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Recommendation

ITU-T G.9802.2 (07/2023)

SERIES G: Transmission systems and media, digital systems and networks

Access networks – Optical line systems for local and access networks

Wavelength division multiplexed passive optical networks (WDM PON): physical media dependent (PMD) layer and transmission convergence (TC) layer specifications

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Recommendation ITU-T G.9802.2

Wavelength division multiplexed passive optical networks (WDM PON): physical media dependent (PMD) layer and transmission convergence (TC) layer specifications

Summary

Recommendation ITU-T G.9802.2 describes a wavelength routed optical distribution network (WR-ODN) based wavelength division multiplexed passive optical network (WDM PON).

This Recommendation, as part of the multiple-wavelength passive optical network (MW-PON) ITU-T G.9802 series Recommendations, specifies a PON system utilizing a wavelength multiplexer in the optical distribution network (ODN).

The specifications of both the physical media dependent (PMD) and transmission convergence (TC) layers of WR-ODN based WDM PON are captured in this Recommendation.

The PMD layer specification includes aspects such as the reference logical architecture, wavelength plan, optical path loss, transmitter and receiver specifications, compatible ODN, etc.

The TC layer specification includes the details of the forward error correction (FEC) code, implementation methods of the management channel, management functions, a set of processes and messages, etc. to provide similar operation experience as legacy PON systems, e.g., silent start and capability to map a local physical layer operation, administration and maintenance (PLOAM) channel.

History*

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PMD, TC, WRP.

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Wavelength division multiplexed passive optical networks (WDM PON): physical media dependent (PMD) layer and transmission convergence (TC) layer specifications

1 Scope

This Recommendation, as part of the multiple-wavelength passive optical network (MW-PON) ITU-T G.9802 series Recommendation, specifies a PON system utilizing a wavelength multiplexer in the optical distribution network (ODN).

The specifications of both the physical media dependent (PMD) and transmission convergence (TC) layers of WR-ODN based WDM PON are captured in this recommendation.

The PMD layer specification includes aspects such as the reference logical architecture, wavelength plan, optical path loss, transmitter and receiver specifications, compatible ODN, etc.

The TC layer specification includes the details of the forward error correction (FEC) code, implementation methods of the management channel, management functions, a set of processes and messages, etc. to provide similar operation experience as legacy PON systems, e.g., silent start and capability to map a local physical layer operation, administration and maintenance (PLOAM) channel.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.657] Recommendation ITU-T G.657 (2016), *Characteristics of a bending-loss insensitive single-mode optical fibre and cable*.

[ITU-T G.694.1] Recommendation ITU-T G.694.1 (2020), *Spectral grids for WDM applications: DWDM frequency grid*.

[ITU-T G.825] Recommendation ITU-T G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)*.

[ITU-T G.985] Recommendation ITU-T G.985 (2003), *100 Mbit/s point-to-point Ethernet based optical access system*.

[ITU-T G.987] Recommendation ITU-T G.987 (2012), *10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms*.

[ITU-T G.987.3] Recommendation ITU-T G.987.3 (2014), *10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification*.

[ITU-T G.988] Recommendation ITU-T G.988 (2022), *ONU management and control interface (OMCI) specification*.

[ITU-T G.989.2] Recommendation ITU-T G.989.2 (2019), *40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification*.

[ITU-T G.989.3] Recommendation ITU-T G.989.3 (2021), *40-Gigabit-capable passive optical networks 2 (NG-PON2): Transmission convergence layer specification*.

[ITU-T G.9802] Recommendation ITU-T G.9802 (2015), *Multiple-wavelength passive optical networks (MW-PONs)*.

[ITU-T G.9804.2] Recommendation ITU-T G.9804.2 (2021), *Higher speed passive optical networks – Common transmission convergence layer specification*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 channel pair: A set of one downstream wavelength channel and one upstream wavelength channel that provides connectivity between an OLT and one ONU.

3.1.2 optical distribution network (ODN) [b-ITU-T G.989]: A point-to-multipoint optical fibre infrastructure. A simple ODN is entirely passive and is represented by a single-rooted point-to-multipoint tree of optical fibres with splitters, combiners, filters, and possibly other passive optical components. A composite ODN consists of two or more passive segments interconnected by active devices, each of the segments being either an optical trunk line segment or an optical distribution segment. A passive optical distribution segment is a simple ODN itself. Two ODNs with distinct roots can share a common subtree.

3.1.3 optical distribution segment (ODS) [b-ITU-T G.989]: A simple ODN, that is, a point-to-multipoint optical fibre infrastructure that is entirely passive and is represented by a single-rooted tree of optical fibres with splitters, combiners, filters and possibly other passive optical components.

3.1.4 optical line termination (OLT) [ITU-T G.987]: A network element in an ODN-based optical access network that terminates the root of at least one ODN and provides an OAN SNI.

3.1.5 optical network unit (ONU) [ITU-T G.987]: A network element in an ODN-based optical access network that terminates a leaf of the ODN and provides an OAN UNI.

3.1.6 passive optical network (PON) system [ITU-T G.987]: A combination of network elements in an ODN based optical access network that includes an OLT and multiple ONUs and implements a particular coordinated suite of physical medium dependent layer, transmission convergence layer, and management protocols.

3.1.7 wavelength routed ODN (WR-ODN) [b-ITU-T G.9802.1]: An optical distribution network where the branching node (splitter) is wavelength selective and the port to which an optical network unit (ONU) is connected determines the channel pair (CP) to be used for communications.

3.1.7 spectral excursion [b-ITU-T G.989]: For a transmitter in a stationary wavelength channel state, the absolute difference between the nominal central frequency of the channel and the −15 dB points of the transmitter spectrum furthest from the nominal central frequency measured at the transmitter output at the appropriate reference point (S/R-CG for downstream direction, R/S for upstream direction).

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 auxiliary management and control channel (AMCC): A management and control channel between optical line terminal (OLT) and optical network unit (ONU), which doesn't require the termination of the data channel.

3.2.2 OLT CT: Each of the physical ports in the optical line termination (OLT) that connects to/from a fibre of the optical distribution network (ODN) is named as channel termination (CT). In the context of wavelength router-based transmission it is interpreted as terminating a channel pair (CP).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ACK	Acknowledgment
ASCII	American Standard Code for Information Interchange
BER	Bit Error Ratio
BIP	Bit-Interleaved Parity
CG	Channel group (Multiple Channel Pairs)
CP	Channel Pair
CPRI	Common Public Radio Interface
CT	Channel Termination
EMS	Element Management System
ER	Extinction Ratio
FEC	Forward Error Correction
FFS	For Further Study
FS	Framing Sublayer
HEC	Hybrid Error Correction
ID	Identifier
LODS	Loss of Downstream Synchronization
LSB	Least Significant Bit
MAC	Media Access Control
MIB	Management Information Base
MIC	Message Integrity Check
MSB	Most Significant Bit
MSK	Master Session Key
MW	Multiple Wavelength
NACK	Negative Acknowledgment
NRZ	Non-Return to Zero
OAM	Operation, Administration and Maintenance
OAN	Optical Access Network
OC	Operation Control
ODN	Optical Distribution Network

ODS	Optical Distribution Segment
OLT	Optical Line Termination
OMCC	ONU Management and Control Channel
OMCI	ONU Management and Control Interface
ONU	Optical Network Unit
OPP	Optical Path Penalty
OPS	Optical (Achromatic) Power Splitter
OOB	Out-of-Band
OOB-PSD	Out-of-Band Power Spectral Density
OOC	Out-of-Channel
OOC-PSD	Out-of-Channel Power Spectral Density
ORL	Optical Return Loss
OSS	Operations Support System
PCS	Physical Coding Sublayer
PHY	Physical Interface
PLOAM	Physical Layer Operation, Administration and Maintenance
PM	Performance Monitoring
PMD	Physical Media Dependent
PON	Passive Optical Network
PSB	Physical Synchronization Block
PSD	Power Spectral Density
R/S	Receive/Send Reference Point at ONU Side
Rx	Receiver
SFC	Superframe Counter
SK	Session Key
SMSR	Side Mode Suppression Ratio
SN	Serial Number
SNI	Service Node Interface
S/R	Send/Receive Reference Point at OLT Side
S/R-CP	S/R for Channel Pair
S/R-CG	S/R for Channel Group
TC	Transmission Convergence
TWDM	Time and Wavelength Division Multiplexing
Tx	Transmitter
UI	Unit Interval
UNI	User Network Interface
VSSN	Vendor-Specific Serial Number

WDM	Wavelength Division Multiplexing
WNE-PSD	When Not Enabled Power Spectral Density
WR	Wavelength Router
WRP	Wavelength Routed PON
WR-ODN	Wavelength Routed ODN (as opposed to OPS-ODN containing achromatic power splitters)
XGEM	10-Gigabit-capable PON Encapsulation Method
XML	Extensible Markup Language

5 Conventions

This Recommendation uses conventions defined in [ITU-T G.987].

6 Overview of the WDM PON PMD and TC Recommendation

This Recommendation consists of PMD layer specifications and TC layer specifications for WR-ODN based WDM PON. These aspects of WDM PON are not considered in dedicated standalone Recommendations and are instead captured in annexes of the present Recommendation.

The PMD layer of WR-ODN based WDM PON is based on [ITU-T G.989.2] and is specified in Annex A.

The major changes to the PMD layer of WR-ODN based WDM PON relative to [ITU-T G.989.2] are: (a) support of new symmetric 10G class and the addition of symmetric 25G class, (b) specific PMD parameters (e.g., OPL classes, operating channels) of 10G class and 25G class for WR-ODN based WDM PON, (c) the addition of mask of transmitter eye diagram, X/S tolerance and jitter performance of 25G class.

The TC layer of WR-ODN based WDM PON is based on [ITU-T G.989.3] and is specified in Annex B.

The major changes to the TC layer of WR-ODN based WDM PON relative to [ITU-T G.989.3] are: (a) identifiers common for WR-ODN based WDM PON, (b) simple channel functionality (e.g., no channel handover) and mechanism (e.g., WDM PON ONU activation process), (c) management channel and interface.

To aid the implementers of the management channel, several descriptions of different management channel implementations are provided in Annex E and Annex F.

The layered structure of WR-ODN based WDM PON system is described in Table 6-1. The protocol reference model is divided into the transmission convergence (TC) and physical medium dependent (PMD) layers, which are specified in this Recommendation.

Table 6-1 – Layered structure of WR-ODN based WDM PON

<table>
<tr><th colspan="2">Path layer</th><th></th><th></th></tr>
<tr><td rowspan="3">Transmission media layer</td><td rowspan="2">WR-ODN based
WDM PON transmission convergence (TC) layer</td><td>Adaptation</td><td>Encapsulation</td></tr>
<tr><td>PON transmission</td><td>Service transporting
Privacy and security
Synchronization
Management capabilities</td></tr>
<tr><td colspan="2">Physical medium dependent (PMD) layer</td><td>Electrical/optical adaptation
Wavelength division multiplexing
Fibre connection</td></tr>
</table>

Annex A

Physical media dependent layer specification

(This annex forms an integral part of this Recommendation.)

This annex describes the physical media dependent layer specification of WR-ODN based WDM PON.

A.1 Physical media dependent layer overview

This Annex includes comprehensive physical media dependent (PMD) layer specifications of WR-ODN based WDM PON.

The structure and text of PtP WDM PON PMD from [ITU-T G.989.2] are partly retained. The general characteristics of PMD layer such as reference architecture, operating wavelength channels, line rate options, OPL classes and optical interface parameters are captured in this annex.

A.1.1 Physical media and transmission method

A.1.1.1 Transmission medium

This Recommendation is based on the fibre described in [ITU-T G.652]. Other fibre types compatible with this Recommendation, e.g., [ITU-T G.657], may be used for indoor cabling and/or drop section.

A.1.1.2 Transmission direction

Signals are transmitted both upstream and downstream through the optical transmission medium of the ODN.

A.1.1.3 Transmission method

Bidirectional transmission is accomplished by use of a wavelength division multiplexing (WDM) technique on a single fibre.

A.2 Reference configuration

The functional reference architecture for a WR-ODN based WDM PON is illustrated in Figure A.1.

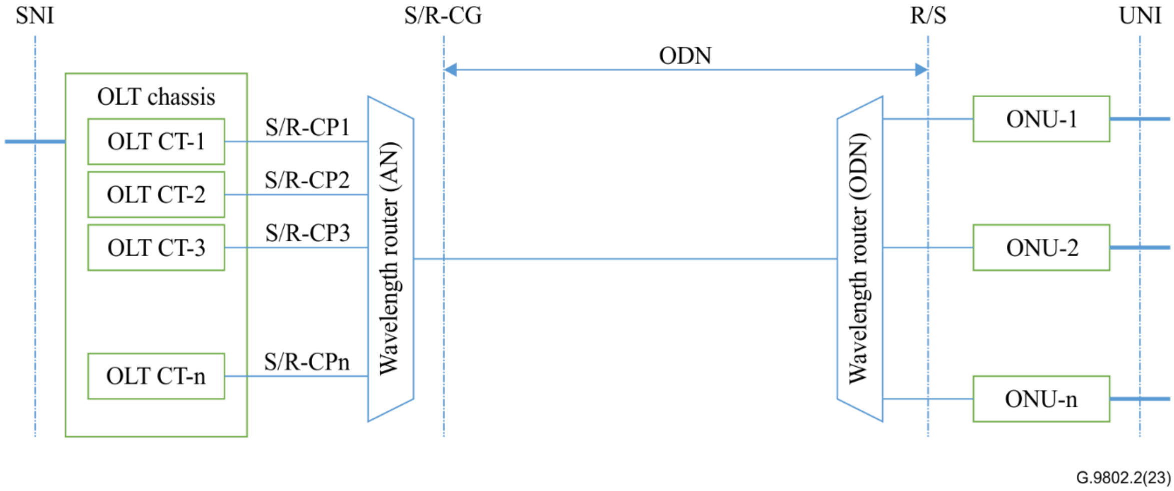


Figure A.1 – Functional reference architecture and reference points for WR-ODN based WDM PON

The following reference points from Figure A.1 are defined below:

– S: The sending interface to the network

– R: The receiving interface from the network

– S/R (S/R-CG or S/R-CP), R/S: The S/R-CG and S/R-CP points should be bidirectional mode. Combination of points S and R existing simultaneously in a single fibre, when operating in bidirectional mode. The S/R point is referenced to the OLT side, the R/S point is referenced to the ONU side.

The two directions for optical transmission in the ODN are defined as follows:

– Downstream direction for signals travelling from the OLT to the ONU(s); and

– Upstream direction for signals travelling from the ONU(s) to the OLT.

Transmission in downstream and upstream directions takes place on the same fibre and components (duplex/diplex configuration).

The primary method of optical parameter specification is in reference to the S/R point for channel group (S/R-CG reference point of Figure A.1 for the individual wavelength channels). This method is used in the PMD tables appearing in clause A.3.7. An alternative informative optical parameter specification method is in reference to the S/R point for channel pair (S/R-CP reference point of Figure A.1). The alternative method is applicable in the situations when the primary reference point, S/R-CG, is not practical or not accessible for performing measurements or it is desirable to provide a simple sensitivity specification to an OLT transceiver vendor.

