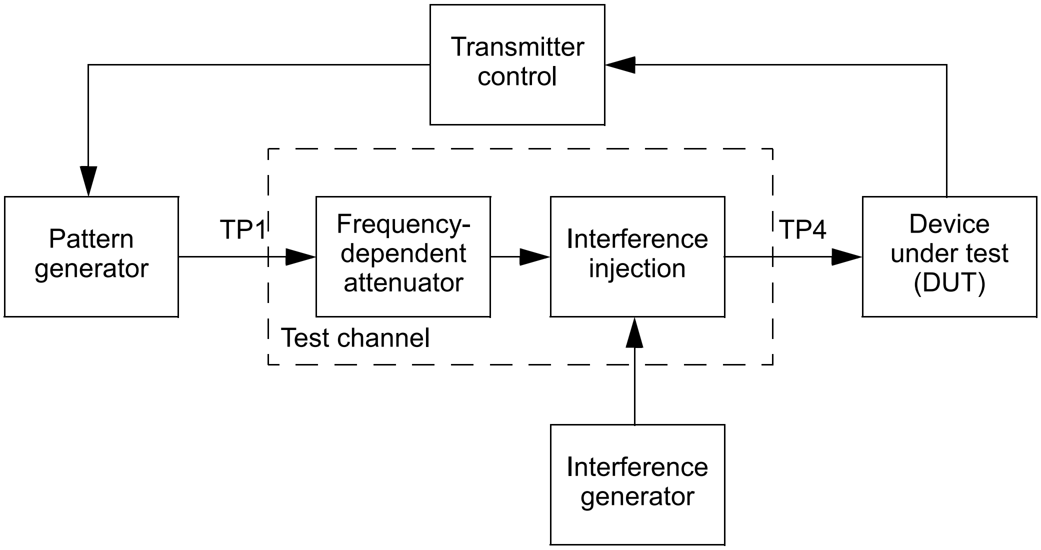


Figure 69A–1—Interference tolerance test setup

69A.2.1 Pattern generator

For 1000BASE-KX and 10GBASE-KX4, the amplitude delivered by the pattern generator to the test channel shall be no greater than the specified minimum transmitter output amplitude for the port type being tested adjusted by a gain b_{TC} as defined in 69A.2.2.

For 10GBASE-KR and 40GBASE-KR4, the peak-to-peak amplitude delivered by the pattern generator, as measured on a sequence of alternating ones and zeros, shall be no more than 800 mV, adjusted by a gain b_{TC} as defined in 69A.2.2, regardless of equalization setting.

The applied transition time at the pattern generator output shall be no less than the minimum value specified for the port type being tested. If the transition time of the pattern generator is less than the minimum specified applied transition time, an equivalent stress may be introduced in the test channel. The test channel, defined in 69A.2.2, is chosen so that the insertion loss of the test channel has a specific relationship to the maximum fitted attenuation, A_{max}, defined in 69B.4.2. If the minimum specified applied transition time is $T_r(min)$, and the transition time of the pattern generator is T_r, then the test channel may be used to generate an equaivalent stress by incrementing the parameter b_3 in A_{max} by Δb_3 as defined in Equation (69A–1).

$$\Delta b_3 = 6.8 \times (T_r(\min)^2 - T_r^2) \tag{69A–1}$$

The signaling speed of the pattern generator shall be offset ±100 ppm relative to the nominal signaling speed of the port type being tested.

The pattern generator shall have jitter on its output. This jitter shall consist of sinusoidal jitter at a frequency no less than 1/250 of signaling speed, duty cycle distortion, and random jitter. The random jitter shall be measured at the output of a single pole high-pass filter with cut-off frequency at 1/250 of the signaling speed. The sinusoidal jitter, duty cycle distortion, and random jitter shall each be no less than the amount specified for the port type being tested.

The pattern generator may include equalization depending on the port type being tested. For 1000BASE-KX, the pattern generator shall not include equalization. For 10GBASE-KX4, the pattern generator shall include equalization such that the differential output template defined in 71.7.1.6 is met. For 10GBASE-KR, equalization equivalent to a three-tap transversal filter meeting the requirements of 72.7.1.10 shall be included.

69A.2.2 Test channel

The test channel is a 100 Ω differential system consisting of a frequency-dependent attenuator and an interference injection block.

The interference injection block may be a pair of directional couplers, a pair of pick-off tees, or any other component, as long as the combination of the interference injection block and the frequency-dependent attenuator satisfies the requirements of the test channel.

The frequency dependent attenuator is recommended to be constructed in such a way that it accurately represents the insertion loss and group delay characteristics of differential traces on an FR-4 printed circuit board.

The test channel is specified with respect to transmission magnitude response, IL_{TC}, and return loss. Assuming the transmission magnitude response is measured at N uniformly-spaced frequencies f_n spanning the frequency range f_1 to f_2, the transmission magnitude is described by two parameters, m_{TC} and b_{TC}, as defined in Equation (69A–2) through Equation (69A–7).

$$m_{\mathrm{X}} = \frac{1}{N}\sum_{n} A_{\mathrm{max}}(f_{\mathrm{n}}) \tag{69A–2}$$

$$m_{\mathrm{Y}} = \frac{1}{N}\sum_{n} IL_{\mathrm{TC}}(f_{\mathrm{n}}) \tag{69A–3}$$

$$m_{\mathrm{XY}} = \frac{1}{N}\sum_{n} A_{\mathrm{max}}(f_{\mathrm{n}}) IL_{\mathrm{TC}}(f_{\mathrm{n}}) \tag{69A–4}$$

$$m_{\mathrm{XX}} = \frac{1}{N}\sum_{n} A_{\mathrm{max}}(f_{\mathrm{n}}) A_{\mathrm{max}}(f_{\mathrm{n}}) \tag{69A–5}$$

$$m_{\mathrm{TC}} = \frac{m_{\mathrm{XY}} - m_{\mathrm{X}} m_{\mathrm{Y}}}{m_{\mathrm{XX}} - m_{\mathrm{X}} m_{\mathrm{X}}} \tag{69A–6}$$

$$b_{\mathrm{TC}} = m_{\mathrm{Y}} - m_{\mathrm{TC}} m_{\mathrm{X}} \tag{69A–7}$$

The values f_1 and f_2 are a function of the port type under test (see Table 69B–1) and A_{max} is defined in 69B.4.2.

The test channel shall have m_{TC} greater than the minimum value specified for the port type under test and the test being performed. The test channel return loss, as measured at TP1 and TP4, shall be greater than or equal to 20 dB from f_{min} to f_2.

69A.2.3Interference generator

The interference generator is a broadband noise generator capable of producing white Gaussian noise with adjustable amplitude. The power spectral density shall be flat to ±3 dB from f_1 to 0.5 times the signaling speed for the port type under test with a crest factor of no less than 5. The noise shall be measured at the output of a filter connected to TP4. The filter for this measurement shall have no more than a 40 dB/decade roll-off and a 3 dB cut-off frequency at least 0.5 times the signaling speed.

69A.2.4Transmitter control

For 10GBASE-KR testing, the pattern generator is controlled by transmitter control. Transmitter control responds to inputs from the receiver to adjust the equalization of the pattern generator. The receiver may communicate through its associated transmitter, using the protocol described in 72.6.10, or by other means.

69A.3 Test methodology

For 10GBASE-KR testing, the pattern generator shall first be configured to transmit the training pattern defined in 72.6.10.2. During this initialization period, the DUT shall configure the pattern generator equalizer, via transmitter control, to the coefficient settings it would select using the protocol described in 72.6.10. During training, the broadband noise measured at TP4 shall have RMS amplitude less than 1 mV.

The pattern generator shall be configured to transmit the test pattern defined for the port type under test.

The broadband noise source shall then be set to the amplitude specified for the port type being tested, as measured at TP4. The measured BER shall be less than the target BER specified for the port type under test.

The interference tolerance test parameters are specified in Table 70–7 for 1000BASE-KX, in Table 71–7 for 10GBASE-KX4, and in Table 72–10 for 10GBASE-KR and 40GBASE-KR4.

Annex 69B

(informative)

Interconnect characteristics

69B.1 Overview

Backplane Ethernet is primarily intended to operate over differential, controlled impedance traces up to 1 m, including two connectors, on printed circuit boards residing in a backplane environment. The performance of such an interconnect is highly dependent on implementation.

69B.2 Reference model

The backplane interconnect is defined between test points TP1 and TP4 as shown in Figure 69B–1. The transmitter and receiver blocks include all off-chip components associated with the respective block. For example, external AC-coupling capacitors, if required, are to be included in the receiver block.

Informative characteristics and methods of calculation for the insertion loss, insertion loss deviation, return loss, crosstalk, and the ratio of insertion loss to crosstalk between TP1 and TP4 are defined in 69B.4.3, 69B.4.4, 69B.4.5, 69B.4.6, and 69B.4.6.4 respectively. These characteristics may be applied to a specific implementation of the full path (including transmitter and receiver packaging and supporting components) for a complete assessment of system performance and the interaction of these components.

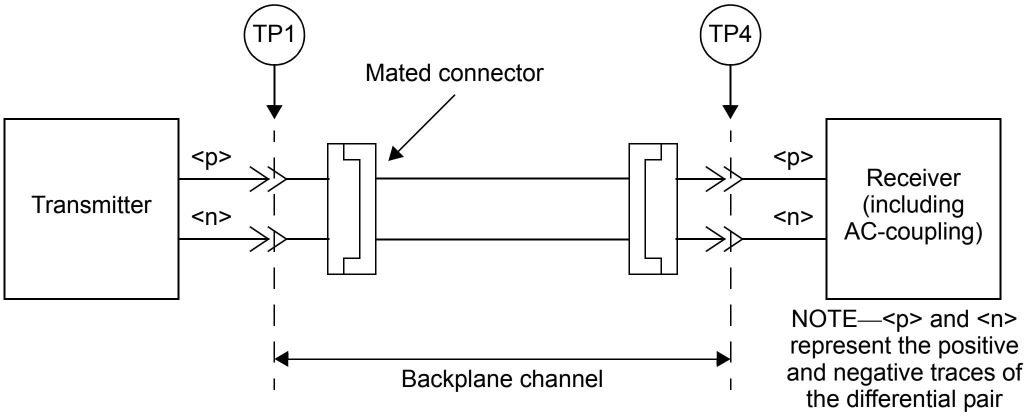


Figure 69B–1—Interconnect reference model

69B.3 Characteristic impedance

The recommended differential characteristic impedance of circuit board trace pairs is 100 Ω ± 10%.

The total differential skew from TP1 to TP4 is recommended to be less than the minimum transition time for port type of interest.