Each ONU in Figure A.1 is equipped with a tunable transmitter. The tunable ONU transmitter must be able to adjust to the wavelength channels within the bands specified in Table A.3.

This Recommendation specifies 12 and 20 wavelength channel pairs (CPs) for wavelength routed PON (WRP) (the frequency plan for 40 wavelength CPs is for further study). The number of wavelength channels supported by a given equipment implementation or network instance is not specified; however, the optical parameter tables should be consulted for the specific assumptions made for the parameters given.

The architecture can be extended to support multiple OLTs on a common ODN for other purposes such as pay-as-you-grow deployment and spectral flexibility.

A.2.1 Physical grouping of logical functions

The logical functions identified in Figure A.1 for WRP could be considered to be individual physical items, or fully integrated into a single device.

A.2.2 Optical path loss classes

See Table A.4 for recommended classes for optical path loss.

A.2.3 Categories for fibre differential distance

Fibre distance classes are specified in Table A.1.

Table A.1 – ODN fibre distance classes

Fibre distance class	Minimum fibre distance (km)	Maximum fibre distance (km)
DD10	0	10
DD20	0	20

A.3 PMD layer requirements

All parameters are specified as follows, and are in accordance with Table A.2 to Table A.9. The WDM channel frequency plan is specified in Table A.3, WDM PON line rate options and optical parameter are specified in Table A.2, ODN optical path loss classes (ODN classes) are specified in Table A.4, optical interface parameters of 10G and 25G class are specified in Table A.6 to Table A.9.

All parameter values specified are worst-case values, to be met over the range of standard operating conditions (i.e., temperature and humidity), and they include ageing effects. The parameters are specified relative to an optical section design objective of a bit error ratio (BER) not worse than the values specified in Table A.6 to Table A.9, for the extreme case of optical path attenuation and dispersion conditions.

A.3.1 Wavelength allocation

For the downstream direction, the WRP wavelength band is 1529.553-1544.526 nm; for upstream direction, the WDM PON wavelength band is 1550.116-1565.496 nm. These wavelength bands align with those defined in [b-ITU-T G.698.4] to maximize the potential to use common components.

A.3.2 Nominal line rate and clock accuracy

Parameters to be specified are categorized by downstream and upstream nominal line rates and downstream/upstream rate combinations as shown in Table A.2. Each WDM channel in the channel group on a WDM PON can use any of the line rate options specified in Table A.2.

Table A.2 – Relation between WDM PON line rate options and optical parameter tables

Line rate class	Nominal line rate, symmetric downstream/upstream (Gbit/s)	Supported user network interface (UNI)	Optical parameter table, downstream/upstream
10G	9.8304, 9.95328 10.1376, 10.3125	CPRI option 7 OC-192 CPRI option 8 10G Ethernet	Table A.6/Table A.8
25G	24.33024 25.78125	CPRI option 10 25G Ethernet	Table A.7/Table A.9

When the OLT and the end office (the facility of the OLT and synchronization source) are in their normal operating state, the OLT is typically traceable to a Stratum-1 reference (accuracy of 1×10^{-11}). When the OLT is in its free running mode, the accuracy of the downstream signal is at least that of a Stratum-4 clock (3.2×10^{-5}). OLTs intended for timing-critical applications such as mobile backhaul require Stratum-3 quality in free-running mode.

NOTE – The OLT may derive its timing from either a dedicated timing signal source or from a synchronous data interface (line timing). A packet-based timing source may also be used.

A.3.3 Line code

Line coding for WRP is determined by the specific application.

For 10G/25G Ethernet, the line code is scrambled non-return to zero (NRZ).

A.3.4 Operating wavelength channels

The operating wavelength bands for WRP are specified in clause A.3.1.

The WDM channel frequency plan is described in Table A.3.

Table A.3 – WDM channel frequency plan

Channel	Downstream Central frequency (THz)	Downstream Central Wavelength (nm)	Upstream Central frequency (THz)	Upstream Central Wavelength (nm)
1	194.1	1544.526	191.5	1565.496
2	194.2	1543.730	191.6	1564.679
3	194.3	1542.936	191.7	1563.863
4	194.4	1542.142	191.8	1563.047
5	194.5	1541.349	191.9	1562.233
6	194.6	1540.557	192.0	1561.419
7	194.7	1539.766	192.1	1560.606
8	194.8	1538.976	192.2	1559.794
9	194.9	1538.186	192.3	1558.983
10	195.0	1537.397	192.4	1558.173
11	195.1	1536.609	192.5	1557.363
12	195.2	1535.822	192.6	1556.555
13	195.3	1535.036	192.7	1555.747
14	195.4	1534.250	192.8	1554.940
15	195.5	1533.465	192.9	1554.134
16	195.6	1532.681	193.0	1553.329
17	195.7	1531.898	193.1	1552.524
18	195.8	1531.116	193.2	1551.721
19	195.9	1530.334	193.3	1550.918
20	196.0	1529.553	193.4	1550.116
21	FFS	FFS	FFS	FFS
22	FFS	FFS	FFS	FFS
23	FFS	FFS	FFS	FFS
24	FFS	FFS	FFS	FFS
25	FFS	FFS	FFS	FFS
26	FFS	FFS	FFS	FFS
27	FFS	FFS	FFS	FFS
28	FFS	FFS	FFS	FFS
29	FFS	FFS	FFS	FFS
30	FFS	FFS	FFS	FFS
31	FFS	FFS	FFS	FFS
32	FFS	FFS	FFS	FFS
33	FFS	FFS	FFS	FFS
34	FFS	FFS	FFS	FFS
35	FFS	FFS	FFS	FFS
36	FFS	FFS	FFS	FFS
37	FFS	FFS	FFS	FFS
38	FFS	FFS	FFS	FFS
39	FFS	FFS	FFS	FFS
40	FFS	FFS	FFS	FFS
NOTE – Channels 1-12 are assigned to WRP with 12 wavelength CPs. Channels 1-20 are assigned to WRP with 20 wavelength CPs. The frequency plan for 40 wavelength CPs is for further study.				

Table A.3 – WDM channel frequency plan

Channel	Downstream Central frequency (THz)	Downstream Central Wavelength (nm)	Upstream Central frequency (THz)	Upstream Central Wavelength (nm)
The frequency values in this table are normative, while the wavelength values are for information only.				

A.3.5 FEC code selection

The choice of FEC depends on the service protocol.

For common public radio interface (CPRI) with 64B/66B coding, FEC is optional.

For 10G Ethernet and 25G Ethernet, the FEC code is RS (528, 514) (clause 108 of [b-IEEE 802.3-2022]).

A.3.6 Electronic dispersion compensation

Electronic dispersion compensation (EDC) may be used in the OLT (ONU) transmitter to achieve the optical path penalty (OPP) specified in the optical interface parameter tables. At the ONU (OLT) receiver, EDC may also be used.

A.3.7 PMD parameters

A.3.7.1 Compatible ODN

ODN optical path loss classes (ODN classes) are specified in Table A.4.

The optical path loss for each class is specified between the S/R-CG and R/S reference points in either direction.

Table A.4 – ODN optical path loss classes (ODN classes) for wavelength router (WR)-based WDM PON reference logical architecture

	Class X (10 km)	Class Y (20 km)
Minimum optical path loss	3.2 dB	3.2 dB
Maximum optical path loss	13 dB	17 dB
Maximum differential optical path loss	8 dB	12 dB

WRP shall operate over an ODN whose parameters are described in Table A.5.

Table A.5 – Physical parameters of a simple ODN (ODS)

Item	Unit	Specification
Fibre type	–	[ITU-T G.652] or compatible
Attenuation range	dB	Class X: 3.2-13 Class Y: 3.2-17
Maximum fibre distance between S/R and R/S points	km	DD10: 10 DD20: 20
Minimum fibre distance between S/R and R/S points	km	0
Bidirectional transmission	–	1-fibre WDM
Maintenance wavelength	nm	FFS

A.3.7.2 Optical interface parameters

A.3.7.2.1 Optical interface parameters of downstream direction

The following downstream optical interface tables are applicable for up to 20 km fibre length.

Table A.6 – Optical interface parameters for 10G class (from 9.8304 Gbit/s to 10.3125 Gbit/s) downstream direction

Item	Unit	Value	
OLT transmitter (optical interface S)			
Nominal line rate	Gbit/s	9.8304 to 10.3125	
Operating wavelength band	nm	1529.553-1544.526	
Operating central frequency	THz	Table A.3	
Operating channel spacing	GHz	100	
Maximum spectral excursion	GHz	±20	
Line code	–	Determined by application (Scrambled NRZ assumed for parameter values)	
Mask of the transmitter eye diagram	–	See clause A.3.8.6	
Maximum reflectance of equipment at S/R-CG, measured at transmitter wavelength	dB	Not applicable	
Minimum ORL of ODN at S/R-CG	dB	32	
ODN class		X	Y
Mean channel launch power minimum (at S/R-CG) without FEC	dBm	–8	–4
Mean channel launch power minimum (at S/R-CG) with FEC	dBm	FFS	FFS
Mean channel launch power maximum (at S/R-CG) without FEC	dBm	–4	0
Mean channel launch power maximum (at S/R-CG) with FEC	dBm	FFS	FFS
Maximum downstream WNE-PSD	dBm	FFS	
Minimum extinction ratio (Note 1)	dB	6	
Tolerance to reflected optical power	dB	–15	
Dispersion range (Note 2)	ps/nm	0 to $\frac{0.092 \times \lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right] \times 10$ (DD10), 0 to $\frac{0.092 \times \lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right] \times 20$ (DD20)	
Minimum side mode suppression ratio (at S/R-CP) (Note 3)	dB	30	
Maximum downstream per channel out-of-band optical power spectral density (PSD)	dBm	FFS	
Maximum downstream per channel out-of-channel optical PSD	dBm	FFS	
Jitter generation	–	See clause A.3.8.6.3	
ONU receiver (optical interface R)			

Table A.6 – Optical interface parameters for 10G class (from 9.8304 Gbit/s to 10.3125 Gbit/s) downstream direction

Item	Unit	Value	
Maximum OPP (Note 4)	dB	2.5	
Maximum reflectance of equipment at R/S, measured at receiver wavelength	dB	FFS	
ODN class		X	Y
Sensitivity (at R/S) @ BER=10^{-12}	dBm	−23.5	
Sensitivity (at R/S) @ BER=10^{-3} (Note 5)	dBm	FFS	FFS
Overload (at R/S) @ BER=10^{-12}	dBm	−7.2	−3.2
Overload (at R/S) @ BER=10^{-3} (Note 5)	dBm	FFS	FFS
In-band crosstalk tolerance	dB	FFS	
Consecutive identical digit immunity	bit	72	
Jitter tolerance	–	See clause A.3.8.6.3	

NOTE 1 – A lower extinction ratio is allowed but must be compensated by a larger transmitter launch power within the limits of the "Mean launch power maximum" value. However, the impact of reduced ER on OOB/OOC power must be considered.

NOTE 2 – This formula (see clause 6.10 of [ITU-T G.652]) is used instead of the worst-case value due to the large variation of dispersion within the WRP wavelength band. This allows implementers to build devices only to the desired dispersion specification. λ is the longest possible wavelength in each channel, in nanometre units, considering the spectral excursion.

NOTE 3 – For downstream, side mode suppression ratio (SMSR) is measured on the laser output, before any filtering. This prevents a significant mode partition noise penalty.

NOTE 4 – The specified OPP is valid up to a 20-channel system. If the actual OPP is worse than the specified value, it must be compensated by the transmitter launch power increase up to the limits of the Mean launch power maximum.

NOTE 5 – See clause 9.4.1 of [b-ITU-T G.Sup39] for additional details.

Table A.7 – Optical interface parameters for 25G class (from 24.33024 Gbit/s to 25.78125 Gbit/s) downstream direction

Item	Unit	Value
OLT transmitter (optical interface S)		
Nominal line rate	Gbit/s	24.33024-25.78125
Operating wavelength band	nm	1529.553-1544.526
Operating central frequency	THz	Table A.3
Operating channel spacing	GHz	100
Maximum spectral excursion	GHz	±20
Line code	–	Determined by application (Scrambled NRZ assumed for parameter values)
Mask of the transmitter eye diagram	–	See clause A.3.8.6

Table A.7 – Optical interface parameters for 25G class (from 24.33024 Gbit/s to 25.78125 Gbit/s) downstream direction

Item	Unit	Value
Maximum reflectance of equipment at S/R-CG, measured at transmitter wavelength	dB	Not applicable
Minimum ORL of ODN at S/R-CG	dB	32
ODN class		X
Mean channel launch power minimum (at S/R-CG) without FEC	dBm	FFS
Mean channel launch power minimum (at S/R-CG) with FEC	dBm	−4
Mean channel launch power maximum (at S/R-CG) without FEC	dBm	FFS
Mean channel launch power maximum (at S/R-CG) with FEC	dBm	0
Maximum downstream WNE-PSD	dBm	FFS
Minimum extinction ratio (Note 1)	dB	8
Tolerance to reflected optical power	dB	−15
Dispersion range (Note 2)	ps/nm	0 to $\frac{0.092\times\lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right]\times 10$ (DD10), 0 to $\frac{0.092\times\lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right]\times 20$ (DD20)
Minimum side mode suppression ratio (at S/R-CP) (Note 3)	dB	30
Maximum downstream per channel out-of-band optical PSD	dBm	FFS
Maximum downstream per channel out-of-channel optical PSD	dBm	FFS
Jitter generation	–	See clause A.3.8.6.3
ONU receiver (optical interface R)		
Maximum OPP (Note 4)	dB	3
Maximum reflectance of equipment at R/S, measured at receiver wavelength	dB	FFS
ODN class		X
Sensitivity (at R/S) @ BER=10^{-12}	dBm	FFS
Sensitivity (at R/S) @ BER=5×10^{-5} (Note 5)	dBm	−20
Overload (at R/S) @ BER=10^{-12}	dBm	FFS
Overload (at R/S) @ BER=5×10^{-5} (Note 5)	dBm	−3.2
In-band crosstalk tolerance	dB	FFS
Consecutive identical digit immunity	bit	72
Jitter tolerance	–	See clause A.3.8.6.3

Table A.7 – Optical interface parameters for 25G class (from 24.33024 Gbit/s to 25.78125 Gbit/s) downstream direction

Item	Unit	Value
NOTE 1 – A lower extinction ratio is allowed but must be compensated by a larger transmitter launch power within the limits of the "Mean launch power maximum" value. However, the impact of reduced ER on OOB/OOC power must be considered. NOTE 2 – This formula (see clause 6.10 of [ITU-T G.652]) is used instead of the worst-case value due to the large variation of dispersion within the WRP wavelength band. This allows implementers to build devices only to the desired dispersion specification. λ is the longest possible wavelength in each channel, in nanometre units, considering the spectral excursion. NOTE 3 – For downstream, SMSR is measured on the laser output, before any filtering. This prevents a significant mode partition noise penalty. NOTE 4 – The specified OPP is valid up to a 20-channel system. If the actual OPP is worse than the specified value, it must be compensated by the transmitter launch power increase up to the limits of the Mean launch power maximum. NOTE 5 – See clause 9.4.1 of [b-ITU-T G.Sup39] for additional details.		

A.3.7.2.2 Optical interface parameters of upstream direction

The following upstream optical interface tables are applicable for up to 20 km fibre length.

Table A.8 – Optical interface parameters for 10G class (from 9.8304 Gbit/s to 10.3125 Gbit/s) upstream direction

Item	Unit	Value	
ONU transmitter (optical interface S)			
Nominal line rate	Gbit/s	9.8304 to 10.3125	
Operating wavelength band	nm	1550.116-1565.496	
Operating channel spacing	GHz	100	
Line code	–	Determined by application (Scrambled NRZ assumed for parameter values)	
Mask of the transmitter eye diagram	–	See clause A.3.8.6	
Maximum reflectance of equipment at R/S, measured at transmitter wavelength	dB	FFS	
Minimum ORL of ODN at R/S	dB	32	
ODN Class		X	Y
Mean channel launch power minimum (at R/S) without FEC	dBm	−1	−1
Mean channel launch power minimum (at R/S) with FEC	dBm	FFS	FFS
Mean channel launch power maximum (at R/S) without FEC	dBm	4	4
Mean channel launch power minimum (at R/S) with FEC	dBm	FFS	FFS
Minimum extinction ratio (Note 1)	dB	6	
Tolerance to reflected optical power	dB	–15	

Table A.8 – Optical interface parameters for 10G class (from 9.8304 Gbit/s to 10.3125 Gbit/s) upstream direction

Item	Unit	Value	
Dispersion range (Note 2)	ps/nm	0 to $\frac{0.092\times\lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right]\times 10$ (DD10), 0 to $\frac{0.092\times\lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right]\times 20$ (DD20)	
Minimum side mode suppression ratio (Note 3)	dB	30	
Maximum upstream out-of-band optical PSD	dBm	FFS	
Maximum upstream out-of-channel optical PSD – OOC1	dBm	FFS	
Maximum upstream out-of-channel optical PSD – OOC2	dBm	FFS	
Jitter transfer	–	See clause A.3.8.6.3	
Jitter generation	–	See clause A.3.8.6.3	
OLT receiver (optical interface R)			
Maximum OPP (Note 4)	dB	2.5	
Maximum reflectance of equipment at S/R-CG, measured at receiver wavelength	dB	FFS	
ODN Class		X	Y
Sensitivity (at S/R-CG) @ BER=10^{-12}	dBm	−20.5	−28.5
Sensitivity (at S/R-CG) @ BER=10^{-3} (Note 5)	dBm	FFS	FFS
Overload (at S/R-CG) @ BER=10^{-12}	dBm	3	–5
Overload (at S/R-CG) @ BER=10^{-3} (Note 5)	dBm	FFS	FFS
In-band crosstalk tolerance	dB	FFS	
Consecutive identical digit immunity	bit	72	
Jitter tolerance	–	See clause A.3.8.6.3	

NOTE 1 – A lower extinction ratio must be compensated by a larger transmitter launch power within the limits of the mean launch power maximum value.

NOTE 2 – This formula (see clause 6.10 of [ITU-T G.652]) is used instead of the worst-case value due to the large variation of dispersion within the WRP wavelength band. This allows implementers to build devices only to the desired dispersion specification. λ is the longest possible wavelength in each channel, in nanometre units, considering the spectral excursion.

NOTE 3 – For upstream at the ONU, SMSR is measured on the laser output, before any filtering. This prevents a significant mode partition noise penalty.

NOTE 4 – The specified OPP is valid up to a 20-channel system. If the actual OPP is worse than the specified value, it must be compensated by the transmitter launch power increase up to the limits of the Mean launch power maximum.

NOTE 5 – See clause 9.4.1 of [b-ITU-T G.Sup39] for additional details.

Table A.9 – Optical interface parameters for 25G class (from 24.33024 Gbit/s to 25.78125 Gbit/s) upstream direction

Item	Unit	Value
ONU transmitter (optical interface S)		
Nominal line rate	Gbit/s	24.33024-25.78125
Operating wavelength band	nm	1550.116-1565.496
Operating channel spacing	GHz	100
Line code	–	Determined by application (Scrambled NRZ assumed for parameter values)
Mask of the transmitter eye diagram	–	See clause A.3.8.6
Maximum reflectance of equipment at R/S, measured at transmitter wavelength	dB	FFS
Minimum ORL of ODN at R/S	dB	32
ODN Class		X
Mean channel launch power minimum (at R/S) without FEC	dBm	FFS
Mean channel launch power minimum (at R/S) with FEC	dBm	–1
Mean channel launch power maximum (at R/S) without FEC	dBm	FFS
Mean channel launch power minimum (at R/S) with FEC	dBm	3
Minimum extinction ratio (Note 1)	dB	8
Tolerance to reflected optical power	dB	−15
Dispersion range (Note 2)	ps/nm	0 to $\frac{0.092\times\lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right]\times 10$ (DD10), 0 to $\frac{0.092\times\lambda}{4}\left[1-\left(\frac{1300}{\lambda}\right)^2\right]\times 20$ (DD20)
Minimum side mode suppression ratio (Note 3)	dB	30
Maximum upstream out-of-band optical PSD	dBm	FFS
Maximum upstream out-of-channel optical PSD – OOC1	dBm	FFS
Maximum upstream out-of-channel optical PSD – OOC2	dBm	FFS
Jitter transfer	–	See clause A.3.8.6.3
Jitter generation	–	See clause A.3.8.6.3
OLT receiver (optical interface R)		
Maximum OPP (Note 4)	dB	3
Maximum reflectance of equipment at S/R-CG, measured at receiver wavelength	dB	FFS
ODN Class		X

Table A.9 – Optical interface parameters for 25G class (from 24.33024 Gbit/s to 25.78125 Gbit/s) upstream direction

Item	Unit	Value
Sensitivity (at S/R-CG) @ BER=10^{-12}	dBm	FFS
Sensitivity (at S/R-CG) @ BER=5×10^{-5} (Note 5)	dBm	−17
Overload (at S/R-CG) @ BER=10^{-12}	dBm	FFS
Overload (at S/R-CG) @ BER=5×10^{-5} (Note 5)	dBm	−0.2
In-band crosstalk tolerance	dB	FFS
Consecutive identical digit immunity	bit	72
Jitter tolerance	–	See clause A.3.8.6.3
NOTE 1 – A lower extinction ratio must be compensated by a larger transmitter launch power within the limits of the mean launch power maximum value. NOTE 2 – This formula (see clause 6.10 of [ITU-T G.652]) is used instead of the worst-case value due to the large variation of dispersion within the WRP wavelength band. This allows implementers to build devices only to the desired dispersion specification. λ is the longest possible wavelength in each channel, in nanometre units, considering the spectral excursion. NOTE 3 – For upstream at the ONU, SMSR is measured on the laser output, before any filtering. This prevents a significant mode partition noise penalty. NOTE 4 – The specified OPP is valid up to a 20-channel system. If the actual OPP is worse than the specified value, it must be compensated by the transmitter launch power increase up to the limits of the Mean launch power maximum. NOTE 5 – See clause 9.4.1 of [b-ITU-T G.Sup39] for additional details.		

A.3.8 Transmitter at reference point S

All parameters are defined as follows and are in accordance with Table A.6 to Table A.9.

A.3.8.1 Source type

Considering the attenuation/dispersion characteristics of the target fibre channel, feasible transmitter devices include only single-longitudinal mode (SLM) lasers. The indication of a nominal source type in this Recommendation is not a requirement though it is also expected that only SLM lasers meet all the distance and line rate requirements of the WRP system both for the downstream and upstream links.

A.3.8.2 Spectral characteristics

For SLM lasers, the laser is specified by its fibre dispersion range, the range over which the laser characteristics and fibre dispersion result in a defined penalty at a specified fibre distance, under standard operating conditions. Additionally, for control of mode partition noise in SLM systems, a minimum value for the laser side-mode suppression ratio is specified. The actual spectral characteristics are limited by the maximum amount of OPP produced with the worst-case optical dispersion in the data signal.

A.3.8.3 Operating wavelength band

Operating wavelength band specification options are summarized in Table A.3.

A.3.8.4 Nominal central frequency

The central frequencies are based on the frequency grid given in [ITU-T G.694.1]. The downstream central frequencies are specified in Table A.3.

Note that the value of "c" (speed of light in a vacuum) that is used for converting between frequency and wavelength is 2.99792458×10^8 m/s.

A.3.8.5 Mean launch optical power

The mean launch optical power is specified as a range to allow for some cost optimization and to cover all allowances for operation under standard operating conditions, transmitter connector degradation, measurement tolerances and ageing effects.

In the operating state, the lower figure is the minimum power to be provided and the higher one is the power never to be exceeded.

A.3.8.6 Mask of transmitter eye diagram

This clause specifies the pulse shape characteristics for the OLT and ONU transmitters. For the purpose of assessing the transmit signal, it is important to consider not only the eye opening, but also the overshoot and undershoot limitations.

A.3.8.6.1 OLT transmitter

The parameters specifying the mask of the eye diagram (see Figure A.2) for the OLT transmitter are shown in Table A.10. The test set-up for the measurement of the mask of the eye diagram is shown in Figure A.3.

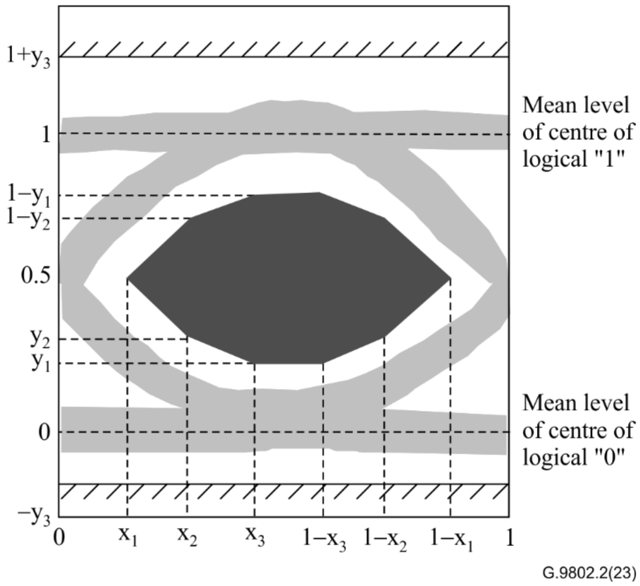
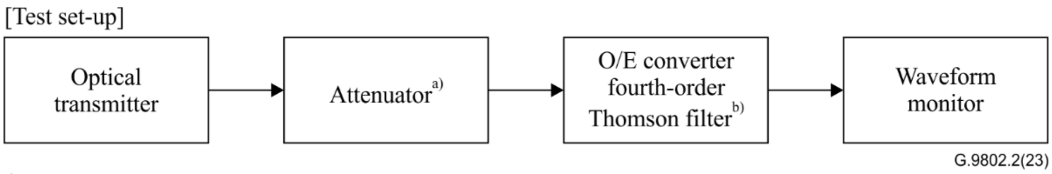


Figure A.2 – Mask of the eye diagram for OLT

Table A.10 – Mask of the eye diagram for OLT transmitter – Numeric values

	10G	25G
x1	0.25	0.25
x2	0.4	0.4
x3	0.45	0.45
y1	0.25	0.25
y2	0.28	0.28
y3	0.4	0.4
Maximum hit ratio	5×10^{-5}	5×10^{-5}
NOTE – The values are taken from clause 7.2.2.14 of [b-ITU-T G.959.1], "NRZ 10G Ratio small" and "NRZ 25G Ratio". The "hit ratio" is the acceptable ratio of samples inside to outside the shaded area.		



a) Attenuator is used if necessary.
b) Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure A.3 – Test set-up for measuring the mask of the eye diagram for OLT transmitter

A.3.8.6.2 ONU transmitter

A.3.8.6.2.1 ONU transmitter eye diagram

The parameters specifying the mask of the eye diagram (see Figure A.4) for the ONU transmitter are shown in Table A.11. The test set-up for the measurement of the mask of the eye diagram is shown in Figure A.5.

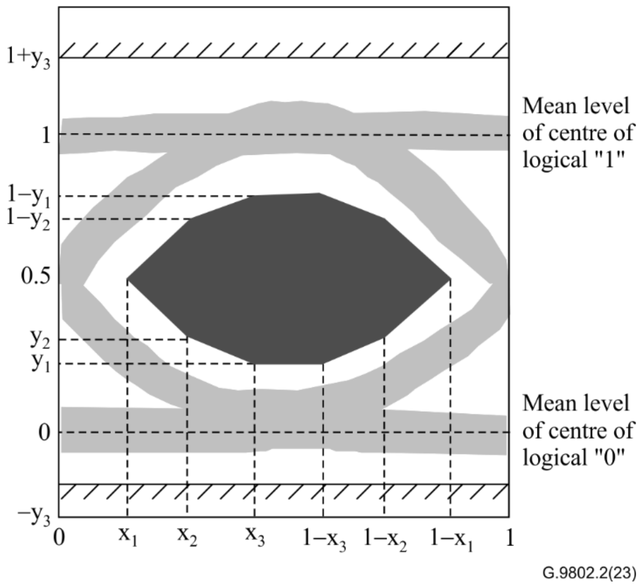
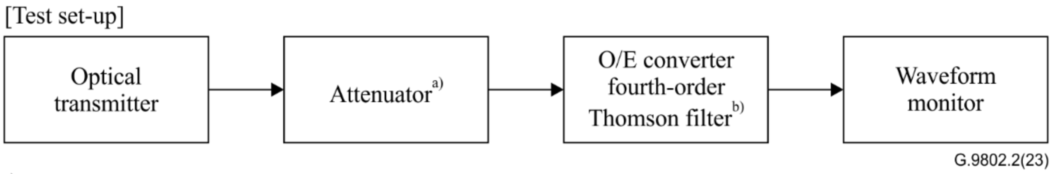


Figure A.4 – Mask of the eye diagram for ONU transmitter

Table A.11 – Mask of the eye diagram for ONU transmitter – numeric values

	10G	**25G**
x1	0.25	0.25
x2	0.4	0.4
x3	0.45	0.45
y1	0.25	0.25
y2	0.28	0.28
y3	0.4	0.4
Maximum hit ratio	5×10^{-5}	5×10^{-5}
NOTE – The "hit ratio" is the acceptable ratio of samples inside to outside the shaded area.		



a) Attenuator is used if necessary.

b) Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure A.5 – Test set-up for measuring the mask of the eye diagram for ONU transmitter

A.3.8.6.3 Jitter performance

This clause describes jitter requirements for optical interfaces of WDM PON.

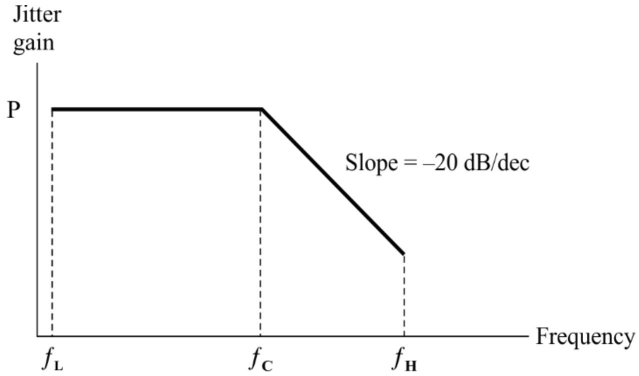
A.3.8.6.3.1 Jitter transfer

The jitter transfer specification applies only to the ONU.