69B.4 Channel parameters

69B.4.1 Overview

A series of informative parameters are defined for use in backplane channel evaluation. These parameters address the channel insertion loss and crosstalk.

The informative parameters for channel insertion loss are based on the amount of loss allowed for a given level of interference as verified by the interference tolerance test procedure defined in Annex 69A.

The informative parameters for channel insertion loss are summarized in Table 69B–1.

The maximum fitted attenuation (A_{max}) due to trace skin effect and dielectric properties is defined in 69B.4.2. The maximum insertion loss (IL_{max}) is defined in 69B.4.3. The maximum deviation of insertion loss from the best-fit attenuation (ILD) is defined in 69B.4.4. The minimum return loss (RL_{min}) is defined in 69B.4.5. The limit on crosstalk in relation to insertion loss (ICR_{min}) is defined in 69B.4.6.4. All of the different parameters must be considered together in evaluating the overall channel performance.

Table 69B–1—Insertion loss parameters

Parameter	1000BASE-KX	10GBASE-KX4	10GBASE-KR 40GBASE-KR4	Units
f_{min}	0.05			GHz
f_{max}	15.00			GHz
b_1	2.00×10^{-5}			
b_2	1.10×10^{-10}			
b_3	3.20×10^{-20}			
b_4	-1.20×10^{-30}			
f_1	0.125	0.312	1.000	GHz
f_2	1.250	3.125	6.000	GHz
f_a	0.100	0.100	0.100	GHz
f_b	1.250	3.125	5.15625	GHz

69B.4.2 Fitted attenuation

The fitted attenuation, A, is defined to be the least mean squares line fit to the insertion loss computed over the frequency range f_1 to f_2. Assuming the transmission magnitude response is measured at N uniformly-spaced frequencies f_n spanning the frequency range f_1 to f_2, the least mean squares line fit procedure is defined by Equation (69B–1) through Equation (69B–5).

$$f_{\text{avg}} = \frac{1}{N}\sum_{n} f_n \qquad (69B–1)$$

$$IL_{\text{avg}} = \frac{1}{N}\sum_{n} IL(f_{\text{n}}) \tag{69B–2}$$

$$m_{\text{A}} = \frac{\sum_{n}(f_{\text{n}} - f_{\text{avg}})(IL(f_{\text{n}}) - IL_{\text{avg}})}{\sum_{n}(f_{\text{n}} - f_{\text{avg}})^{2}} \tag{69B–3}$$

$$b_{\text{A}} = IL_{\text{avg}} - m_{\text{A}} f_{\text{avg}} \tag{69B–4}$$

$$A(f) = m_{\text{A}} f + b_{\text{A}} \tag{69B–5}$$

It is recommended that the fitted attenuation of the channel be less than or equal to A_{max} as defined by the Equation (69B–6), where f is expressed in Hz and the coefficients b_1 through b_4 are given in Table 69B–1.

$$A(f) \leq A_{\text{max}}(f) = 20\log_{10}(e) \times (b_1\sqrt{f} + b_2 f + b_3 f^2 + b_4 f^3) \tag{69B–6}$$

for $f_1 \leq f \leq f_2$. The fitted attenuation limit is illustrated in Figure 69B–2.

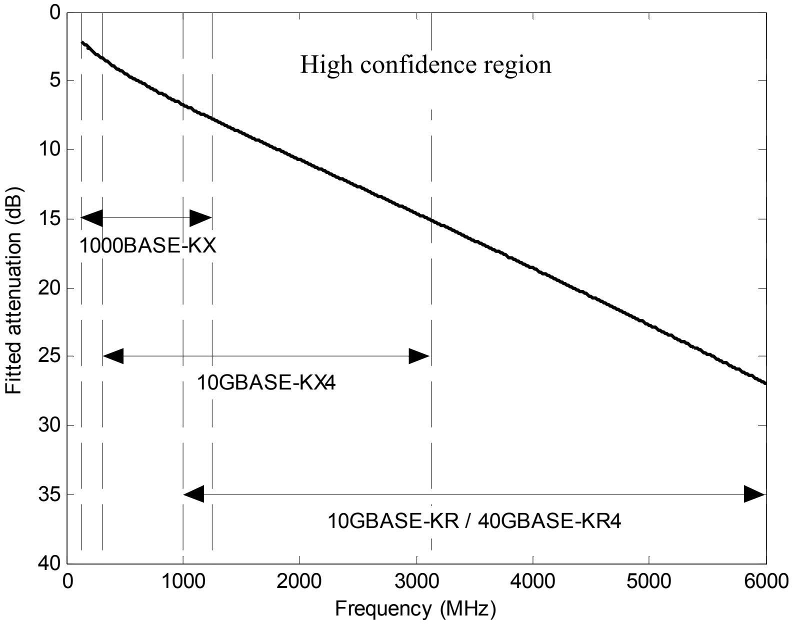


Figure 69B–2—Fitted attenuation limit

69B.4.3 Insertion loss

Insertion loss is defined as the magnitude, expresssed in decibels, of the differential response measured from TP1 to TP4. It is recommended that the insertion loss magnitude, *IL*, be within the high confidence region defined by Equation (69B–7) and Equation (69B–8).

$$IL(f) \leq IL_{\text{max}}(f) = A_{\text{max}}(f) + 0.8 + 2.0\times10^{-10} f \tag{69B–7}$$

for $f_{\text{min}} \leq f \leq f_2$

$$IL(f) \le IL_{\max}(f) \;=\; A_{\max}(f) + 0.8 + 2.0\times10^{-10}f_2 + 1\times10^{-8}(f - f_2) \qquad (69B\text{–}8)$$

for $f_2 < f \le f_{\max}$

The values of $f_{\min}$, f_2, and $f_{\max}$ are given in Table 69B–1 and $A_{\max}$ is given in Equation (69B–6). The insertion loss limit is illustrated in Figure 69B–3, Figure 69B–4 and Figure 69B–5.

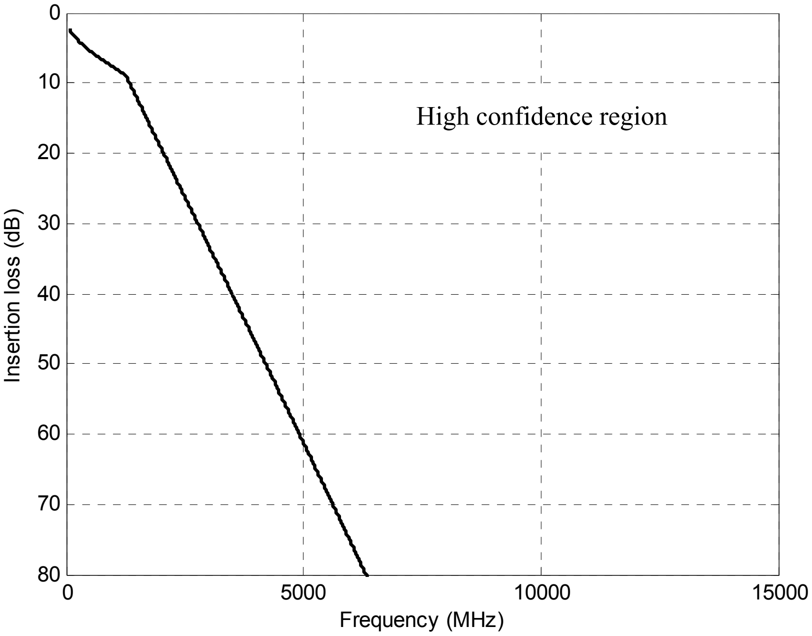


Figure 69B–3—Insertion loss limit for 1000BASE-KX

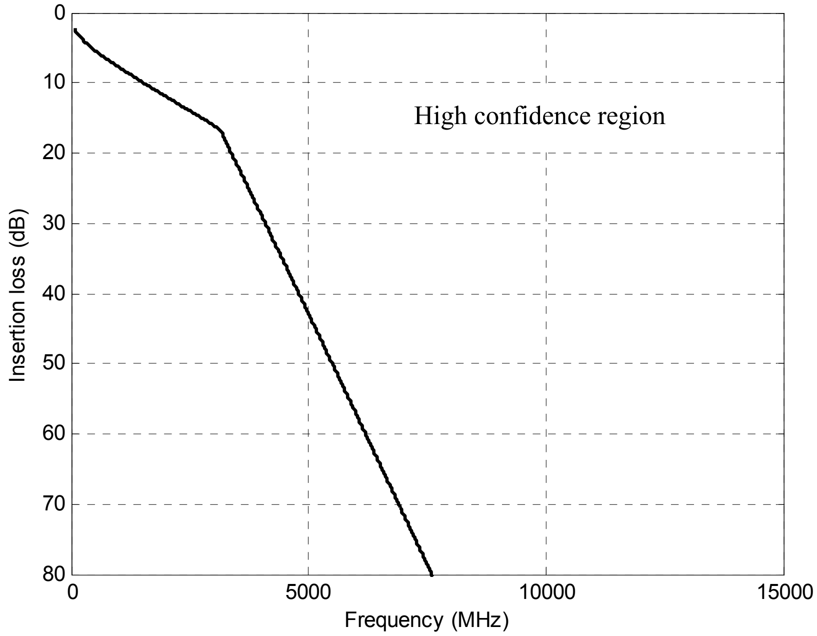


Figure 69B–4—Insertion loss limit for 10GBASE-KX4

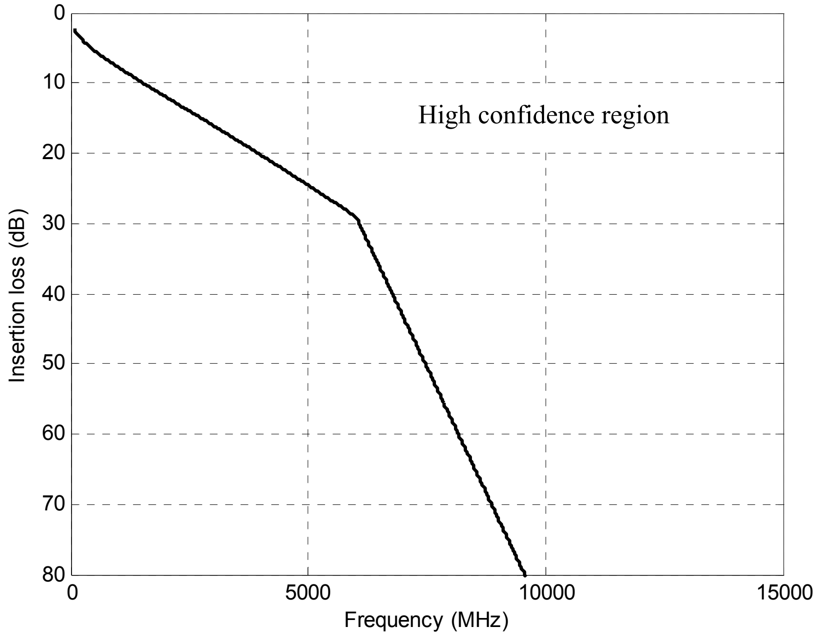


Figure 69B–5—Insertion loss limit for 10GBASE-KR and 40GBASE-KR4

69B.4.4 Insertion loss deviation

The insertion loss deviation, as defined by Equation (69B–9), is the difference between the insertion loss and the fitted attenuation defined in 69B.4.2.

$$ILD(f) = IL(f) - A(f) \tag{69B–9}$$

It is recommended that *ILD* be within the high confidence region defined by the following equations:

$$ILD(f) \geq ILD_{\min}(f) = -1.0 - 0.5 \times 10^{-9} f \tag{69B–10}$$

$$ILD(f) \leq ILD_{\max}(f) = 1.0 + 0.5 \times 10^{-9} f \tag{69B–11}$$

for $f_1 \leq f \leq f_2$.