The jitter transfer function is defined as:

$$jitter\ transfer = 20log_{10}\left[\frac{jitter\ on\ upstream\ signal\ UI}{jitter\ on\ downstream\ signal\ UI} \times \frac{downstream\ bit\ rate}{upstream\ bit\ rate}\right]$$

The jitter transfer function of an ONU shall be under the curve given in Figure A.6, when input sinusoidal jitter up to the mask level in Figure A.7 is applied, with the parameters specified in this figure for each line rate.



Line rate class	f_L (kHz)	f_C (kHz)	f_H (kHz)	P (dB)
10 G	10	4000	80 000	0.1
25 G	10	4000	200 000	0.1

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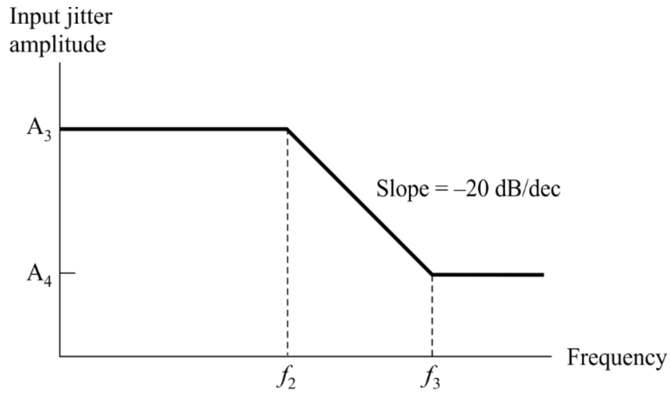
Figure A.6 – Jitter transfer for ONU



Line rate class	A_3 (UI)	A_4 (UI)	f_2 (kHz)	f_3 (kHz)
10 G	1.5	0.15	400	4000
25 G	1.5	0.15	400	4000

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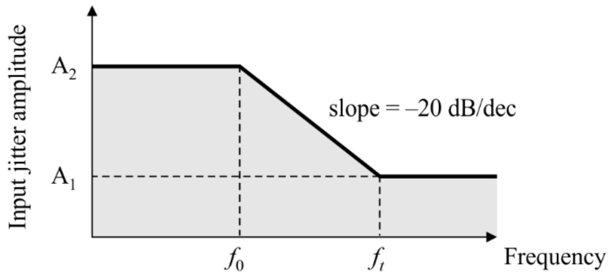
Figure A.7 – High-band portion of sinusoidal jitter mask for jitter transfer

A.3.8.6.3.2 Jitter tolerance

Jitter tolerance is defined as the peak-to-peak amplitude of sinusoidal jitter applied on the input of WDM PON signal that causes a 1 dB optical power penalty at the optical receiver. Note that it is a stress test to ensure that no additional penalty is incurred under typical operating conditions.

The ONU must tolerate, as a minimum, the input jitter applied according to the mask in Figure A.8, with the parameters specified in that figure for the downstream line rate. The OLT must tolerate, as a minimum, the input jitter applied according to the mask in Figure A.8, with the parameters specified in that figure for the upstream line rate. The jitter tolerance specification for the OLT is informative as it can only be measured in a setting that permits continuous operation of the upstream.



Line rate class	f_0 [kHz]	f_t [kHz]	A_1 [UIp-p]	A_2 [UIp-p]
10 G	400	4000	0.075	0.75
25 G	400	4000	0.075	0.75

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Figure A.8 – Jitter tolerance mask

A.3.8.6.3.3 Jitter generation

An ONU must not generate a peak-to-peak jitter amplitude more than shown in Table A.12 at line rates of 10G and 25G classes, with no jitter applied to the downstream input and with a measurement bandwidth as specified in Table A.12. An OLT must not generate a peak-to-peak jitter amplitude more than shown in Table A.12 with no jitter applied to its timing reference input and with a measurement band as specified in Table A.12.

Table A.12 – Jitter generation requirements

Line rate class	Measurement band (−3 dB frequencies) (Note 1)		Peak-peak amplitude (UI) (Note 2)
	high-pass (kHz)	low-pass (MHz) −60 dB/dec	
10G	20	80	0.30
	4 000	80	0.10
25G	50	200	0.30
	4 000	200	0.10
NOTE 1 – The high-pass and low-pass measurement filter transfer functions are defined in clause 5 of [ITU-T G.825]. NOTE 2 – The measurement time and pass/fail criteria are defined in clause 5 of [ITU-T G.825].			

Annex B

Transmission convergence layer specification

(This annex forms an integral part of this Recommendation.)

B.1 WDM PON management TC layer overview

TC layer provides a similar operational experience as for legacy PON systems such as G-PON (ITU-T G.984.x Series Recommendations). Thus, features such as silent start, power saving, and capability to map a local PLOAM channel are captured.

The TC layer supports a WDM PON system containing a set of WDM channels.

This section overviews the management TC layer. Any reference to one channel termination clearly pertains to a set of one downstream wavelength channel and one upstream wavelength channel. The term optical line termination channel termination (OLT CT) is generically used to address the channel termination.

The remainder of clause B.1 is structured as follows. Clause B.1.1 introduces the distinct channel modes of WDM PON channels; clause B.1.2 describes WDM PON system supported line rates; clause B.1.3 discusses the principles and identifiers.

B.1.1 WDM PON management channel modes

In WDM PON, the user data path and the operation, administration and maintenance (OAM) data path are separate through the TC layer. The user data is unprocessed by the TC layer, while the OAM data is processed by the WDM PON management TC layer.

There are two distinct modes of WDM PON management channels: transparent and transcoded. At the highest level, the arrangement of functions of these two modes is shown in Figure B.1. In transparent mode, both the user data and the WDM PON management TC data are passed directly to the PMD. In this case, the PMD has two separate interfaces. Transparent mode is basically agnostic to the bitrate and protocol of client signal. Transcoded mode is to transform the user data to add OAM features. In transcoded mode, the user data and framed WDM PON management TC data are passed to the two interfaces of the transcoder. The transcoder multiplexes and processes the two streams, and passes the result to the PMD.

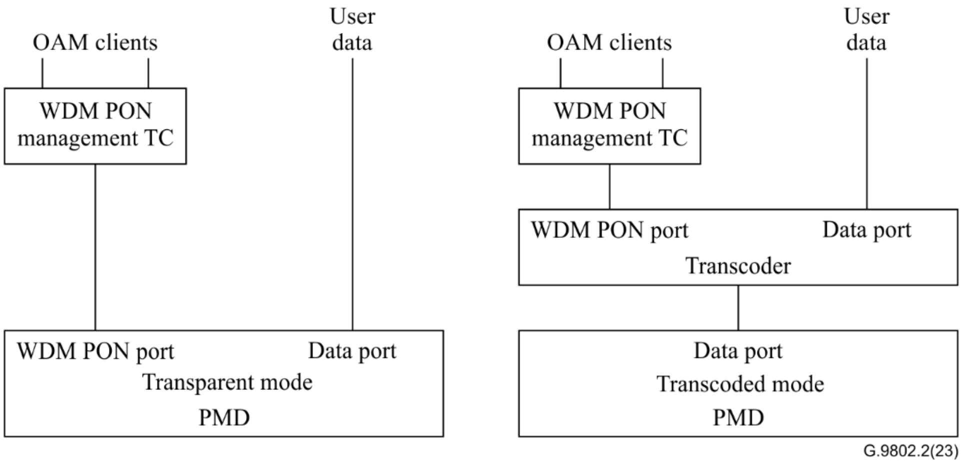


Figure B.1 – Relationship of the WDM PON management TC layer with other system functions

B.1.2 Supported nominal line rates

The management TC layer specification is applicable to the OLT CTs that support the nominal line rate combination options defined in Annex A.

The management TC layer specification is applicable to ONUs that support a nominal line rate combination defined in Annex A.

B.1.3 WDM architecture

B.1.3.1 Overview

For a WDM PON system, the WDM aspect is represented by multiple OLT CTs, each OLT CT providing bi-directional connectivity through a pair of wavelengths constituting a channel pair (CP), OLT CTs are independent from one another, in line rates and modulation format.

B.1.3.2 Identifiers common for WRP

B.1.3.2.1 WRP system identifier

A WRP system identifier (SYS ID) is a 20-bit number that identifies a specific WRP system among multiple systems under common administration. The SYS ID may be coded to include data to support administration such as an operator name, geographical location, service profile, and whether the system is for protection. It is supplied by an EMS/OSS to the OLT CT and is identical for all WDM channels within the system. An ONU stores the SYS ID and uses it as a reference.

B.1.3.2.2 WRP CT identifier

A WRPCT-ID is a 34-bit structured number that uniquely identifies a WRP channel termination (CT) entity within a domain.

In a WRP system, WRPCT-ID consists of a 28-bit administrative label and a 6-bit WLCH ID. The administrative label is supplied by an EMS/OSS to the OLT NE. It is expected to follow some consistent physical or logical equipment numbering plan, and is treated transparently by the OLT.

The WRPCT-ID of the specific WRP channel termination is carried within the operation control (OC) structure of the physical synchronization block (PSB) field.

B.1.3.2.3 Downstream wavelength channel identifier

In a WRP system, downstream wavelength channel ID (DWLCH ID) is a 6-bit number that identifies a downstream wavelength channel and is equal to the ordinal number of the channel defined in Table A.3, converted to the range from 0 to 39, as shown in Table B.1.

Table B.1 – DWLCH ID to channel mapping

Channel	Frequency (THz)	Wavelength (nm)	DWLCH ID
1	194.1	1 544.526	000000
2	194.2	1 543.730	000001
3	194.3	1 542.936	000010
4	194.4	1 542.142	000011
5	194.5	1 541.349	000100
6	194.6	1 540.557	000101
7	194.7	1 539.766	000110
8	194.8	1 538.976	000111
9	194.9	1 538.186	001000
10	195.0	1 537.397	001001

Table B.1 – DWLCH ID to channel mapping

Channel	Frequency (THz)	Wavelength (nm)	DWLCH ID
11	195.1	1 536.609	001010
12	195.2	1 535.822	001011
13	195.3	1 535.036	001100
14	195.4	1 534.250	001101
15	195.5	1 533.465	001110
16	195.6	1 532.681	001111
17	195.7	1 531.898	010000
18	195.8	1 531.116	010001
19	195.9	1 530.334	010010
20	196.0	1 529.553	010011
21	FFS	FFS	010100
22	FFS	FFS	010101
23	FFS	FFS	010110
24	FFS	FFS	010111
25	FFS	FFS	011000
26	FFS	FFS	011001
27	FFS	FFS	011010
28	FFS	FFS	011011
29	FFS	FFS	011100
30	FFS	FFS	011101
31	FFS	FFS	011110
32	FFS	FFS	011111
33	FFS	FFS	100000
34	FFS	FFS	100001
35	FFS	FFS	100010
36	FFS	FFS	100011
37	FFS	FFS	100100
38	FFS	FFS	100101
39	FFS	FFS	100110
40	FFS	FFS	100111

DWLCH ID is a part of WRPCT-ID (see clause B.1.3.2.2), which is transmitted downstream within the OC structure of the PSB field.

B.1.3.2.4 Upstream wavelength channel identifier

In a WRP system, upstream wavelength channel ID (UWLCH ID) is a 6-bit number that identifies an upstream wavelength channel and is equal to the ordinal number of the channel defined in Table A.3, converted to the range from 0 to 39, as shown in Table B.2.

Table B.2 – UWLCH ID to channel mapping

Channel	Frequency (THz)	Wavelength (nm)	UWLCH ID
1	191.5	1 565.496	000000
2	191.6	1 564.679	000001
3	191.7	1 563.863	000010
4	191.8	1 563.047	000011
5	191.9	1 562.233	000100
6	192.0	1 561.419	000101
7	192.1	1 560.606	000110
8	192.2	1 559.794	000111
9	192.3	1 558.983	001000
10	192.4	1 558.173	001001
11	192.5	1 557.363	001010
12	192.6	1 556.555	001011
13	192.7	1 555.747	001100
14	192.8	1 554.940	001101
15	192.9	1 554.134	001110
16	193.0	1 553.329	001111
17	193.1	1 552.524	010000
18	193.2	1 551.721	010001
19	193.3	1 550.918	010010
20	193.4	1 550.116	010011
21	FFS	FFS	010100
22	FFS	FFS	010101
23	FFS	FFS	010110
24	FFS	FFS	010111
25	FFS	FFS	011000
26	FFS	FFS	011001
27	FFS	FFS	011010
28	FFS	FFS	011011
29	FFS	FFS	011100
30	FFS	FFS	011101
31	FFS	FFS	011110
32	FFS	FFS	011111
33	FFS	FFS	100000
34	FFS	FFS	100001
35	FFS	FFS	100010
36	FFS	FFS	100011
37	FFS	FFS	100100
38	FFS	FFS	100101
39	FFS	FFS	100110
40	FFS	FFS	100111

UWLCH ID is a part of WRPCT-ID (see clause B.1.3.2.2), which is transmitted upstream within the OC structure of the PSB field.

B.1.3.2.5 ONU identifier

In a WRP system, the ONU identifier (ONU-ID) is an 8-bit identifier.

The ONU-ID is unique across the optical distribution network (ODN). When an ONU enters the Initial state (O1) of the ONU activation state machine, it discards the previously assigned ONU-ID along with all dependent WRP TC layer configuration assignments. The semantics of the ONU-ID values is shown in Table B.3.

Table B.3 – ONU-ID values

ONU-ID	Designation	Comment
0..63	Assignable	Advertised by OLT CT at ONU activation; used to identify the sender of an upstream transmission or a PLOAMu message and the recipient of a PLOAMd message.
64..254	Reserved	The number shall not be assigned to any ONU, and shall not be used as an ONU-ID.
255	Unassigned	Unassigned ONU in PLOAMu.

B.1.3.2.6 Channel partition index

An operator may subdivide the set of WDM channels in a WRP system into non-overlapping subsets using an arbitrary criterion, such as commonality of service profile, equipment or geographical location. Each such channel subset is known as a channel partition and is identified by an index which is unique within the WRP system. Channel partition index (CPI) is contained in the Channel_Profile PLOAM message.

As an operational attribute, an ONU carries a channel partition index, storing it in a non-volatile memory and ensuring that its value is retained through ONU reactivation, warm and cold reboot, power cycle, management information base (MIB) reset and/or power loss. The value of ONU's CPI is read/write-accessible via OMCI. If the OLT changes the ONU's specific CPI value via OMCI, the OLT is expected to reactivate the ONU immediately thereafter. The ONU's CPI value is only checked against the current channel partition at the start of an activation cycle.

An ONU's CPI can be specific (non-zero) or default (zero). An ONU with a specific CPI may activate only on channels whose Channel_Profile CPI matches the CPI of the ONU. An ONU with a default CPI can attempt to activate on a channel belonging to any channel partition, and learns its specific channel partition association at the time of ONU-ID assignment. An ONU with a specific CPI refuses an instruction to tune to a channel belonging to a different channel partition than that of the ONU.