The values of f_1 and f_2 are dependent on port type and are given in Table 69B–1. The insertion loss deviation limits for each port type is illustrated in Figure 69B–6.

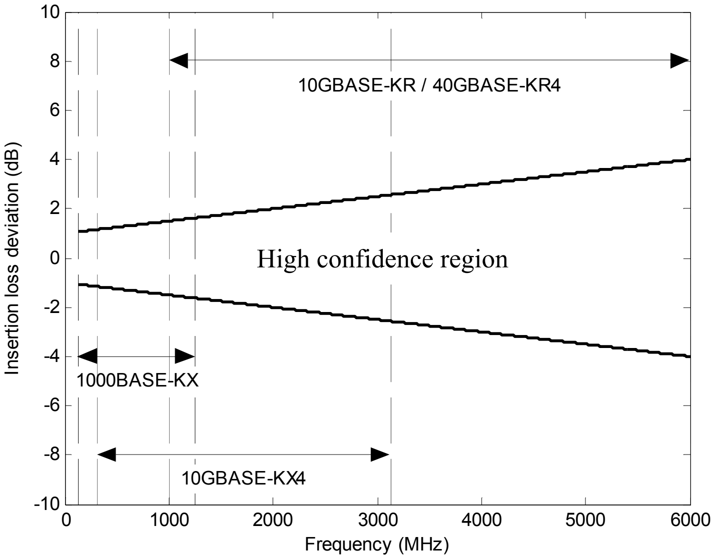


Figure 69B–6—Insertion loss deviation limits

69B.4.5 Return loss

It is recommended that the channel return loss, *RL*, measured in dB at TP1 and TP4, be greater than or equal to $RL_{\min}$ as defined by Equation (69B–12) through Equation (69B–14).

$$RL(f) \geq RL_{\min}(f) = 12 \tag{69B–12}$$

for 50 MHz $\leq f <$ 275 MHz and

$$RL(f) \geq RL_{\min}(f) = 12 - 6.75\log_{10}\left(\frac{f}{275\ \text{MHz}}\right) \quad (69\text{B–}13)$$

for 275 MHz ≤ f < 3000 MHz and

$$RL(f) \geq RL_{\min}(f) = 5 \quad (69\text{B–}14)$$

for 3000 MHz ≤ f ≤ 10312.5 MHz.

The recommendation applies from 50 MHz to the signaling speed of the PHY type of interest. The return loss limit is illustrated in Figure 69B–7.

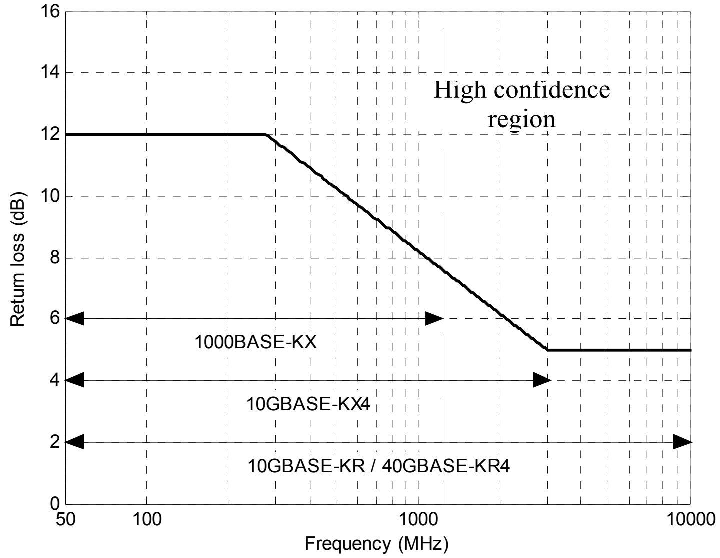


Figure 69B–7—Return loss limit

69B.4.6 Crosstalk

The following equations and informative model assume that aggressors and victim are driven by a compliant PHY of any type.

69B.4.6.1 Power sum differential near-end crosstalk (PSNEXT)

The differential near-end crosstalk at TP4 is calculated as the power sum of the individual NEXT aggressors (*PSNEXT*). *PSNEXT* is computed as shown in Equation (69B–15), where $NEXT_n$ is the crosstalk loss, in dB, of aggressor n. Note that for the case of a single aggressor, *PSNEXT* will be the crosstalk loss for that single aggressor.

$$PSNEXT(f) = -10\log\left(\sum_{n} 10^{-NEXT_n(f)/10}\right) \quad (69\text{B–}15)$$

69B.4.6.2 Power sum differential far-end crosstalk (PSFEXT)

The differential far-end crosstalk at TP4 is calculated as the power sum of the individual FEXT aggressors (*PSFEXT*). *PSFEXT* is computed as shown in Equation (69B–16), where $FEXT_{\mathrm{n}}$ is the crosstalk loss, in dB, of aggressor *n*. Note that for the case of a single aggressor, *PSFEXT* will be the crosstalk loss for that single aggressor.

$$PSFEXT(f) = -10\log\left(\sum_{n} 10^{-FEXT_n(f)/10}\right) \quad (69B\text{–}16)$$

69B.4.6.3 Power sum differential crosstalk

The differential crosstalk at TP4 is calculated as the power sum of the individual NEXT and FEXT aggressors (*PSXT*). *PSXT* may be computed as shown in the following equation:

$$PSXT(f) = -10\log(10^{-PSNEXT(f)/10} + 10^{-PSFEXT(f)/10}) \quad (69B\text{–}17)$$

69B.4.6.4 Insertion loss to crosstalk ratio (ICR)

Insertion loss to crosstalk ratio (*ICR*) is the ratio of the insertion loss, measured from TP1 to TP4, to the total crosstalk measured at TP4. *ICR* may be computed from *IL* and *PSXT* as shown in the following equation:

$$ICR(f) = -IL(f) + PSXT(f) \quad (69B\text{–}18)$$

Assuming ICR is computed at *N* uniformly-spaced frequencies f_{n} spanning the frequency range f_{a} to f_{b}, ICR_{fit} may be computed using Equations (69B–19) through (69B–23). The values of f_{a} and f_{b} are dependent on port type and are provided in Table 69B–1.

$$x_{\mathrm{avg}} = \frac{1}{N}\sum_{n}\log(f_{\mathrm{n}}) \quad (69B\text{–}19)$$

$$ICR_{\mathrm{avg}} = \frac{1}{N}\sum_{n} ICR(f_{\mathrm{n}}) \quad (69B\text{–}20)$$

$$m_{\mathrm{ICR}} = \frac{\sum_{n}(\log(f_{\mathrm{n}}) - x_{\mathrm{avg}})(ICR(f_{\mathrm{n}}) - ICR_{\mathrm{avg}})}{\sum_{n}(\log(f_{\mathrm{n}}) - x_{\mathrm{avg}})^2} \quad (69B\text{–}21)$$

$$b_{\mathrm{ICR}} = ICR_{\mathrm{avg}} - m_{\mathrm{ICR}}x_{\mathrm{avg}} \quad (69B\text{–}22)$$

$$ICR_{\mathrm{fit}}(f) = m_{\mathrm{ICR}}\log(f) + b_{\mathrm{ICR}} \quad (69B\text{–}23)$$

It is recommended that ICR_{fit} be greater than or equal to ICR_{min} as defined by the following equation:

$$ICR_{\mathrm{fit}}(f) \geq ICR_{\mathrm{min}}(f) = 23.3 - 18.7\log_{10}\left(\frac{f}{5\ \mathrm{GHz}}\right) \quad (69B\text{–}24)$$

for $f_{\mathrm{a}} \leq f \leq f_{\mathrm{b}}$. ICR_{fit} accounts for the worst-case differences in characteristcs (e.g. amplitude, transition times) between the victim and aggressor transmitters. It also assumes a 3 dB signal-to-noise ratio penalty related to insertion loss deviation.

The insertion loss to crosstalk ratio limit for each port type is illustrated in Figure 69B–8.

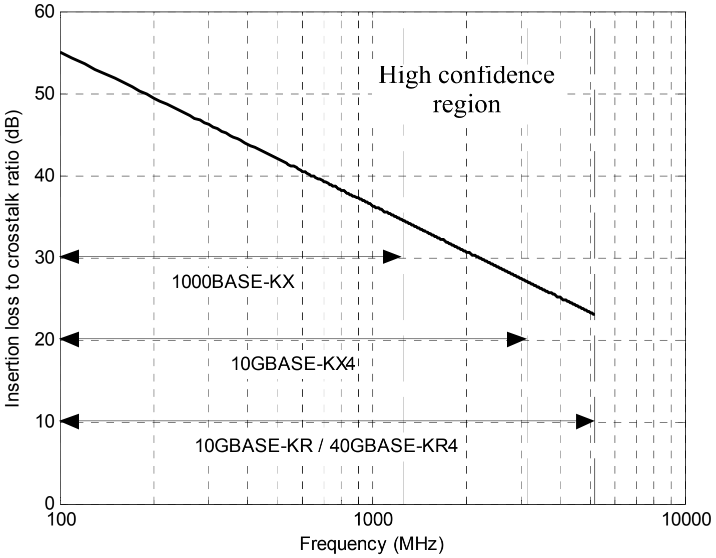


Figure 69B–8—Insertion loss to crosstalk ratio limit

Annex 73A

(normative)

Next page message code field definitions

This Annex defines the Next Page message code fields for devices using Clause 73 Auto-Negotiation. The message code field of a message page used in Next Page exchange shall be used to identify the meaning of a message. Table 73A–1 identifies the types of messages that may be sent. As new messages are developed, this table will be updated accordingly.