B.2 TC layer structure and sublayer functions

B.2.1 WDM PON management TC layer structure

The WDM PON management TC is implemented at both the OLT and ONU sides of a WRP system. In both downstream and upstream directions, it interfaces with the PMD or the transcoder as a continuous bitstream, which is partitioned into cyclic frames. The downstream and upstream frames have the same format.

The WDM PON management TC layer is composed of three sublayers: the management TC service adaptation sublayer, the management TC framing sublayer and the management TC PHY adaptation sublayer. Figure B.2 shows the key transformation stages involved in the mapping between the upper layer management data units (MDUs) and the physical interface (PHY) or transcoder bitstream for the downstream and the upstream directions in WDM PON system. Note that MDUs may carry OMCI messages, OAM messages, XML-formatted data and other management data units. Also, note that the FEC function is optional and in the transparent mode is applicable to the WDM PON management TC path only.

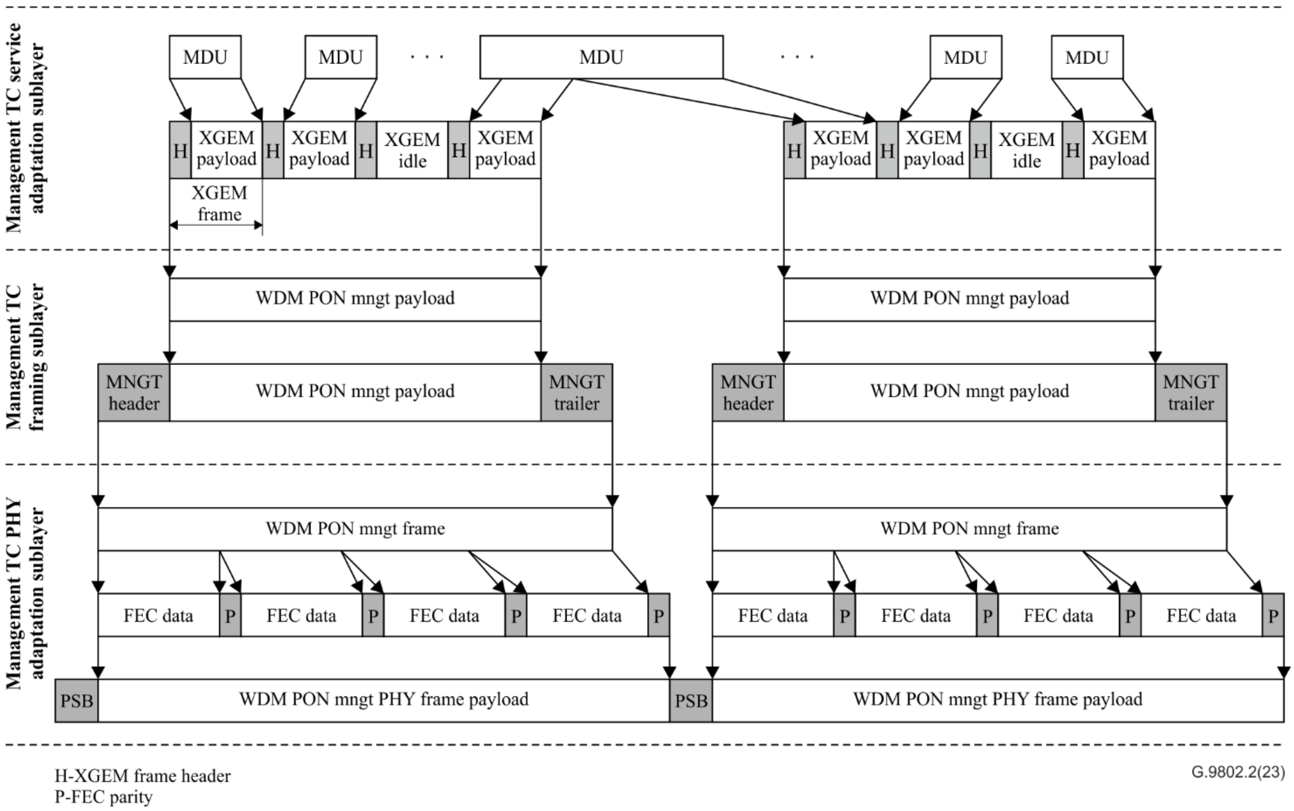


Figure B.2 – MDU mapping for WDM PON management TC channel

B.2.2 Management TC sublayer functions

B.2.2.1 Management TC service adaptation sublayer

The WDM PON management TC service adaptation sublayer is responsible for the upper layer MDU encapsulation, multiplexing and delineation in the course of transmission in WDM PON.

On the transmitter side, the management TC service adaptation sublayer accepts MDUs from the clients, performs MDU fragmentation as necessary, assigns a XGEM Port-ID to an MDU or MDU fragment and applies the XGEM encapsulation method to it to obtain a XGEM frame. The XGEM frame payload can be optionally encrypted. A series of XGEM frames form a payload of the management TC frame.

On the receiver side, the management TC service adaptation sublayer accepts the payload of the management TC frames, performs XGEM frame delineation, filters XGEM frames based on the XGEM Port-IDs, decrypts the XGEM payload if encryption has been performed by the transmitter, reassembles the fragmented MDUs and delivers the MDUs to the respective clients.

See clauses 9.1 and 9.2 of [ITU-T G.9804.2] for the details of XGEM framing and XGEM frame delineation, respectively. MDU fragmentation follows procedures for SDU fragmentation (see clause 9.3 of [ITU-T G.9804.2]).

B.2.2.2 Management TC framing sublayer

The management TC framing sublayer is responsible for the construction and parsing of the overhead fields that support the necessary PON management functionality. The management TC framing sublayer formats are devised so that the frames and their elements are aligned to 4-byte word boundaries, whenever possible.

On the transmitter side, the management TC framing sublayer accepts the payload from the management TC service adaptation sublayer, and constructs the management TC frames by providing the overhead fields for the embedded operation, administration and maintenance (OAM) and the Physical layer operation, administration and maintenance (PLOAM) messaging channels.

On the receiver side, the management TC framing sublayer accepts the management TC frames, parses the management TC management information, extracts the incoming embedded management and PLOAM messaging flows and delivers the management TC management payloads to the service adaptation sublayer. The incoming PLOAM messages are delivered to the PLOAM processor. The embedded OAM information is delivered to the control entities outside of the framing sublayer.

B.2.2.3 Management TC PHY adaptation sublayer

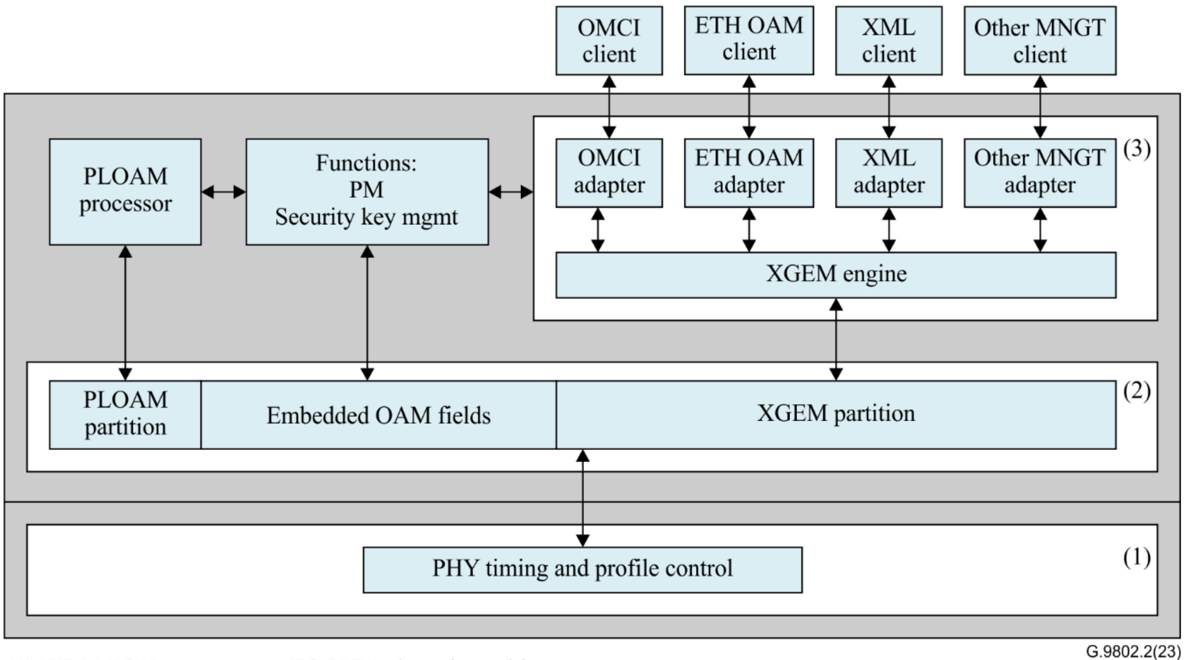
The management TC PHY adaptation sublayer encompasses functions that modify the bitstream modulating the optical transmitter with the goal to improve the detection, reception and delineation properties of the signal transmitted over the optical medium.

On the transmitter side, the management TC PHY adaptation sublayer accepts the TC frames from the framing sublayer, optionally performs FEC encoding, performs scrambling of the content, prepends the physical synchronization block and provides timing alignment of the resulting bitstream.

On the receiver side, the management TC PHY adaptation sublayer performs physical synchronization and delineation of the incoming bitstream, descrambles the content of the PHY frame, optionally performs FEC decoding, delivering the resulting management TC frames to the management TC framing sublayer.

The use of FEC improves the effective sensitivity and overload characteristics of the optical receiver. FEC is for further study.

Outline of the WDM PON management TC information flow is illustrated in Figure B.3.



(1) WDM PON management TC PHY adaptation sublayer
(2) WDM PON management TC framing sublayer
(3) WDM PON management service adaptation sublayer

Figure B.3 – Outline of WDM PON TC management information flow

B.2.3 WDM PON management TC management functions

The ONU control, operation and management information in a WDM PON system is carried over three channels: embedded OAM, PLOAM and OMCC. The embedded OAM and PLOAM channels manage the functions of the PMD and WDM PON management TC layers. The OMCC carries the messages of the OMCI protocol, which provides a uniform system for managing higher (service-defining) layers. The characteristics of these channels mimic those of the TWDM-TC layer (as detailed in clauses 8, 9 and 10 of [ITU-T G.989.3]), with some modifications.

It is also possible to carry other management traffic over the management TC payload, as the content of XGEM frames. The functionality and use of such messages is out of the scope of this Recommendation.

In addition, the inter-CT communication channel carrying the inter-channel-termination protocol (ICTP) primitives supports the multiple-wavelength aspect of the WDM PON system operation.

B.3 WDM PON management framing sublayer

This clause specifies the structure of the WDM PON management frame along with the format of the header and trailer.

The format of WDM PON management frame is the same in both the downstream and the upstream directions. It consists of the WDM PON management header, WDM PON management payload and WDM PON management trailer. The WDM PON management payload is formed on the transmit side (OLT CT in the downstream direction, ONU in the upstream direction) and is processed on the receive side (ONU in the downstream direction, OLT CT in the upstream direction) by the corresponding WDM PON management service adaptation sublayer entity. Figure B.4 illustrates the WDM PON management frame format.

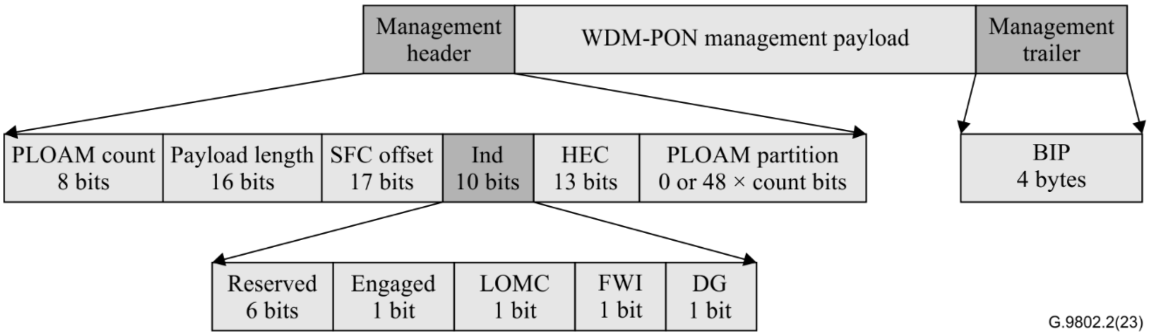


Figure B.4 –WDM PON management frame format

B.3.1 PLOAM count

This field contains an 8-bit unsigned integer, indicating the number of PLOAM messages in the PLOAM partition.

B.3.2 Payload length

This field contains a 16-bit unsigned integer, indicating size of the WDM PON management payload, measured in 4-byte words.

B.3.3 SFC offset

This field represents the offset in nanoseconds between the instant that the superframe counter (SFC) has been most recently incremented and the instant the first bit of the WDM PON management frame is transmitted.

Together with the SFC value carried within the PSB, the SFC offset represents the start time of a WDM PON management PHY frame. The ONU uses this information to synchronize with the OLT; the OLT may use this information to estimate the round-trip delay of the ONU.

B.3.4 Ind field

The indication (Ind) field has ten bits that provide fast signalling and are allocated as follows.

Bits 9 – 4: Reserved, set to 000000 by the transmitter and ignored by the receiver.

Bit 3: Reserved.

Bit 2: Loss of management channel (LOMC) flag indicating loss of synchronization to the received AMCC by the sender of the management frame.

Bit 1: Reserved - usage is for further study.

Bit 0 (LSB): Dying gasp (DG); When this bit is set, it indicates that the ONU has detected a local condition that may prevent the ONU from transmitting upstream. This indication may assist the OLT in distinguishing fibre plant problems from premises issues. Sending a DG indication does not necessarily constitute a commitment or intent on the part of ONU to cease transmitting. If the condition that has led to DG indication does not persist, the ONU revokes the indication and continues operation. For upstream use and set to 0 in the downstream WDM PON management frame.

B.3.5 HEC field

The error detection and correction field for the upstream framing sublayer (FS) header is a combination of a truncated BCH(63, 12, 2) code operating on the 31 initial bits of the header and a single parity bit. The details of the hybrid error correction (HEC) construction and verification are specified in Annex G.

B.3.6 PLOAM partition

Refer to clause B.7.2.

B.3.7 WDM PON management frame trailer

The WDM PON management frame trailer contains a 4-byte bit-interleaved even parity (BIP) field computed over the entire management frame. Note: The ONU and OLT CT uses the FS frame trailer (BIP) to estimate the BER of the management PHY link. If FEC is supported in management channel in PHY adaptation sublayer, the ONU uses the FEC correction results to obtain the BER of the management PHY link.

B.3.8 XGEM port identifier

The XGEM port identifier, or XGEM Port-ID, is a 16-bit number that is assigned by the OLT CT to an individual logical connection. The XGEM Port-ID assignment to the OMCC logical connection is implicit by virtue of the ONU-ID assignment to the given ONU. The OMCC Port-ID is numerically equal to the respective ONU-ID.