The Message code field uses an 11-bit binary encoding that allows 2048 messages to be defined. All message codes not specified are reserved for IEEE use or allocation.

Table 73A–1—Message code field values

Message code	M 10	M 9	M 8	M 7	M 6	M 5	M 4	M 3	M 2	M 1	M 0	Message code description
1	0	0	0	0	0	0	0	0	0	0	1	Null Message
5	0	0	0	0	0	0	0	0	1	0	1	Organizationally Unique Identifier Tagged Message
6	0	0	0	0	0	0	0	0	1	1	0	AN device Identifier Tag Code
10	0	0	0	0	0	0	0	1	0	1	0	EEE Technology Message Code. EEE capability is advertised using unformatted message code field in the Message Next Page (see 73A.4).

73A.1 Message code 1—Null Message code

The Null Message code shall be transmitted during Next Page exchange when the Local Device has no further messages to transmit and the Link Partner is still transmitting valid Next Pages. See 73.7.7 for more details.

73A.2 Message code 5—Organizationally Unique Identifier (OUI) tag code

The OUI tag code message shall consist of a Message Next Page with the message code field 000 0000 0101 followed by one Unformatted Next Page defined as follows. The unformatted code field of Message Next Page 5 shall contain the most significant 11 bits of the OUI or CID (bits 23:13) in bits 26:16 (bits U0 to U10) with the most significant OUI or CID bit in bit 26 (bit U10) of the unformatted code field, the next 11 most significant bits of the OUI or CID (bits 12:2) in bits 42:32 (bit U26 to U16) with the most significant bit in bit 42 (bit U26). The unformatted code field of the Unformatted Next Page shall contain the remaining least significant 2 bits of the OUI or CID (bits 1:0) in bits 10:9 (U10 and U9) with OUI or CID bit 1 in bit 10 (bit U10) with the bits 8:0, 26:16 (bits U8 to U0, U21 to U11) as a user-defined user code value that is specific to the OUI or CID transmitted. The remaining unformatted code field bits in the Message Next Page and the Unformatted Next Page shall be sent as zero and ignored on receipt.

For example, assume that a manufacturer's IEEE-assigned OUI/CID value is AC-DE-48 and the manufacturer-selected user-defined user code associated with the OUI or CID is $1100\,1110\,0001\,1111\,1100_2$. The message code values generated from these two numbers is encoded into the message Next Page and Unformatted Next Page codes, as specified in Figure 73A–1. For clarity, the position of the global broadcast g is illustrated.

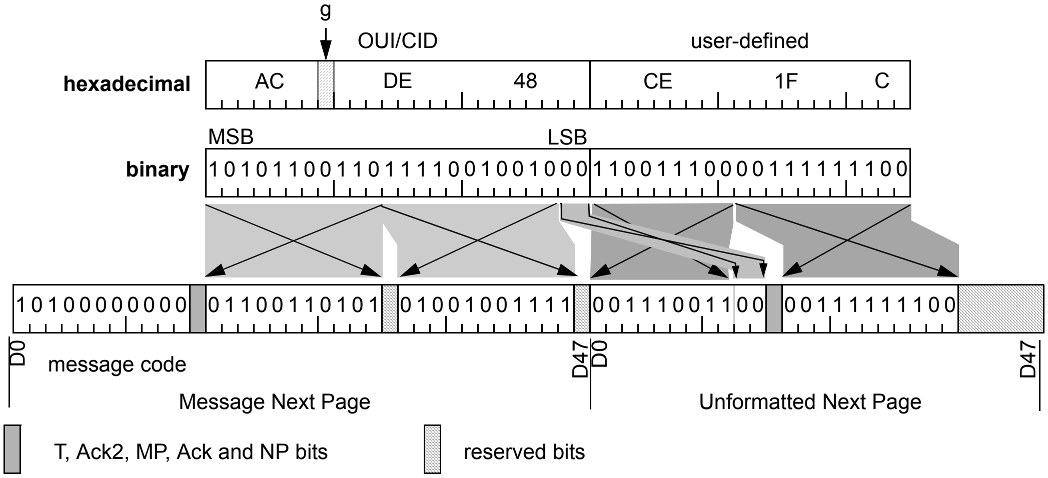


Figure 73A–1—Message code 5 sequence

NOTE—Figure 73A–1 shows the order Next Pages are transmitted, with the first transmitted Next Page shown in the leftmost position. This bits within each page are shown with the first transmitted bit (i.e., least significant bit) in the leftmost postion. This is the same convention for bit order in the figures of Clause 73. Figure 28C–1 uses the opposite convention for bit order.

73A.3 Message code 6—AN device identifier tag code

The AN device ID tag code message shall consist of a Message Next Page with the message code field 000 0000 0110 followed by one Unformatted Next Page defined as follows. The unformatted fields of this message contain the AN device identifier (registers 7.2 and 7.3). The unformatted code field of Message Next Page 6 shall contain the most significant 11 bits of the AN device identifier (7.2.15:5) in bits 26:16 (bits U0 to U10) with the most significant AN device identifier bit in bit 26 (bit U10) of the unformatted code field, and the next 11 most significant bits of the AN device identifier (bits 7.2.4:0 to 7.3.15:10) in bits 42:32 (bit U26 to U16) with the most significant bit in bit 42 (bit U26) of the unformatted code field. The unformatted code field of the Unformatted Next Page shall contain the remaining least significant 10 bits of the AN device identifier (bits 7.3.9:0) in bits 10:1 (bit U10 to U1). Bits 0, 26:16 (bits U0, U21 to U11) of the unformatted code field of the Unformatted Next Page shall contain a user-defined user code value that is specific to the device identifier transmitted. The remaining unformatted code field bits in the Message Next Page and the Unformatted Next Page shall be sent as zero and ignored on receipt.

73A.4 Message code 10—EEE technology message code

Multiple clauses use Next Page message code 10 as an identifier for EEE technology. The EEE technology code message shall consist of only a Message Next Page. The message code field, 000 0000 1010, shall be contained in bits 10:0. The contents of the unformatted code bits U31:U0 (D47:D16) shall be as defined in 45.2.7.13.

EEE capability negotiation is defined in 78.3.

Annex 74A

(informative)

FEC block encoding examples

This annex provides an example FEC block encoding with (2112, 2080) code. See Table 74–1 for the format of the FEC block. The length of the FEC block is 2112 bits. Each FEC block contains 32 rows of 65 bits each; 64 bits of payload and 1 bit transcoding overhead (T bits). At the end of each block there is 32-bit overhead or parity check bits.

The data pattern in this annex is represented in a tabular form. For the tables within this annex the contents are transmitted from left to right within each row and from top to bottom between rows. The first bit out on the wire starts at the top left hand corner. Note that there is both binary representation and hexadecimal symbol representation in the table; in case of the hex symbol, the most significant bit of each hex symbol is sent first.

74A.1 Input to the FEC (2112,2080) Encoder

Table 74A–1 provides an example 64B/66B block stream at the input to the FEC (2112,2080) encoder. The example shows a stream of 32 64B/66B symbols generated from the output of the PCS layer when the link was sending out IDLE symbols.

Table 74A–1— 64B/66B block stream

Sync [0:1]	64 bit payload hex [0:63]	Sync [0:1]	64 bit payload hex [0:63]	Sync [0:1]	64 bit payload hex [0:63]	Sync [0:1]	64 bit payload hex [0:63]
10	40ea1e77eed301ec	10	ad5a3bf86d9acf5c	10	de55cb85df0f7ca0	10	e6ccff8e8212b1c6
10	d63bc6c309000638	10	70e3b0ce30e0497d	10	dc8df31ec3ab4491	10	66fb9139c81cd37b
10	b57477d4f05e3602	10	8cfd495012947a31	10	e7777cf0c6d06280	10	44529cf4b4900528
10	85ce1d27750ad61b	10	456d5c71743f5c69	10	c1bf62e5dc5464b5	10	dc6011be7ea1ed54
10	1cf92c450042a75f	10	cc4b940eaf3140db	10	77bb612a7abf401f	10	c22d341e90545d98
10	ce6daf1f248bbd6d	10	dd22d0b3f9551ed6	10	574686c3f9e93898	10	2e52628f4a1282ce
10	f20c86d71944aab1	10	55133c9333808a2c	10	1aa825d8b817db4d	10	637959989f3021eb
10	976806641b26aae9	10	6a37d4531b7ed5f2	10	53c3e96d3b12fb46	10	528c7eb8481bc969

74A.2 Output of the FEC (2112,2080) Encoder

Table 74A–2 provides one FEC block (65b block stream) at the output of the FEC (2112,2080) encoder. The corresponding 64B/66B block stream input to the encoder is as described in Table 74A–1. The example shows one FEC block, a stream of 32 65b symbols generated from the output of the FEC (2112,2080) encoder with 32 bit parity appended at the end of the FEC block.

Table 74A–2— Transcoded FEC block

T bit [0]	64 bit payload hex [0:63]	T bit [0]	64 bit payload hex [0:63]	T bit [0]	64 bit payload hex [0:63]	T bit [0]	64 bit payload hex [0:63]
1	40ea1e77eed301ec	0	ad5a3bf86d9acf5c	0	de55cb85df0f7ca0	1	e6ccff8e8212b1c6
0	d63bc6c309000638	1	70e3b0ce30e0497d	1	dc8df31ec3ab4491	1	66fb9139c81cd37b
0	b57477d4f05e3602	1	8cfd495012947a31	0	e7777cf0c6d06280	0	44529cf4b4900528
1	85ce1d27750ad61b	0	456d5c71743f5c69	1	c1bf62e5dc5464b5	0	dc6011be7ea1ed54
1	1cf92c450042a75f	0	cc4b940eaf3140db	1	77bb612a7abf401f	0	c22d341e90545d98
0	ce6daf1f248bbd6d	0	dd22d0b3f9551ed6	0	574686c3f9e93898	0	2e52628f4a1282ce
0	f20c86d71944aab1	0	55133c9333808a2c	1	1aa825d8b817db4d	0	637959989f3021eb
0	976806641b26aae9	0	6a37d4531b7ed5f2	1	53c3e96d3b12fb46	1	528c7eb8481bc969
Parity hex [0:31] d96e7685							

74A.3 Output of the FEC (2112,2080) Encoder after scrambling with PN-2112 sequence

Table 74A–3 provides the data stream at the output of the FEC (2112,2080) encoder after the data is scrambled with the PN-2112 sequence as described in 74.7.4.4.1. The corresponding 2112 bit FEC block input to the scrambler is as describled in Table 74A–2. The example shows the stream of data in 64 bit format (33 64b symbols) generated from the output of the FEC (2112,2080) encoder after the PN-2112 scrambler.