The semantics of the XGEM Port-ID values is shown in Table B.4.

Table B.4 – XGEM Port-ID values

XGEM Port-ID	Designation	Comment
0..63	Default	Default XGEM Port-ID, which is implicitly assigned with and is equal to the ONU-ID. It identifies the XGEM port used by the OMCC traffic.
64…65534	Reserved	The number shall not be assigned by any OLT CT, and not be used as XGEM Port-ID.
65535	Idle	Reserved for Idle XGEM Port-ID

B.4 Management TC PHY adaptation sublayer

This clause discusses matters of physical synchronization and delineation, forward error correction and transcoding for the transmission at the WDM PON management TC PHY adaptation sublayer.

B.4.1 Management TC PHY frame

An in-service WDM PON OLT CT or ONU is continuously transmitting. The transmission is partitioned into management TC PHY frames. The duration of a management TC PHY frame is a flexible period. A management TC PHY frame consists of a 24-byte physical synchronization block (PSB) and a PHY frame payload. The PHY payload is represented by the management TC frame whose content is optionally protected by FEC.

The start of a particular PHY frame is defined in the context of the given network element and corresponds to transmission (by the OLT CT) or receipt (by the ONU) of the first bit of its PSB.

B.4.1.1 Physical synchronization block (PSB)

The WDM PON PSB structure shown in Figure B.5 has the same structure as the TWDM PSBd structure. The physical synchronization sequence (PSync) contains a fixed 64-bit pattern. The OLT CT and ONU use this sequence to achieve alignment at the boundary of the upstream and downstream PHY frame, respectively. The coding of the PSync field is 0xC5E51840 FD59BB49.

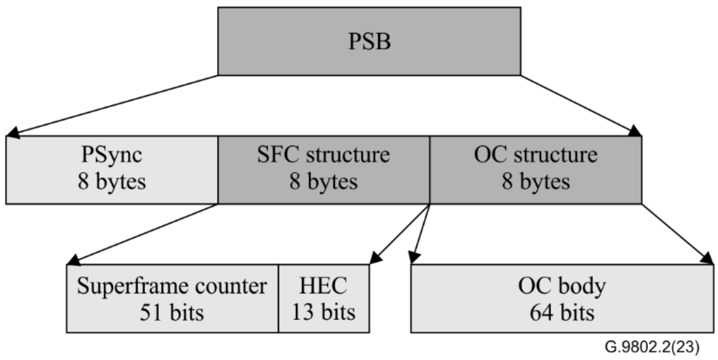


Figure B.5 – Physical synchronization block (PSB)

B.4.1.2 Superframe counter structure

The SFC structure is a 64-bit field that contains a 51-bit superframe counter (SFC) and a 13-bit HEC field (see Figure B.5). The SFC is maintained by the OLT CT and is incremented by one every PHY frame. Whenever the SFC reaches its maximum value (all ones), it is set to 0 on the next increment operation.

The SFC structure in a downstream management TC frame is populated with OLT CT's SFC value at the moment the first bit of the frame is transmitted. Note that the SFC values in consecutive management TC frames are not necessarily represented by consecutive integers. A WDM PON management TC frame also carries the SFC offset (see clause B.3.3), which provides the length of the time interval between the instant the SFC has been incremented and the moment the first bit of the frame is transmitted.

The ONU uses the SFC and SFC offset in a received downstream management TC frame to set its own copy of the SFC. The ONU increments its copy of the SFC every PHY frame using a local clock source in-between downstream management TC frames and may adjust its copy of the SFC to the OLT CT's value each time a downstream management frame is received.

B.4.1.3 Operation control structure

The OC structure contains a 64-bit OC body (see Figure B.6) which has the particular format described below and is filled in by the OLT CT in accordance with explicitly specified data.

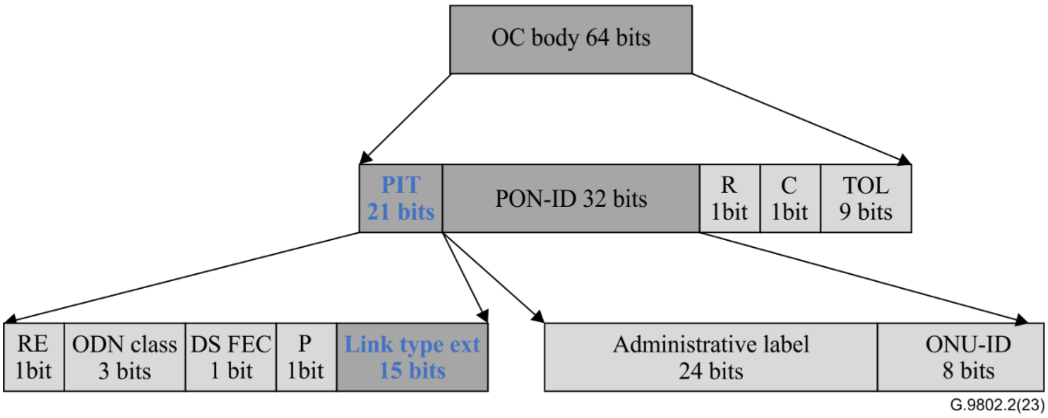


Figure B.6 – Operation control structure in WDM PON management TC PHY frame

The OC structure is shown in Figure B.6 and the content of the WRP OC body as follows:

PIT, or **PON-ID type** (21 bits, static, provisioned by the operator): an indication of the ODN architecture, the source of the reported launch power and the ODN class. The PON-ID type (PIT) field is further partitioned as follows:

- **RE flag** (1 bit): indicates whether the transmit optical level (TOL) field contains the launch power of the OLT (RE = 0) or of a reach extender (RE = 1).
- **ODN class** (3 bits): identifies the nominal optical parameters of the transceiver according to ODN optical path loss (OPL) class as defined in Table B.5 reusing [ITU-T G.985] and [ITU-T G.989.3] code values.

Table B.5 – ODN optical path loss (OPL) class encoding

Code value	ODN OPL class
000	X
001	Y
010	Reserved
011	Reserved
100	Reserved
101	Reserved
110	Reserved
111	Reserved

- **DS FEC flag** (1 bit): Indicates whether FEC is enabled in the downstream direction. When this bit is set to 1, the FEC of the carried downstream channel is enabled. When this bit is set to 0, the FEC of the carried downstream channel is disabled.
- **P flag** (1 bit): Initially set to zero, the P flag is set when an ONU has been detected and round-trip delay confirmation is expected from the ONU.
- **Link type ext** (15 bits): The link type "extended" is segmented in two sections.
  - **Distance estimation** (13 bits): Set to zero by default, it contains upon reception of a valid answer from an ONU the estimated distance between the OLT and ONU in multiple of 10 m. 13 bits enable to cover up to 80 km.
  - **Link type legacy** (2 bits): reserved

    NOTE – This two-bit field inherited from PON OC could be used to indicate the ITU-T G.9802 mode (transparent or transcoded, or data rate or else …) and the type of application/terminal supported by the OLT. This application remains for further study.

PON-ID (32 bits, static, provisioned by the operator): identifies the WDM PON channel termination within a certain domain. PON-ID consists of two fields:

– **Administrative label**: 24-bit field, assigned by EMS/OSS in accordance with some certain physical or logical numbering plan. The Administrative Label is treated transparently by the OLT CT;

– **ONU-ID**: 8-bit field, used in upstream WDM PON management PHY frame.

TOL (9 bits, dynamic, maintained by the system): Transmit optical level. An indication of the current OLT transceiver channel launch power into the ODN (at the S/R reference point), if RE = 0, or reach extender transceiver launch power, if RE = 1. Its value is an integer representing a logarithmic power measure having 0.1 dB granularity with respect to −30 dBm (i.e., the value zero represents −30 dBm, 0x12C represents 0 dBm, and 0x1FE represents 21 dBm). The 0x1FF default value indicates that TOL is not supported on the given WRP interface.

B.4.2 WDM PON Management frame synchronization

The WDM PON management TC frames are transmitted with the specified format, and the receiver must process these to locate the frame boundaries to facilitate further processing. While the details of the synchronization mechanism are internal to the receiver and are not subject to standardization, the following description represents the reference synchronization state machine that is reasonably immune to both false lock (on an independent uniformly random bitstream) and false loss of synchronization. The vendor implementation of the receiver synchronization mechanism is expected to match the performance of the reference state machine.

The reference implementation of the receiver synchronization state machine is shown in Figure B.7.

The receiver begins in the Hunt state. While in the Hunt state, the receiver searches for the PSync pattern in all possible alignments (both bit and byte) within the signal. Once an exact match with the PSync pattern specified in clause B.4.1.1 is found, the receiver verifies if the 64 bits immediately following the PSync pattern form a valid (i.e., error-free or correctable) HEC-protected SFC structure (see Table A.4 of [ITU-T G.987.3] for the HEC verification rules). If the 64-bit protected SFC structure is uncorrectable, the receiver remains in the Hunt state and continues searching for a PSync pattern. If the 64-bit protected SFC structure is valid, the receiver transitions into the PreSync state.

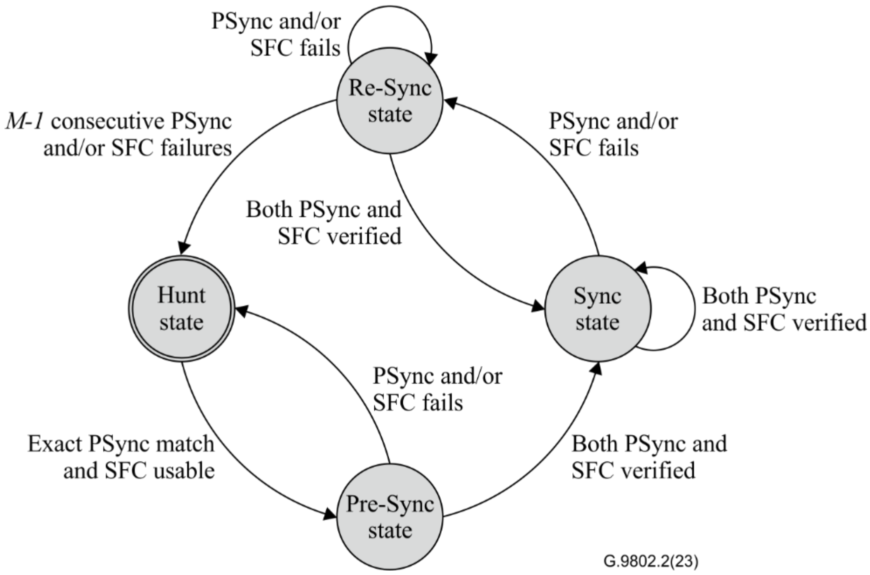


Figure B.7 – Synchronization state machine at the receiver side

Once the receiver locates a boundary of a PHY frame and leaves the Hunt state, it performs PSync and SFC verification on each subsequent PHY frame boundary. The following PHY frame boundary is located 9+PLOAM_count×12+Payload_len words later in the signal bitstream. The PSync verification is successful if at least 62 bits of the incoming 64-bit sequence match the fixed PSync pattern; otherwise, the PSync verification fails. The SFC verification is successful if the incoming 64-bit sequence forms a valid (error-free or correctable) HEC-protected field.

Once in the Pre-Sync state, the ONU transitions to the Sync state if both PSync verification and SFC verification are successful, and returns to the Hunt state if either PSync verification or SFC verification fails.

Once in the Sync state, the receiver remains in that state as long both PSync verification and SFC verification are successful, and transitions into the Re-Sync state, if either PSync verification or SFC verification fails.

Once in the Re-Sync state, the receiver transitions back to Sync state if both PSync and SFC are successfully verified once. However, if for $M - 1$ consecutive PHY frames either PSync verification or SFC verification fails, the ONU declares loss of downstream synchronization, and transitions into the Hunt state.

The recommended value of the parameter M is 3.

B.4.3 Forward error correction

FEC in transparent WDM PON management channel for further study.

See Annex F for FEC in transcoding WDM PON management channel.

B.4.4 Transcoding

Transcoding is neither needed nor supported when transmitting the WDM PON management frames using transparent WDM PON management channel.

Transcoding WDM PON management channel supports the transcoding function in the WDM PON management PHY adaptation sublayer. See Annex E for the involved transcoding procedures.

B.5 Management channel and interface

In WDM PON system, the OAM data is transmitted in auxiliary management and control channel (AMCC), which can be implemented in either transparent mode or transcoding mode. If operator selects one implementation, the interface of the management channel shall be specific.

For transparent mode, the pilot-tone is used to overlay AMCC onto the data channel (e.g., CPRI and eCPRI transmission). The interfaces and implementations of AMCC Transparent mode shall be based on the mechanisms described in Annex B of [ITU-T G.989.2].

For transcoded mode, the implementations depend on the line coding and FEC code of the data transmission channel. The interfaces and implementations of AMCC transcoding mode shall be based on the mechanisms described in Annex E and Annex F.

B.6 Channel management (per channel, per channel group, and inter-channel management)

This clause contains the procedural specification of the profile announcement function:

B.6.1 Overview

The profile announcement in a WDM PON system is transmitted in a form of a series of unacknowledged unassigned ONU-IDPLOAM messages on each downstream wavelength channel and consists of:

– a single System_Profile PLOAM message;

– a set of Channel_Profile PLOAM messages, one per deployed channel pair.

The complete set of profiles is distributed periodically with the period TminProfile, which can be set between 1 and 5 seconds.

A channel profile consists of a block of common parameter, a downstream wavelength channel descriptor, and an upstream wavelength channel descriptor.

A Channel_Profile message can include parameters for both of a downstream wavelength channel and an upstream wavelength channel.

Each Channel_Profile message specifies a static one-to-one association between the upstream and downstream wavelength channels: an ONU which is listening to the given downstream wavelength channel responds in the given upstream wavelength channel.

B.6.1.1 WDM PON system and channel descriptors

A system descriptor is a collection of system parameters and their specified values. A System_Profile PLOAM message carries System parameters.

Table B.6 – System descriptor content

Parameter	Description
Channel count	The number of WDM PON channels with distinct channel profile identifiers that exist in the system. NOTE – Each channel is counted once, regardless of the number of its peer CTs in any protection scheme.
MSE	Maximum spectral excursion represented as an unsigned integer indicating the value in units of 1 GHz.

A wavelength channel descriptor is a collection of parameters and their specified values pertaining to the downstream and upstream wavelength channels. A Channel_Profile PLOAM message carries channel profile parameter set.

Table B.7 – Channel profile elements

Parameter	Description
Common parameters	
Channel profile identifier	Channel profile identification that must be unique for each WDM PON channel that exists in the system. The total number of channel profiles is set by the Channel count of the system descriptor (see Table B.6).
AMCC type	Indicates whether the AMCC is transported in the transparent or transcoded mode.
Protection flag	The flag is set if and only if the profile pertains to a WDM PON channel to be used for protection. (For further study)
PON-ID	A 32-bit static value which is carried in the OC structure and uniquely identifies a WDM PON channel termination (CT) entity within a domain.
Downstream wavelength channel descriptor	
DWLCH ID	Assigned downstream wavelength channel ID.
Downstream line rate	The specification of the data rates supported by the OLT in the given wavelength channel in the downstream direction. In a profile of this channel this parameter is included for reference only, as the ONU already knows the value when receiving the message.
Downstream FEC indication	Downstream FEC ON/OFF indicator. In a profile of this channel this parameter is included for reference only, as the ONU already knows the value when receiving the message.
Channel partition index	An index of the operator-specified channel subset in an WDM PON system. During operation, the ONUs can be re-tuned between the channels within a channel partition, but not across the boundaries of the channel partition.
Upstream wavelength channel descriptor	
UWLCH ID	Assigned upstream wavelength channel identifier.
Upstream frequency	The frequency specification of the upstream wavelength channel: a single nominal central frequency, or a root frequency of a cyclic set of nominal central frequencies forming an upstream wavelength channel.
Optical link type	Upstream optical link type described in the Link type ext. field of the OC structure in clause B.4.1.3
Upstream line rate	The specification of the data rates supported by the OLT in the given wavelength channel in the upstream direction.
PON-TAG digest	A cryptographic hash over the public PON-TAG value computed using a shared secret.

B.6.1.2 Profile parameter learning by ONU

An OLT CT transmits each component of the profile announcement at regular intervals, frequently enough to ensure proper operation of the ONUs. The transmission frequencies of the individual profile announcement components should be reasonably consistent; however, strict periodicity and phase alignment are not required.

In order to be able to activate on the WDM PON system, an ONU should receive and process at least: the System_Profile PLOAM message, a Channel_Profile PLOAM message for the downstream wavelength channel and the upstream wavelength channel the ONU intends to operate on.

The ONU begins learning the system, and channel, profile parameters once it reaches state O1.2 of the ONU activation cycle state machine, and continues learning the profile parameters through the activation cycle, as long as it stays synchronized to the downstream PHY frames.

The ONU retains the system and channel profile parameters through the completion of the activation cycle, unless it enters state O1.1 from state O7, that is, recovers from Emergency Stop state (O7). In the latter case, the system and channel profile parameters are discarded.

B.7 WDM PON PLOAM messaging channel

B.7.1 Overview

The physical layer OAM (PLOAM) messaging channel in a WDM PON system is an operations and management facility between OLT CTs and ONUs that is based on a fixed set of 48-byte messages transported within a designated field of the XGTC frame header (downstream) and the XGTC header (upstream). The OLT CT and ONU PLOAM processors appear as clients of the respective management TC framing sublayers. The PLOAM channel provides more flexible functionality than the embedded management channel and is generally faster than the OMCC.

B.7.1.1 PLOAM channel functionality

The PLOAM channel supports the following WDM PON TC layer management functions:

– Profile announcement;

– ONU activation;

– ONU registration;

– Power management.

B.7.1.2 PLOAM channel rate limitations

Downstream PLOAM messages fall into two categories, the messages that are transmitted to un-activated ONUs associated with the given OLT CT, and the messages that are unicast to a specific ONU identified by its ONU-ID. Within a given frame, the OLT CT may transmit at most one PLOAM message to each ONU.

The ONU should be able to store eight downstream PLOAM messages before they are processed. The PLOAM processing model is single threaded. The normative processing time of a PLOAM message is 6 PHY frame duration. That is, once a downstream PLOAM message is received in an empty queue in downstream PHY frame *N*, the ONU should be able to remove the message from the queue, perform all associated processing and generate a response to be sent upstream not later than in upstream PHY frame *N*+6. Furthermore, if at the start of the upstream frame in which a PLOAM response is sent upstream, the PLOAM queue remains not empty, the message at the head of the queue should be processed and the response, if required for the given message type, be prepared for upstream transmission not later than in the 6th subsequent upstream PHY frame.

Note that under these requirements, the OLT CT can determine the maximum number of unacknowledged PLOAM messages directed to a given ONU as well as the expected response time for any downstream PLOAM message.

B.7.1.3 PLOAM channel robustness

When as a result of unicast PLOAM message processing the ONU enters or remains in the Operation state (O5), it acknowledges the processing outcome by generating an upstream PLOAM message. (See clause B.8 for the ONU activation cycle states and transitions.) Such a response PLOAM can be either of a specific type required by the particular PLOAM protocol, or of the general Acknowledgement type. An Acknowledgement PLOAM message is generated also in case of a downstream PLOAM format or processing error. Both a specific type response and the Acknowledgement type response carry the sequence number of the downstream message being acknowledged. In addition, the Acknowledgement type response carries a completion code that indicates the outcome of PLOAM message processing.

Moreover, a PLOAM message of Acknowledgement type is used in response to a PLOAM allocation when no upstream PLOAM is available for transmission. In this case, the completion code allows to distinguish between the idle condition (no PLOAM message in the transmit queue or being processed) and the busy condition (the PLOAM upstream transmit queue is empty, but a downstream PLOAM message is being processed).

Downstream PLOAM messages that fail the integrity check are not acknowledged.

If the OLT CT expects the ONU to acknowledge or respond to a message, and instead receives merely a keep-alive acknowledgement to a PLOAM request, it can infer that the ONU has failed to process the message. If ONU_i repeatedly fails to acknowledge a downstream PLOAM message, the OLT CT detects the $LOPC_i$ defect.

B.7.1.4 Extensibility

The implementation of the PLOAM channel should be flexible to accommodate future enhancements in a backward-compatible way.

B.7.2 PLOAM message format

The PLOAM message structure is shown in Table B.8, with each field being further defined in the following clauses.

Table B.8 – Generic PLOAM message structure

Octet	Field	Description
1-2	ONU-ID	Eight bits, aligned at the least significant bit (LSB) end of the 2-byte field. The eight most significant bits are reserved, and should be set to 0 by the transmitter and ignored by the receiver.
3	Message type ID	This byte indicates the message type. The enumerated code point for each message type is defined below.
4	SeqNo	Sequence number.
5-40	Message_Content	The message content is defined in the clause that describes each message type ID.
41-48	MIC	Message integrity check.

B.7.2.1 ONU-ID

The ONU-ID field includes eight reserved bits, plus an actual 8-bit ONU identifier that specifies the message recipient in the downstream direction or the message sender in the upstream direction. During ONU activation, the ONU is assigned an ONU-ID in the range from zero to 63. The reserved ONU-ID value 255 (0x00FF) indicates a message to un-activated ONU in the downstream direction or an ONU that has not been assigned an ONU-ID in the upstream direction.

B.7.2.2 Message type ID

Message type ID is an 8-bit field that indicates the type of the message and defines the semantics of the message payload. Message type ID code points are defined in clause B.7.3. Message type ID code points that are not explicitly defined in this Recommendation are reserved. Reserved Message type ID code points should not be allocated by any vendor for any purpose and should not be transmitted in a PLOAM message. Upon receipt of an upstream PLOAM message with an unsupported message type ID, an OLT CT should ignore the message, including the sequence number field. Upon receipt of a downstream PLOAM message with a reserved or unsupported message type ID, an ONU should ignore the message, if it was sent with the unassigned ONU-ID, or negatively acknowledge the message as an unknown message type, if it was sent to that specific ONU-ID.

B.7.2.3 SeqNo

SeqNo is an 8-bit field containing a sequence number counter that is used to ensure robustness of the PLOAM messaging channel.

In the downstream direction, the SeqNo field is populated with the value of a corresponding OLT CT sequence number counter. The OLT CT maintains a separate sequence number counter for each ONU PLOAM message flow. For each ONU, the OLT CT initializes the sequence number counter to 1 upon ONU-ID assignment during activation. Upon transmission of a PLOAM message, the appropriate sequence number counter is incremented. Each sequence number counter rolls over from 255 to 1; the value 0 is not used in the downstream direction.

In the upstream direction, whenever an upstream PLOAM message is a response to a downstream PLOAM message, the content of the SeqNo field is equal to the content of the SeqNo field of the downstream message. The same SeqNo may appear on more than one upstream PLOAM message. If a PLOAM message is originated autonomously by the ONU, the value SeqNo = 0 is used.

B.7.2.4 Message content

Octets five to 40 of the PLOAM message are used for the payload of PLOAM messages. The message payload content is specific to a particular message type ID and is defined in clause B.7.3. Unused octets of the message payload content are padded with the value 0x00 by the transmitting PLOAM processor and are ignored by the receiving PLOAM processor.

B.7.2.5 Message integrity check

The message integrity check (MIC) is an 8-byte field that is used to verify the sender's identity and to prevent a forged PLOAM message attack.

MIC generation is specified in clause B.11.4. Key generation and management for PLOAM MIC is specified in clause B.11.5.

For the purpose of MIC verification, there is no distinction between the significant octets and padding octets of the message payload content. Using the PLOAM message content and the shared PLOAM integrity key, the sender computes the MIC and transmits it with the PLOAM message. Using the same message content and shared key, the receiver computes its version of the MIC and compares it with the MIC value carried in the received PLOAM message. If the two MIC values are equal, the PLOAM message is valid. Otherwise, the message is declared invalid and should be discarded.

The shared PLOAM integrity key can be either ONU-specific, derived based on the master session key (MSK) or default (see clauses B.11.3.1 and B.11.5.1, respectively). The selection of either ONU-specific or default PLOAM integrity keys for each PLOAM message type is specified in clauses B.7.3.3 and B.7.3.4.

B.7.2.6 Common elements of PLOAM message format

B.7.2.6.1 Vendor_ID

Vendor_ID is the first of the two components of the ONU serial number, which ONU reports to the OLT CT in the course of activation or upon handover, and which the OLT CT stores and subsequently uses to address the ONU when the ONU-ID is not yet available or is considered unreliable.

The code set for the Vendor_ID is specified in [b-ATIS-0300220].

The four characters are mapped into the 4-byte field by taking each ASCII/ANSI character code and concatenating them. For example, Vendor_ID = ABCD fills the four octets of the PLOAM message format element as follows:

Character	Octet	Value
A	1	0x41
B	2	0x42
C	3	0x43
D	4	0x44

B.7.2.6.2 VSSN

Vendor-specific serial number (VSSN) is the second of the two components of the ONU serial number, which ONU reports to the OLT CT in the course of activation or upon handover, and which the OLT CT uses to address the ONU when the ONU-ID is unavailable or unreliable.

VSSN is a four-byte unsigned integer, selected by the ONU vendor.

B.7.2.6.3 Correlation tag

For the upstream message types that may have to be transmitted multiple times with varying optical power (Serial_Number_ONU), the ONU generates and inserts the Correlation tag into the transmitted message. Once the upstream PLOAM message is received, the OLT CT copies the correlation tag of the successful upstream PLOAM message into the downstream PLOAM response, so that the ONU is able to associate the response with the variable parameters of the successfully transmitted message.

In an upstream PLOAM message, the correlation tag is an ONU-generated non-zero 16-bit field, which should take a different value each time the transmitter optical power is changed. In a downstream PLOAM message, the correlation tag of all zeros indicates that the message is not sent as a response to an ONU's activation.

B.7.3 PLOAM message definitions

B.7.3.1 Downstream PLOAM message summary

Table B.9 summarizes the downstream PLOAM messages.

Table B.9 – Downstream PLOAM messages

Message type ID	Message name (applicability)	Function	Trigger	Effect of receipt
0x03	Assign_ONU-ID	To link a free ONU-ID value with the ONU's serial number.	When the OLT CT recognizes the unique serial number of an ONU during the discovery process.	The ONU with the specified serial number sets its ONU-ID and also its default Alloc-ID and OMCC XGEM port-ID. No Acknowledgement.
0x05	Deactivate_ ONU-ID	To instruct a specific ONU to stop sending upstream traffic and reset itself. It can also be an unassigned ONU-ID message.	At the implementor's discretion.	The ONU with the specified ONU-ID switches off its laser. The ONU-ID, default and explicit Alloc-IDs and default XGEM Port-ID are discarded. The ONU transitions to the Initial state (O1). No Acknowledgement.

Table B.9 – Downstream PLOAM messages

Message type ID	Message name (applicability)	Function	Trigger	Effect of receipt
0x06	Disable_Serial_ Number (Invariant)	Unassigned ONU-ID message to disable/enable a specific ONU or a specific ONU set.	At the implementor's discretion. Note that to effectively bring an ONU out of the Emergency Stop state, the Disable_Serial_Number PLOAM message with the Enable option must be transmitted in all available WRP channels.	The addressed ONUs (that is, the ONU with the specified serial number, or, the tuned-in ONUs in the Serial Number state (O2-3), or all tuned-in ONUs) switch off the laser and transition to the Emergency Stop state (O7). The disabled ONUs are prohibited from transmitting. Enable option: The addressed ONUs (that is, the ONU with the specified serial number or all tuned-in ONUs in the Emergency Stop state (O7)) transition to the Initial state (O1). The enabled ONUs discard the TC layer configuration and restart the activation, as specified in clause B.8. No Acknowledgement.
0x09	Request_ Registration	To request an ONU's Registration_ID.	At the implementor's discretion; ONU has been previously activated.	Send the Registration message.
0x12	Reserved for Sleep Mode	FFS	FFS	FFS
0x17	System_Profile	Unassigned ONU-ID message containing a copy of the system descriptor (see clause B.6.1.1).	Periodically with programmable periodicity.	The ONU stores the profile information or updates the profile information previously stored for use in subsequent channel management and operation tasks. No Acknowledgement.

Table B.9 – Downstream PLOAM messages

Message type ID	Message name (applicability)	Function	Trigger	Effect of receipt
0x18	Channel_Profile (Specific message format)	Unassigned ONU-ID message containing a copy of one downstream wavelength channel descriptor and one upstream wavelength channel descriptor (see clause B.6.1.1).	Periodically with programmable periodicity.	The ONU stores the profile information or updates the profile information previously stored for use in subsequent channel management and operation tasks. No Acknowledgement.
0x1C	Rate_Control	To instruct an ONU to change its receive or transmit data rate.	At the OLT's discretion.	The ONU sends acknowledgement and modifies its receive and/or transmit rate according to the instructions.
0x1D	Reboot_ONU	Unassigned ONU-ID or unicast message to cause one or more ONUs to reboot.	At the implementer's discretion.	This is downstream only message and OLT does not expect ACK for this message. All addressed ONUs are expected to reboot.

B.7.3.2 Upstream PLOAM message summary

Table B.10 summarizes the upstream messages.

Table B.10 – Upstream PLOAM messages

Message type ID	Message name (applicability)	Function	Trigger	Effect of receipt
0x01	Serial_Number_ ONU (Specific field formats)	To report the serial number of an activating ONU.	An ONU in the Serial Number state (O2-3) sends a Serial_Number_ONU message after tuning to the correct upstream wavelength to announce its presence on the PON.	The OLT CT detects an activation attempt, discerns the activating ONU's serial number and provides feedback to the activating ONU, which can be in the form of Assign_ONU-ID message.
0x02	Registration	To report the Registration_ID of an ONU.	When the ONU is in the Operation state (O5) and is responding to the Request_ Registration message.	The OLT CT may use the ONU's Registration_ID as described further in clause B.11.2.1.