Table 74A–3— FEC block scrambled with PN-2112 sequence

	64 bit stream hex [0:63]		64 bit stream hex [0:63]		64 bit stream hex [0:63]		64 bit stream hex [0:63]
	5f8af0c4083cd5b6		2b57dbab4e33e17d		b1354680bbe0bac1		4193315242cb81b6
	cc1ba1c9f7b7fe64		90838ec46d969470		a913b019c27f5689		7633f46ec762b6d9
	d1e410905587d0e4		f9b66a42540af04a		9909b64535a725b8		5005107c48b4a6aa
	f9d684ce4396f7a9		1b26e0a025c5d0fd		a4f2c62bc4611217		3638dc7504ea755e
	13fe232e3cdd2a84		5c5118ed10f6ffd8		5077fba23970c87d		52ec1279d355fc57
	48263899cc6652da		f746ec8b31bd6b40		006f5809784c86a7		989b9bd1aab70f0f
	57d99a87b9a9cc74		09ffb2754f318f33		ca8fce7654fb1e57		03a9c3acc87e6cdd
	b2574be1e93fcc9a		26c4fde242df5ca6		c645fd2bf2d3d525		5b25e6d7f9d78153
	bd49683cd87b293a						

74A.4 Output of the PN-2112 sequence generator

Table 74A–4 provides the PN-2112 sequence of length 2112 bits as described in 74.7.4.4.1.

Table 74A–4— PN-2112 sequence

	64 bit stream hex [0:63]		64 bit stream hex [0:63]		64 bit stream hex [0:63]		64 bit stream hex [0:63]
	ffffffffff555540		00015555555552aa		aafffff000015555		5ffffeaaaaeaaaaa
	aaaa7fffeffffe55		5540000755551555		5eaaabfffff80000		55550ffffeaaaa0a
	aabeaaabbfffffff		f8d55510000e5554		155558aaabbfffb4		0001555587ffefaa
	ab5aaabeaaad5fff		abfff51554000000		d555455501aaaabf		ff52001515540bff
	feaaad52aaffaaa5		0ffeabfff5f55414		004115555555872a		baeffe5b00141552
	0dffbeeaa11eabfe		aaad87ffbaffa4a5		541400a7f5410154		4aeaabfff8d58045
	455b54febfeaa7f8		abaaeae00bfeabff		2aad455501ffa540		0152aa0affebf554
	41555555527fffba		fff1aaabea000dea		abbeaae1555407ff		2d00105aab5bffeb
	f552a15501155fbf						

74A.5 Output of the FEC (2112,2080) Encoder to Support Rapid Block during the wake state in EEE (optional)

If the optional EEE function is supported (see Clause 78) then the reverse gearbox of the remote FEC encoder will be receiving unscrambled data. PCS sublayer will be encoding /I/ during the wake state, which produces the deterministic FEC frame.

Table 74A–5 provides the data stream at the output of the FEC (2112,2080) encoder after the data is scrambled with the PN-2112 sequence as described in 74.7.4.4.1. The example shows the stream of data in 64 bit format (33 64b symbols) generated from the output of the FEC (2112,2080) encoder after the PN-2112 scrambler.

74A.6 Output of the FEC (2112,2080) Encoder to Support Rapid Block during the refresh state in EEE (optional)

If the optional EEE capability is supported (see Clause 78) then the reverse gearbox of the remote FEC encoder will be receiving unscrambled data. PCS sublayer will be encoding /LI/ during the refresh state, which produces the deterministic FEC frame.

Table 74A–6 provides the data stream at the output of the FEC (2112,2080) encoder after the data is scrambled with the PN-2112 sequence as described in 74.7.4.4.1. The example shows the stream of data in 64 bit format (33 64b symbols) generated from the output of the FEC (2112,2080) encoder after the PN-2112 scrambler.

Table 74A–5—FEC block scrambled with PN-2112 sequence for the wake state

	64 bit stream hex [0:63]		**64 bit stream hex [0:63]**		**64 bit stream hex [0:63]**		**64 bit stream hex [0:63]**
	c3ffffffff555540		1e015555555552aa		a5fffff000015555		587ffeaaaaeaaaaa
	a96a7fffeffffe55		54a0000755551555		5e5aabfffff80000		552d0ffffeaaaa0a
	aa82aaabbfffffff		f8cb5510000e5554		155a58aaabbfffb4		0006d55587ffefaa
	ab596abeaaad5fff		abfe151554000000		d555b55501aaaabf		ff52781515540bff
	feaa9152aaffaaa5		0ffeb5fff5f55414		00411a555555872a		baeff9db00141552
	0dffbd2aa11eabfe		aaad861fbaffa4a5		54140057f5410154		4aeaab87f8d58045
	455b54c2bfeaa7f8		abaaeafe0bfeabff		2aad455a01ffa540		0152aa0d7febf554
	41555556927fffba		fff1aaaa0a000dea		abbeaae1a55407ff		2d00105ad35bffeb
	f552a155abb5586a						

Table 74A–6—FEC block scrambled with PN-2112 sequence for the refresh state

	64 bit stream hex [0:63]		**64 bit stream hex [0:63]**		**64 bit stream hex [0:63]**		**64 bit stream hex [0:63]**
	c3cf9f3e7c535958		1e19653594d654a6		a5f3e7c060c0d653		5879f2b29a8a6b29
	a96979f3f7cf9e94		d4a18301594d2535		9e5a6a7cf9f41830		352d6f3e7daca612
	9a829acb7e7cf9f3		e0cb4d2060cfd652		195a54b29bdf3e37		0606d3599fcf8f6b
	285969b8a6b56f9f		6a7e1496520c1830		b595b59482aca6a7		cf327875d4d70df3
	e69a9162ca3e29a3		03e6b5e7c5959597		064d1a594d65e7eb		39e9f9dd0c0c2532
	cc7cbd29a712b3ce		ca6c061e39f9a8bd		6474c05734c20758		52dacb8798140343
	494364c28f8a667b		ada6f2fe13cecb3e		a9ab495a0de79520		c0d1ac0d79e7ed64
	2194d6569179f3a2		cf916b2a0b830be6		b38eca21a59584f9		2118203ad33b3e68
	f35eb9658ed5d943						

Annex 75A

(informative)

Dual-rate receiver implementation

75A.1 Overview

The OLT receiver supports burst mode operation. If the OLT supports a single upstream data rate e.g., only 1 Gb/s or 10 Gb/s, the receiver can be designed to handle the designated upstream data rate and line code. However, if the OLT supports both 1 Gb/s and 10 Gb/s upstream data rates, the OLT receiver supports both data rates via TDMA.

From a topological point of view, the PMD has a single optical input, sensitive to 1260–1360 nm signal, and two corresponding derived electrical outputs: 1.25 GBd and 10.3125 GBd. Thus, at a certain point in the implementation it is necessary to introduce a signal split, where the location of such a signal split is an implementation choice. The incoming signal can be split in the optical domain and fed into two, independent photodetectors as shown in Figure 75A–1(a). Alternatively, the signal can be detected using a single photodetector as shown in Figure 75A–1(b) and then split in the electrical domain after the transimpedance amplifier (TIA) block.

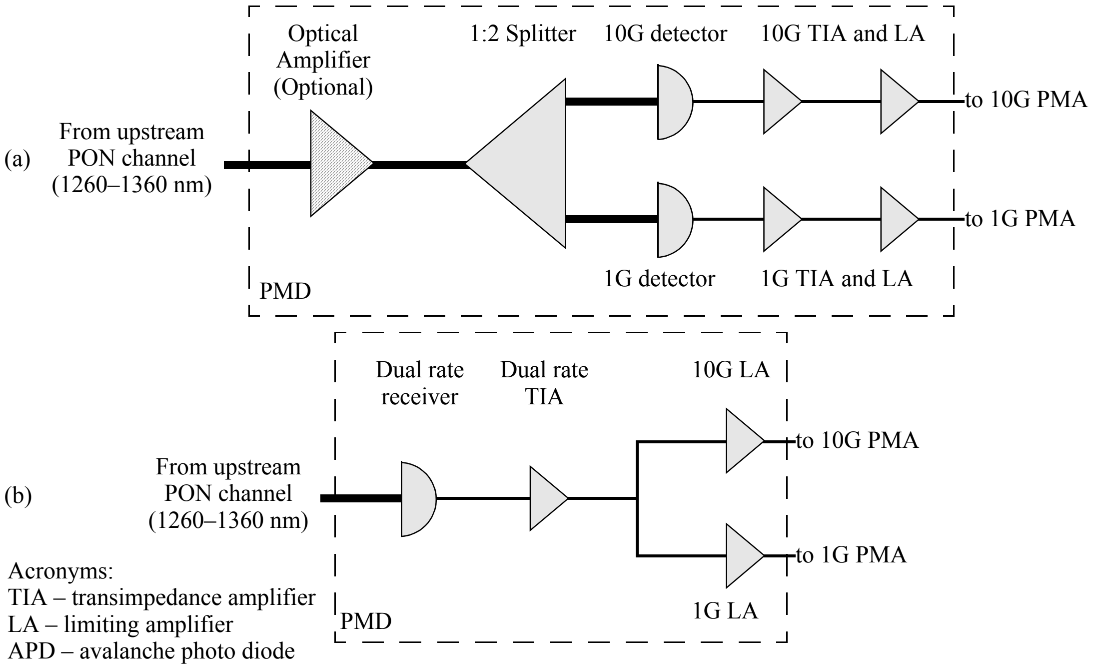


Figure 75A–1—Dual-rate PMD topologies with the split in the (a) optical domain, (b) electrical domain

When the incoming signal is split in the optical domain, it is possible to design each PMD channel specifically to match the signaling speed, offering optimum sensitivity for both 1 Gb/s and 10 Gb/s signals. However, the additional 1:2 optical splitter presented in Figure 75A–1(a) degrades the sensitivity of the

PMD by introducing additional loss and lowering the power of the optical signal. Such a sensitivity reduction may be tolerable in the PX10/PR10/PRX10 type PMDs, but the more stringent power budgets including PX20, PR20, PRX20, PX30, PR30, PRX30, PX40, PR40, and PRX40, may be very challenging or even impossible to implement with such an additional loss on the OLT receiver side.

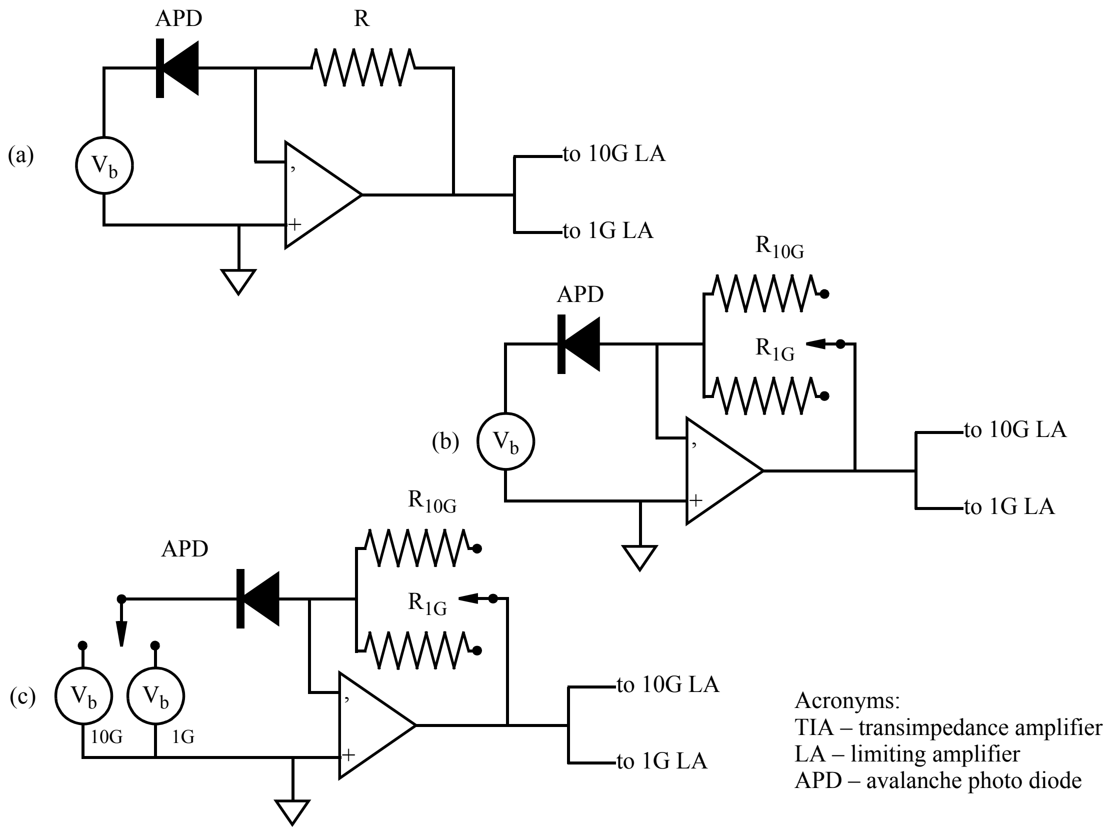
When the incoming signal is split in the electrical domain, only one photodetector and one TIA unit is used. The resulting optical sensitivity theoretically can be maintained without the need for optical amplification, reducing the complexity of the OLT receiver. However, the photodetector and TIA cope with both data rates in quick succession, switching between 1 Gb/s and 10 Gb/s bursts during the guardband. The key aspect here is that the detector-TIA bandwidth directly affects the sensitivity. If the circuit parameters of the detector-TIA can be rapidly adapted to the correct value, optimum sensitivity can be maintained. There are several implementation choices in this regard, three examples of which are shown in Figure 75A–2(a)–(c):

a) This implementation fixes the detector parameters at some predefined value, resulting in the reduction of the OLT receiver sensitivity by approximately 2 dB. However, it should be noted that this penalty can be divided in such a way that both 1 Gb/s and 10 Gb/s sensitivities are 1 dB lower than their ideal values.
b) This implementation fixes the avalanche photo diode (APD) bias, but switches the TIA transimpedance depending on the target signaling speed for the given incoming burst, resulting in the reduction of the receiver sensitivity by approximately 1 dB. The said sensitivity penalty could be subdivided to both data rates by setting the APD bias to a compromise value.
c) This implementation switches both the APD bias and the TIA transimpedance depending on the signaling speed of the incoming burst. This results in ideal performance at both 1 Gb/s and 10 Gb/s data rates. However, it is the most complex implementation in terms of the number of elements and the control complexity.

In the case of dynamic detector designs, it is necessary to determine the data rate of the incoming burst before adjusting the dynamic detector to match the target data rate.

In general, the PMD layer does not have prior knowledge of which data rate is used in the given burst; such information is available only to the MAC Client and is not available to the PMD sublayer. Therefore, some sort of data rate detector circuit should be utilized. One of the simple methods is based on measuring the spectral energy content of the received signal at frequencies well above 1.25 GHz (e.g., in the range of 2–10 GHz). The 1 Gb/s signal has very little energy in this frequency range, while the 10 Gb/s signal has ample energy there. Thus, the presence of 5 GHz energy indicates that a 10 Gb/s signal is incident.

In the dual-rate PMD topologies with the split in the electrical domain, the 10 Gb/s detector and TIA are implemented for receiving both 1 Gb/s and 10 Gb/s signals. Therefore, the damage threshold (max) of the 1/10 Gb/s dual-rate receiver should comply with the 10 Gb/s receiver specification in Table 75–6. Those values for 1000BASE–PX10–D in Table 60–5, for 1000BASE–PX20–D in Table 60–8, for 1000BASE–PX30–D in Table 60–11, and for 1000BASE–PX40–D in Table 60–13, and also those of 10/1GBASE–PRX–D1, 10/1GBASE–PRX–D2, 10/1GBASE–PRX–D3, and 10/1GBASE–PRX–D4 in Table 75–5 cannot be applied for dual-rate OLT receivers.



Acronyms:
TIA – transimpedance amplifier
LA – limiting amplifier
APD – avalanche photo diode

Figure 75A–2—Dual rate APD–TIA implementations: (a) static, (b) half–dynamic, (c) fully–dynamic

Annex 75B

(informative)

Illustrative channels and penalties for 10GBASE-PR and 10/1GBASE-PRX power budget classes

75B.1 Overview

Illustrative power budgets for PR10, PR20, PR30, and PR40 power budget classes are shown in Table 75B–1. Illustrative power budgets for PRX10, PRX20, PRX30, and PRX40 power budget classes are shown in Table 75B–2.

NOTE—The budgets include an allowance for –12 dB reflection at the receiver.

75B.2 Wavelength allocation

The wavelength allocation plan for 10G–EPON systems is specified below.

75B.2.1 Downstream wavelength allocation

The 1 Gb/s downstream transmission uses the 1480–1500 nm wavelength band, as specified in Clause 60. The 10 Gb/s downstream transmission uses the 1575–1580 nm wavelength band, as specified in Clause 75. An OLT supporting both downstream channels may multiplex the output of the two transmitters using a WDM coupler, while the optical filters at an ONU are tuned to receive only one downstream wavelength.

Table 75B–1—Illustrative 10GBASE–PR channel insertion loss and penalties (symmetric-rate, 10 Gb/s power budget classes)

Description[a]	PR10		PR20		PR30		PR40		Unit
	US	DS	US	DS	US	DS	US	DS	
Fiber Type[b]	IEC 60793–2 B1.1, B1.3 SMF ITU–T G.652, G.657 SMF								
Measurement wavelength for fiber	1270	1577[c]	1270	1577[c]	1270	1577[c]	1270	1577[c]	nm
Nominal distance[d]	10		20		20		20		km
Available power budget[e]	23	21.5	27	25.5	32	30.5	35	34.5	dB
Channel insertion loss (max)[f]	20		24		29		33		dB
Channel insertion loss (min)[g]	5		10		15		18		dB
Allocation for penalties[h]	3	2.5[i]	3	1.5	3	1.5	2	1.5	dB
Optical return loss of ODN (min)	20								dB

[a] US stands for Upstream, DS stands for Downstream.

[b] Other fiber types are acceptable if the resulting ODN meets channel insertion loss and dispersion requirements.

[c] The nominal transmit wavelength is 1577 nm.

[d] Nominal distance refers to the expected maximum distance a PMD is capable of achieving in a typical ODN. Numerous ODN implementation practices may result in longer or shorter distances being actually achievable in a user's network.

[e] The available power budget assumes a BER at the PMD service interface of 10^{-3}. The required BER of 10^{-12} at the PCS service interface is achieved by the FEC function of the PCS.

[f] The channel insertion loss is based on the cable attenuation at the target distance and nominal measurement wavelength. The channel insertion loss also includes the loss for connectors, splices and other passive components such as splitters.

[g] The power budgets for PR10, PR20, PR30, and PR40 power budget classes are such that a minimum insertion loss is assumed between transmitter and receiver. This minimum attenuation is required for PMD testing.

[h] The allocation for penalties is the difference between the available power budget and the channel insertion loss; insertion loss difference between nominal and worst case operating wavelength is considered a penalty. This allocation may be used to compensate for transmission related penalties. Further details are given in 75.7.2.

[i] The extra 1 dB of penalty here is to unify the downstream Tx and Rx specifications.

Table 75B–2—Illustrative 10/1GBASE–PRX channel insertion loss and penalties (asymmetric-rate, 10 Gb/s downstream, 1 Gb/s upstream power budget classes)

Description[a]	PRX10		PRX20		PRX30		PRX40		Unit
	US	DS	US	DS	US	DS	US	DS	
Fiber Type[b]	IEC 60793–2 B1.1, B1.3 SMF ITU–T G.652, G.657 SMF								
Measurement wavelength for fiber	1310	1577[c]	1310	1577[c]	1310	1577[c]	1310	1577[c]	nm
Nominal distance[d]	10		20		20		20		km
Available power budget	23	21.5[e]	26	25.5[e]	30.4	30.5[e]	34	34.5[e]	dB
Channel insertion loss (max)[f]	20		24		29		33		dB
Channel insertion loss (min)[g]	5		10		15		18		dB
Allocation for penalties[h]	3	2.5[i]	2	1.5	1.4	1.5	1	1.5	dB
Optical return loss of ODN (min)	20								dB

[a] US stands for Upstream, DS stands for Downstream.
[b] Other fiber types are acceptable if the resulting ODN meets channel insertion loss and dispersion requirements.
[c] The nominal transmit wavelength is 1577 nm.
[d] Nominal distance refers to the expected maximum distance a PMD is capable of achieving in a typical ODN. Numerous ODN implementation practices may result in longer or shorter distances being actually achievable in a user’s network.
[e] The available power budget assumes a BER at the PMD service interface of 10^{-3}. The required BER of 10^{-12} at the PCS service interface is achieved by the FEC function of the PCS.
[f] The channel insertion loss is based on the cable attenuation at the target distance and nominal measurement wavelength. The channel insertion loss also includes the loss for connectors, splices and other passive components such as splitters.
[g] The power budgets for PRX10, PRX20, PRX30, and PRX40 power budget classes are such that a minimum insertion loss is assumed between transmitter and receiver. This minimum attenuation is required for PMD testing.
[h] The allocation for penalties is the difference between the available power budget and the channel insertion loss; insertion loss difference between nominal and worst case operating wavelength is considered a penalty. This allocation may be used to compensate for transmission related penalties. Further details are given in 75.7.2.
[i] The extra 1 dB of penalty here is to unify the downstream Tx and Rx specifications.

75B.2.2 Upstream wavelength allocation

The 1 Gb/s upstream transmission uses the 1260 to 1360 nm wavelength band for 1000BASE–PX10–U, 1000BASE–PX20–U, 1000BASE–PX30–U, 10/1GBASE–PRX–U1, 10/1GBASE–PRX–U2, and 10/1GBASE–PRX–U3 compliant ONUs, and the 1290 to 1330 nm wavelength for 1000BASE–PX40–U and 10/1GBASE–PRX–U4 compliant ONUs, as specified in Clause 60. The 10 Gb/s upstream transmission uses the 1260 to 1280 nm wavelength band, as specified in Clause 75. The two wavelength bands overlap, thus WDM channel multiplexing cannot be used to separate the 1G upstream links operating in 1260 to 1360 nm wavelength band from 10G upstream links operating in 1260 to 1280 nm wavelength band.

An OLT supporting both upstream data rates uses TDMA techniques to avoid collisions between transmissions originating from different ONUs, resulting in a dual-rate burst–mode reception as discussed in 75.6.

Annex 75C

(informative)

Jitter at TP1 to TP8 for 10GBASE–PR and 10/1GBASE–PRX

75C.1 Overview

The jitter values at frequencies above 4 MHz are listed in Table 75C–1 for PR10, PR20, PR30, PR40, PRX10, PRX20, PRX30, and PRX40 downstream and in Table 75C–2 for PR10, PR20, PR30, and PR40 upstream. Those in Table 75C–3 relate to the jitter frequencies above 637 kHz for PRX10, PRX20, PRX30, and PRX40 upstream.

Table 75C–1—10GBASE–PR and 10/1GBASE–PRX downstream jitter budgets

Reference point	DJ (UI p–p)	RJ (UI p–p)	TJ (UI p–p)
TP1	0.09	0.14	0.23
TP2	0.19	0.20	0.39
TP3	0.24	0.20	0.44
TP4	0.42	0.34	0.76

NOTE 1—Jitter measurements should be performed at nominal operating conditions.
NOTE 2—BER conditions for TP1, TP2, and TP3 are 10^{-12}, for TP4 is 10^{-3}.
NOTE 3—All jitter values relate to high frequency (>4 MHz) jitter.
NOTE 4—0.1 UI of sinusoidal jitter stress is assumed at the receiver.
NOTE 5—The Gaussian jitter is assumed to be a weak function of BER.

The upstream jitter transfer function is defined Equation (75C-1). The jitter gain curve and the corresponding jitter gain values are shown in Figure 75C–1 where the jitter gain P and the jitter corner frequency f_c are specified in Table 75C–4 for PR10, PR20, PR30, and PR40, and in Table 75C–5 for PRX10, PRX20, PRX30, and PRX40, respectively.

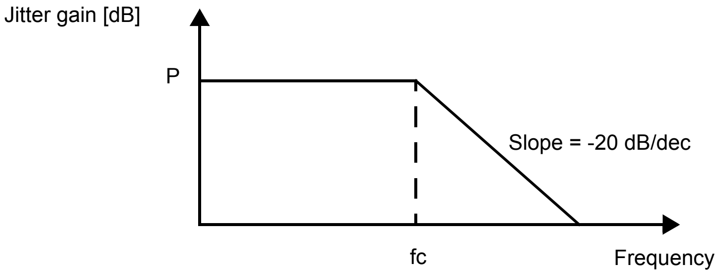


Figure 75C–1—Jitter gain curve values for 10GBASE–PR10/1GBASE-PRX

Table 75C–2—10GBASE–PR upstream jitter budgets

Reference point	DJ (UI p–p)	RJ (UI p–p)	TJ (UI p–p)
TP5	0.12	0.16	0.28
TP6	0.30	0.21	0.51
TP7	0.35	0.21	0.56
TP8	0.53	0.23	0.76

NOTE 1—Jitter measurements should be performed at nominal operating conditions.
NOTE 2—BER conditions for TP5, TP6, and TP7 are 10^{-12}, for TP8 is 10^{-3}.
NOTE 3—All jitter values relate to high frequency (>4 MHz) jitter.
NOTE 4—0.1 UI of sinusoidal jitter stress is assumed at the receiver.
NOTE 5—The Gaussian jitter is assumed to be a weak function of BER.

Table 75C–3—10/1GBASE–PRX upstream jitter budgets

Reference point	Total jitter	
	UI	ps
TP5	0.24	192
TP6	0.40	320
TP7	0.49	392
TP8	0.67	536

Table 75C–4—Jitter gain curve values for 10GBASE–PR

	Value	Unit
P	0.3	dB
f_c	8	MHz

Table 75C–5—Jitter gain curve values for 10/1GBASE–PRX

	Value	Unit
P	0.3	dB
f_c	1274	kHz

$$\text{Jitter Transfer} = 20\log_{10}\left[\frac{\text{Jitter on upstream signal (UI)}}{\text{Jitter on downstream signal (UI)}} \times \frac{\text{downstream\_line\_rate}}{\text{upstream\_line\_rate}}\right] \qquad \text{(75C-1)}$$

Annex 76A

(informative)

FEC Encoding example

76A.1 Introduction and rationale

This Annex provides an example of FEC encoding with RS (255,223) code. See 76.3.2.4.3 for the format of the FEC codeword.[44]

76A.2 64B/66B block input

Table 76A–1 provides an example of a 64B/66B block stream received at the input to the RS (255,223) encoder. The example shows a stream of 27 scrambled 64B/66B blocks generated from the output of the PCS layer when the link was sending out Idles.

The 66 bit blocks in the Table 76A–1 are transmitted from left to right within each row and from top to bottom between rows. The 64 bit payload portion of the 66 bit block is described as a series of hexadecimal octets—the left-most octet of each payload portion is transmitted first. Bits within each octet of the payload are transmitted in least-significant bit-first order (i.e., the right-most bit of each octet is transmitted first). Thus, the first ten bits transmitted are: 10 0100 0000 …

---

[44] The tables in the clause are available at http://www.ieee802.org/3/av/online_resources/.

Table 76A–1—Example 64B/66B block stream at the input to FEC encode[a]

Sync [0:1]	**64 bit payload** [7:0]-[15:8]-[23:16]-[31:24]-[39:32]-[47:40]-[55:48]-[63:56]
10	02-57-78-EE-77-CB-80-37
10	B5-5A-DC-1F-B6-59-F3-3A
10	7B-AA-D3-A1-FB-F0-3E-05
10	67-33-FF-71-41-48-8D-63
10	6B-DC-63-C3-90-00-60-1C
10	0E-C7-0D-73-0C-07-92-BE
10	3B-B1-CF-78-C3-D5-22-89
10	66-DF-89-9C-13-38-CB-DE
10	AD-2E-EE-2B-0F-7A-6C-40
10	31-BF-92-0A-48-29-5E-8C
10	E7-EE-3E-0F-63-0B-46-01
10	22-4A-39-2F-2D-09-A0-14
10	A1-73-B8-E4-AE-50-6B-D8
10	A2-B6-3A-8E-2E-FC-3A-96
10	83-FD-46-A7-3B-2A-26-AD
10	3B-06-88-7D-7E-85-B7-2A
10	38-9F-34-A2-00-42-E5-FA
10	33-D2-29-70-F5-8C-02-DB
10	EE-DD-86-54-5E-FD-02-F8
10	43-B4-2C-78-09-2A-BA-19
10	73-B6-F5-F8-24-D1-BD-B6
10	BB-44-0B-CD-9F-AA-78-6B
10	EA-62-61-C3-9F-97-1C-19
10	74-4A-46-F1-52-48-41-73
10	4F-30-61-EB-98-22-55-8D
10	AA-C8-3C-C9-CC-01-51-34
10	58-15-A4-1B-1D-E8-DB-B2

[a] 64 bit payload values are shown in hexadecimal notation.

76A.3 66 bit block input in binary format

Table 76A–2—Example 64B/66B block stream at the input to FEC encoder (binary)

Sync [0:1]	64 bit payload (transmitted from left to right)
10	0100 0000 1110 1010 0001 1110 0111 0111 1110 1110 1101 0011 0000 0001 1110 1100
10	1010 1101 0101 1010 0011 1011 1111 1000 0110 1101 1001 1010 1100 1111 0101 1100
10	1101 1110 0101 0101 1100 1011 1000 0101 1101 1111 0000 1111 0111 1100 1010 0000
10	1110 0110 1100 1100 1111 1111 1000 1110 1000 0010 0001 0010 1011 0001 1100 0110
10	1101 0110 0011 1011 1100 0110 1100 0011 0000 1001 0000 0000 0000 0110 0011 1000
10	0111 0000 1110 0011 1011 0000 1100 1110 0011 0000 1110 0000 0100 1001 0111 1101
10	1101 1100 1000 1101 1111 0011 0001 1110 1100 0011 1010 1011 0100 0100 1001 0001
10	0110 0110 1111 1011 1001 0001 0011 1001 1100 1000 0001 1100 1101 0011 0111 1011
10	1011 0101 0111 0100 0111 0111 1101 0100 1111 0000 0101 1110 0011 0110 0000 0010
10	1000 1100 1111 1101 0100 1001 0101 0000 0001 0010 1001 0100 0111 1010 0011 0001
10	1110 0111 0111 0111 0111 1100 1111 0000 1100 0110 1101 0000 0110 0010 1000 0000
10	0100 0100 0101 0010 1001 1100 1111 0100 1011 0100 1001 0000 0000 0101 0010 1000
10	1000 0101 1100 1110 0001 1101 0010 0111 0111 0101 0000 1010 1101 0110 0001 1011
10	0100 0101 0110 1101 0101 1100 0111 0001 0111 0100 0011 1111 0101 1100 0110 1001
10	1100 0001 1011 1111 0110 0010 1110 0101 1101 1100 0101 0100 0110 0100 1011 0101
10	1101 1100 0110 0000 0001 0001 1011 1110 0111 1110 1010 0001 1110 1101 0101 0100
10	0001 1100 1111 1001 0010 1100 0100 0101 0000 0000 0100 0010 1010 0111 0101 1111
10	1100 1100 0100 1011 1001 0100 0000 1110 1010 1111 0011 0001 0100 0000 1101 1011
10	0111 0111 1011 1011 0110 0001 0010 1010 0111 1010 1011 1111 0100 0000 0001 1111
10	1100 0010 0010 1101 0011 0100 0001 1110 1001 0000 0101 0100 0101 1101 1001 1000
10	1100 1110 0110 1101 1010 1111 0001 1111 0010 0100 1000 1011 1011 1101 0110 1101
10	1101 1101 0010 0010 1101 0000 1011 0011 1111 1001 0101 0101 0001 1110 1101 0110
10	0101 0111 0100 0110 1000 0110 1100 0011 1111 1001 1110 1001 0011 1000 1001 1000
10	0010 1110 0101 0010 0110 0010 1000 1111 0100 1010 0001 0010 1000 0010 1100 1110
10	1111 0010 0000 1100 1000 0110 1101 0111 0001 1001 0100 0100 1010 1010 1011 0001
10	0101 0101 0001 0011 0011 1100 1001 0011 0011 0011 1000 0000 1000 1010 0010 1100
10	0001 1010 1010 1000 0010 0101 1101 1000 1011 1000 0001 0111 1101 1011 0100 1101

76A.4 RS(255,223) input buffer in Binary Format

The input buffer to the RS function begins with 29 ‘0’ bits followed by the 27 65 bit inputs as illustrated in Figure 76–12 and Figure 76–13.

Table 76A–3—Input buffer to the FEC encoder (binary)

```
0000 0000 0000 0000 0000 0000 0000 0001 0000 0011 1010 1000 0111 1001 1101 1111
1011 1011 0100 1100 0000 0111 1011 0001 0101 1010 1011 0100 0111 0111 1111 0000
1101 1011 0011 0101 1001 1110 1011 1000 1101 1110 0101 0101 1100 1011 1000 0101
1101 1111 0000 1111 0111 1100 1010 0000 0111 0011 0110 0110 0111 1111 1100 0111
0100 0001 0000 1001 0101 1000 1110 0011 0011 0101 1000 1110 1111 0001 1011 0000
1100 0010 0100 0000 0000 0001 1000 1110 0000 1110 0001 1100 0111 0110 0001 1001
1100 0110 0001 1100 0000 1001 0010 1111 1010 1101 1100 1000 1101 1111 0011 0001
1110 1100 0011 1010 1011 0100 0100 1001 0001 0011 0011 0111 1101 1100 1000 1001
1100 1110 0100 0000 1110 0110 1001 1011 1101 1010 1101 0101 1101 0001 1101 1111
0101 0011 1100 0001 0111 1000 1101 1000 0000 1001 0001 1001 1111 1010 1001 0010
1010 0000 0010 0101 0010 1000 1111 0100 0110 0010 1110 0111 0111 0111 0111 1100
1111 0000 1100 0110 1101 0000 0110 0010 1000 0000 0010 0010 0010 1001 0100 1110
0111 1010 0101 1010 0100 1000 0000 0010 1001 0100 0010 0001 0111 0011 1000 0111
0100 1001 1101 1101 0100 0010 1011 0101 1000 0110 1100 1000 1010 1101 1010 1011
1000 1110 0010 1110 1000 0111 1110 1011 1000 1101 0010 1100 0001 1011 1111 0110
0010 1110 0101 1101 1100 0101 0100 0110 0100 1011 0101 0110 1110 0011 0000 0000
1000 1101 1111 0011 1111 0101 0000 1111 0110 1010 1010 0000 0111 0011 1110 0100
1011 0001 0001 0100 0000 0001 0000 1010 1001 1101 0111 1101 1001 1000 1001 0111
0010 1000 0001 1101 0101 1110 0110 0010 1000 0001 1011 0110 0111 0111 1011 1011
0110 0001 0010 1010 0111 1010 1011 1111 0100 0000 0001 1111 0110 0001 0001 0110
1001 1010 0000 1111 0100 1000 0010 1010 0010 1110 1100 1100 0011 0011 1001 1011
0110 1011 1100 0111 1100 1001 0010 0010 1110 1111 0101 1011 0101 1011 1010 0100
0101 1010 0001 0110 0111 1111 0010 1010 1010 0011 1101 1010 1100 0101 0111 0100
0110 1000 0110 1100 0011 1111 1001 1110 1001 0011 1000 1001 1000 0001 0111 0010
1001 0011 0001 0100 0111 1010 0101 0000 1001 0100 0001 0110 0111 0011 1100 1000
0011 0010 0001 1011 0101 1100 0110 0101 0001 0010 1010 1010 1100 0100 1010 1010
0010 0110 0111 1001 0010 0110 0110 0111 0000 0001 0001 0100 0101 1000 0001 1010
1010 1000 0010 0101 1101 1000 1011 1000 0001 0111 1101 1011 0100 1101
```

76A.5 RS(255,223) input buffer

Table 76A–4 illustrates the 223 octets of the input buffer constructed by the RS(255,223) encoder prior to computation of the parity octets. The octets of the buffer are formed from the input 66 bit blocks according to the procedure depicted in Figure 76–12 and Figure 76–13.

Note that in Figure 76–12 and Figure 76–13 the right-most bit of each formed octet is the most significant, whereas Table 76A–4 lists the octets in the more typical notation i.e., the least significant bit appears on the right.

Table 76A–4—223 octet input buffer within FEC encoder before computation of parity octets[a]

	Dn	Dn -1	Dn -2	Dn -3	Dn -4	Dn -5	Dn -6	Dn -7	Dn -8	Dn -9	Dn -10	Dn -11	Dn -12	Dn -13	Dn -14	Dn -15
n= 222	00	00	00	80	C0	15	9E	FB	DD	32	E0	8D	5A	2D	EE	0F
n= 206	DB	AC	79	1D	7B	AA	D3	A1	FB	F0	3E	05	CE	66	FE	E3
n= 190	82	90	1A	C7	AC	71	8F	0D	43	02	80	71	70	38	6E	98
n= 174	63	38	90	F4	B5	13	FB	8C	37	5C	2D	92	C8	EC	3B	91
n= 158	73	02	67	D9	5B	AB	8B	FB	CA	83	1E	1B	90	98	5F	49
n= 142	05	A4	14	2F	46	E7	EE	3E	0F	63	0B	46	01	44	94	72
n= 126	5E	5A	12	40	29	84	CE	E1	92	BB	42	AD	61	13	B5	D5
n= 110	71	74	E1	D7	B1	34	D8	6F	74	BA	A3	62	D2	6A	C7	00
n= 94	B1	CF	AF	F0	56	05	CE	27	8D	28	80	50	B9	BE	19	E9
n= 78	14	B8	7A	46	81	6D	EE	DD	86	54	5E	FD	02	F8	86	68
n= 62	59	F0	12	54	74	33	CC	D9	D6	E3	93	44	F7	DA	DA	25
n= 46	5A	68	FE	54	C5	5B	A3	2E	16	36	FC	79	C9	91	81	4E
n= 30	C9	28	5E	0A	29	68	CE	13	4C	D8	3A	A6	48	55	23	55
n= 14	64	9E	64	E6	80	28	1A	58	15	A4	1B	1D	E8	DB	B2	

[a] Dn octet values are shown in hexadecimal notation.

76A.6 Parity symbol output

Table 76A–5 illustrates the 32 parity octets computed by the RS(255,223) encoder for the inputs given above.

Note that in Figure 76–12 and Figure 76–13 the right-most bit of each parity octet is the most significant, whereas Table 76A–5 lists the octets in the more typical notation i.e., the least significant bit is on the right.

Table 76A–5—32 parity octets computed by FEC encoder[a]

	Pn	Pn -1	Pn -2	Pn -3	Pn -4	Pn -5	Pn -6	Pn -7	Pn -8	Pn -9	Pn -10	Pn -11	Pn -12	Pn -13	Pn -14	Pn -15
n= 31	7E	62	35	FB	DB	9F	5E	8E	FD	B2	81	3E	F9	1D	9B	1A
n= 15	32	1E	70	CF	DD	C2	2C	54	43	F1	00	78	3C	4F	BD	F4

[a] Pn values are shown in hexadecimal notation.

76A.7 Parity symbols in binary format

As with the input buffer, this is written with least significant bit left most to correspond with Table 76A–6.

Table 76A–6—32 parity octets computed by FEC encoder (binary)

```
0111 1110 0100 0110 1010 1100 1101 1111 1101 1011 1111 1001 0111 1010 0111 0001
1011 1111 0100 1101 1000 0001 0111 1100 1001 1111 1011 1000 1101 1001 0101 1000
0100 1100 0111 1000 0000 1110 1111 0011 1011 1011 0100 0011 0011 0100 0010 1010
1100 0010 1000 1111 0000 0000 0001 1110 0011 1100 1111 0010 1011 1101 0010 1111
```

76A.8 64B/66B Parity Blocks for Transmit

Table 76A–7 illustrates the 64B/66B blocks carrying parity that are generated by the RS (255,223) encoder for the input blocks in Table 76A–6 above. The RS (255,223) encoder inserts the parity blocks into the transmission stream to the gearbox subsequent to its transmission of the corresponding input 66 bit blocks (as described in 76.3.2.4).

The 66 bit blocks in the Table 76A–7 are transmitted from left to right within each row and from top to bottom between rows. The 64 bit payload portion of the 66 bit block is described as a series of hexadecimal octets—the left-most octet of each payload portion is transmitted first. Bits within each octet of the payload are transmitted in least-significant bit-first order (i.e., the right-most bit of each octet is transmitted first).

Thus, the first 18 bits of the parity blocks transmitted are: 00 0111 1110 0100 0110 …

Table 76A–7—64B/66B blocks carrying 32 parity octets generated by FEC encoder

Sync [0:1]	64 bit payload [7:0]-[15:8]-[23:16]-[31:24]-[39:32]-[47:40]-[55:48]-[63:56]
00	7E-62-35-FB-DB-9F-5E-8E
11	FD-B2-81-3E-F9-1D-9B-1A
11	32-1E-70-CF-DD-C2-2C-54
00	43-F1-00-78-3C-4F-BD-F4

76A.9 Parity 66 bit blocks in binary format

Table 76A-8—64B/66B blocks carrying 32 parity octets generated by FEC encoder (binary)

Sync [0:1]	64 bit payload (transmitted from left to right)
00	0111 1110 0100 0110 1010 1100 1101 1111 1101 1011 1111 1001 0111 1010 0111 0001
11	1011 1111 0100 1101 1000 0001 0111 1100 1001 1111 1011 1000 1101 1001 0101 1000
11	0100 1100 0111 1000 0000 1110 1111 0011 1011 1011 0100 0011 0011 0100 0010 1010
00	1100 0010 1000 1111 0000 0000 0001 1110 0011 1100 1111 0010 1011 1101 0010 1111