Table B.10 – Upstream PLOAM messages

Message type ID	Message name (applicability)	Function	Trigger	Effect of receipt
0x09	Acknowledgement	To indicate reception of specified downstream messages, to report PLOAM processing error, or to provide busy or no-message indication.	Upon receipt of a downstream message that requires acknowledgement.	The OLT CT uses a received Acknowledgement PLOAM message to verify integrity of the PLOAM channel with the given ONU.
0x10	Reserved for Sleep Mode	FFS	FFS	FFS
0x1C	Rate_Response	To respond to the Rate_Control PLOAM message, indicating either the intent or the inability to execute the instruction, along with the applicable response code.	Upon receipt of a Rate_Control message.	The OLT CT either adjusts the line rates according to the instructions, or executes a diagnostic procedure at its discretion.

B.7.3.3 Downstream PLOAM message formats

B.7.3.3.1 Assign_ONU-ID message

Information regarding Assign_ONU-ID message is provided in Table B.11.

Table B.11 – Assign_ONU-ID message

Octet	Content	Description
1-2	ONU-ID	0x00FF, Unassigned ONU-ID ONU-ID.
3	Message type ID	0x03, "Assign_ONU-ID".
4	SeqNo	Eight-bit Unassigned ONU-ID PLOAM sequence number.
5-6	ONU-ID Assignment	LSB-justified 8-bit assigned ONU-ID value padded with eight most significant bit (MSB) zeros; range 0..63 (0x0000..0x003F).
7-10	Vendor_ID	See clause B.7.2.6.1.
11-14	VSSN	See clause B.7.2.6.2.
15-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.3.2 Deactivate_ONU-ID message

Information regarding Deactivate_ONU-ID message is provided in Table B.12.

Table B.12 – Deactivate_ONU-ID message

Octet	Content	Description
1-2	ONU-ID	Directed message to one ONU or unassigned ONU-ID message to all ONUs. As an unassigned ONU-ID message, ONU-ID = 0x00FF.
3	Message type ID	0x05, "Deactivate_ONU-ID".
4	SeqNo	Eight-bit unicast or unassigned ONU-ID PLOAM sequence number, as appropriate.
5-6	Reason Code	Reserved for troubleshooting purposes. Set to 0x0000, if not supported or not specified. An aware ONU's action is limited to logging the value.
7-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.3.3 Disable_Serial_Number message

Information regarding Disable_Serial_Number message is provided in Table B.13.

Table B.13 – Disable_Serial_Number message

Octet	Content	Description
1-2	ONU-ID,	0x00FF, Unassigned ONU-ID.
3	Message type ID	0x06, "Disable_Serial_Number".
4	SeqNo	Eight-bit unassigned ONU-ID PLOAM sequence number.
5	Disable/enable	0xFF: The ONU with this serial number is denied upstream access. 0x00: The ONU with this serial number is allowed upstream access. 0x0F: All tuned-in ONUs are denied upstream access. The content of bytes 6..13 is ignored. 0x3F: Disable_Discovery: the tuned-in ONUs in O2-3 state are denied upstream access. The content of bytes 6..13 is ignored. 0xF0: All tuned-in ONUs are allowed upstream access.
6-9	Vendor_ID	See clause B.7.2.6.1.
10-13	VSSN	See clause B.7.2.6.2
14-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.3.4 Request_Registration message

Information regarding Request_Registration message is provided in Table B.14.

Table B.14 – Request_Registration message

Octet	Content	Description
1-2	ONU-ID	Directed message to one ONU.
3	Message type ID	0x09, "Request_Registration".
4	SeqNo	Eight-bit unicast PLOAM sequence number.
5-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check computed using the default PLOAM integrity key.

B.7.3.3.5 Channel_Profile message

Information regarding Channel_Profile message is provided in Table B.15.

Table B.15 – Channel_Profile message

Octet	Content	Description
1-2	ONU-ID	0x00FF, Unassigned ONU-ID.
3	Message type ID	0x18, "Channel_Profile".
4	SeqNo	Eight-bit unassigned ONU-ID PLOAM sequence number.
5	Control octet	An octet of the form 0AEP 0TDU, where: A – AMCC type indication: A = 0: Transparent; A = 1: Transcoded. E – Engaged flag: E = 0: Channel is available. E = 1: Channel has been paired with an ONU. P – Reserved for Protection (FFS) T – *This* channel indicator: T = 0: The channel profile pertains to another WRP channel. T = 1: The channel profile pertains to the WRP channel in which it is transmitted (necessarily, D = 0). D – Downstream void indicator: D = 0: Downstream descriptor valid. D = 1: Downstream descriptor to be ignored. U – Upstream void indicator: U = 0: Upstream descriptor valid. U = 1: Upstream descriptor to be ignored. Flags T, D and U enable a downstream transmission to supply a descriptor for an upstream channel.
6-7	Channel profile identifier	An identifier which is unique for each WRP channel that exists in the system.
8	Channel profile version	VVVV 0000, where: VVVV – Four-bit channel profile version If the content of the channel profile changes, the OLT CT should ensure that the version also changes, so that the ONU can detect updates solely on the basis of the version field.

Table B.15 – Channel_Profile message

Octet	Content	Description
9-12	PON-ID	A 32-bit static value which is carried in the OC structure of each downstream PHY frame in the specified WRP channel (see clause B.4.1.3); consists of 24-bit administrative label (octets 9 and 10 and 11) and ONU-ID (octet 12).
13	Service type	Type of PtP client service by the channel (WRP) Encoding: For further study.
14-15	DWLCH ID	Assigned downstream wavelength channel ID.
16-19	Downstream frequency	The nominal central frequency of the downstream wavelength channel, expressed as an unsigned integer indicating the value in units of 0.1 GHz.
20	Downstream rate	A bitmap of the form 0000 ABCD indicating the downstream rate support within the WRP channel. A – Rate class 1 (~10 Gbit/s) B – Rate class 2 (~25 Gbit/s) C – Rate class 3 (~50 Gbit/s) D – Rate class 4 (~100 Gbit/s) The bit value of 1 indicates that the respective rate class is supported; the bit value of 0 indicates the respective rate class is not supported.
21	Channel partition	An integer representing the Channel partition index associated with the given Channel_profile.
22-23	UWLCH ID	Assigned upstream wavelength channel ID.
24-27	Upstream frequency	The nominal central frequency of the upstream wavelength channel or a root frequency of the cyclic set of central frequencies forming an upstream wavelength channel, expressed as an unsigned integer indicating the value in units of 0.1 GHz.
28	Upstream rate	A bitmap of the form 0000 ABCD indicating the upstream rate support within the WRP channel. A – Rate class 1 (~10 Gbit/s) B – Rate class 2 (~25 Gbit/s) C – Rate class 3 (~50 Gbit/s) D – Rate class 4 (~100 Gbit/s) The bit value of 1 indicates that the respective rate class is supported; the bit value of 0 indicates the respective rate class is not supported.
29-36	PON-TAG digest	A 64-bit value computed as a cryptographic hash over the public PON-TAG value and the shared secret Registration_ID: Digest = AES-CMAC(PON-TAG|PON-TAG, Registration_ID | "PtoPisSimple", 64).
37-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.3.6 Reboot_ONU message

Table B.16 describes the Reboot ONU message.

Table B.16 – Reboot_ONU message

Octet	Content	Description
1-2	ONU-ID	Directed message to one ONU or unassigned ONU-ID message. A single ONU is addressed in this message either through an assigned ONU-ID or through Vendor_ID and VSSN with ONU-ID set to 0x00FF (Unassigned ONU-ID). All ONUs are addressed on the PON when ONU-ID is set to 0x00FF (Unassigned ONU-ID) and Vendor-ID and VSSN fields are set to 0x00.
3	Message type ID	0x1D, "Reboot_ONU".
4	SeqNo	Eight-bit unicast or unassigned ONU-ID PLOAM sequence number, as appropriate.
5-8	Vendor_ID	See clause B.7.2.6.1. This field is inspected only when ONU-ID is set to 0x00FF (Unassigned ONU-ID).
9-12	VSSN	See clause B.7.2.6.1. This field is inspected only when ONU-ID is set to 0x00FF (Unassigned ONU-ID).
13	Reboot depth	This field defines the enumerated values: 0x0 MIB reset (MIB reset is defined in clause 9.1.3 of [ITU-T G.988]) 0x1 Perform equivalent of OMCI reboot (clause A.2.35 of [ITU-T G.988]) 0x2 Perform equivalent of power cycle reboot 0x3 Configuration reset, then perform MIB reset and reboot* 0x4..0xFF Reserved *Sometimes ONU may not come up even after OMCI reboot or power-cycle reboot due to saved configuration in the non-volatile memory of the ONUs. When action is set to 0x3, ONU will reset, clear its previously saved configuration (e.g., VoIP configuration and dual managed ONU configuration), perform a MIB reset and then reboot. Factory configuration (serial number and MAC) and registration ID, software images and indication of which image is committed should not be affected by this action. These mechanisms are intended to be used as a last resort to revive the ONU. NOTE – Applicable ONU states of the Reboot_ONU PLOAM is up to the implementation.
14	Reboot Image	This field defines which image will be loaded and executed (i.e., which image will be active) upon reboot using the enumerated values: 0x0 Load and execute the image that is currently committed 0x1 Load and execute the image that is not currently committed This field is ignored when Reboot depth = 0x0
15	ONU State	This field defines the enumerated values: 0x0 Reboot if ONU is in any state 0x1 Reboot only if ONU is in states O1, O2-3

Table B.16 – Reboot_ONU message

Octet	Content	Description
16	Flags	Bits 2-1: 00 Reboot regardless of POTS/VoIP call state 01 Reboot only if no POTS/VoIP calls are in progress 10 Reboot only if no emergency call is in progress 11 Reserved Bits 8-3: Reserved
17-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.3.7 System_Profile message

Table B.17 describes the System_Profile message.

Table B.17 – System_Profile message

Octet	Content	Description
1-2	ONU-ID	0x00FF, Unassigned ONU-ID.
3	Message type ID	0x17, "System_Profile".
4	SeqNo	Eight-bit unassigned ONU-ID PLOAM sequence number.
5-7	WRPSYS ID	The 20-bit identity of the WDM PON system within a certain domain. This is a reference value set by the OSS. The eight LSBs of WRPSYS ID are in Octet 7; the four MSBs of WRPSYS ID are in the LSB nibble of Octet 5. The four MSBs of Octet 5 are zeros.
8	System profile version	VVVV 0000, where: VVVV – Four-bit system profile version. If the content of the system profile changes, the OLT CT should ensure that the version also changes, so that the ONU can detect updates solely on the basis of the version field.
9	Channel count	0000 CCCC, where: CCCC – an unsigned integer indicating the number of channels that exist in the system, each described with a Channel_Profile PLOAM message with a distinct Channel profile identifier.
10	Channel spacing	An unsigned integer indicating the value in units of 1 GHz. NOTE – Channel spacing is a system parameter characterizing the grid to which the system is designed, rather than how the wavelength channels are deployed.
11	Upstream MSE	Maximum spectral excursion (MSE) represented as an unsigned integer indicating the value in units of 1 GHz.

Table B.17 – System_Profile message

Octet	Content	Description
12-19	PON-TAG	An 8-byte static attribute of the OLT CT that is chosen by the operator and is used to bind the master session key (MSK) to the context of the security association (see clause B.11.3.3). Unless the profile version is incremented, PON-TAG is the same for System_Profile messages with all profile indices transmitted by the OLT CT. It is good practice to ensure that PON-TAG is unique within OLT CTs belonging to a common WRPSYS ID and fixed for the lifetime of the system.
20-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.3.8 Rate_Control message

Table B.18 describes the Rate_Control message.

Table B.18 – Rate_Control message

Octet	Content	Description
1-2	ONU-ID	Directed message to one ONU.
3	Message type ID	0x1C, "Rate_Control".
4	SeqNo	Unicast PLOAM sequence number.
5	Operation code	0x00: Request; All parameters are applicable. 0x01: Complete_d. Target downstream and upstream line rate parameters are applicable. Octets 6..8 are set to 0x00 by the OLT CT and ignored by the ONU.
6-7	Scheduled SFC	The 16 least significant bits of the superframe counter value of the PHY frame in the future when the ONU has to commence the transceiver tuning operation. The specified value pertains to both downstream and upstream tuning. Whenever separate tuning is deemed beneficial, two unidirectional tuning actions executed serially can be considered.
8	Rollback flag	A bitmap of the form 0000 000R, where: R – Rollback flag: R=1: rollback available when tuning fails; R=0: no rollback available when tuning fails.

Table B.18 – Rate_Control message

Octet	Content	Description
9	Nominal line rates	An octet of the form 0DDD 0UUU, where: DDD – downstream nominal line rate: DDD = 000: Rate class 1 (~10 Gbit/s) DDD = 001: Rate class 2 (~25 Gbit/s) DDD = 010: Rate class 3 (~50 Gbit/s) DDD = 011: Rate class 4 (~100 Gbit/s) UUU – upstream nominal line rate: UUU = 000: Rate class 1 (~10 Gbit/s) UUU = 001: Rate class 2 (~25 Gbit/s) UUU = 010: Rate class 3 (~50 Gbit/s) UUU = 011: Rate class 4 (~100 Gbit/s)
10-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.7.3.4 Upstream PLOAM message formats

B.7.3.4.1 Serial_Number_ONU message

Information regarding Serial_Number_ONU message is provided in Table B.19.

Table B.19 – Serial_Number_ONU message

Octet	Content	Description
1-2	ONU-ID	0x00FF, Unassigned ONU-ID; or in case of an ONU with multiple PON interfaces undergoing activation on the second and subsequent PON interfaces, the ONU-ID previously assigned to the pilot PON interface, which has been activated first.
3	Message type ID	0x01, "Serial_Number_ONU"
4	SeqNo	Set to 0x00 for all instances of Serial_Number_ONU PLOAM message.
5-8	Vendor_ID	See clause B.7.2.6.1.
9-12	VSSN	See clause B.7.2.6.2.
13-16	Reserved	Each octet set to 0x00 by the transmitter, treated as "don't care" by the receiver.
17-18	Correlation tag	See clause B.7.2.6.3.
19-22	Current downstream PON-ID	The PON-ID received by the ONU in its current downstream wavelength channel.
23-26	Current upstream PON-ID	The PON-ID of the Channel_Profile message containing the descriptor of the upstream wavelength channel in which the ONU is transmitting.

Table B.19 – Serial_Number_ONU message

Octet	Content	Description
27-34 (WRP)	SN Digest	A 64-bit value computed as a cryptographic hash over the publicly available serial number (SN) value and the shared secret Registration-ID: Digest = AES-CMAC(Vendor_ID|PON-ID|VSSN|PON-ID, Registration_ID | 0x50746F50697353696D706C65, 64).
35	Reserved	Each octet set to 0x00 by the transmitter, treated as "don't care" by the receiver.
36	Reserved	Each octet set to 0x00 by the transmitter, treated as "don't care" by the receiver.
37 (WRP)	Upstream line rate capability	A bitmap of the form 0000 ABCD indicating the ONU's upstream nominal line rate capability: A – Rate class 1 (10 Gbit/s) B – Rate class 2 (25 Gbit/s) C – Rate class 3 (50 Gbit/s) D – Rate class 4 (100 Gbit/s) The bit value of 1 indicates that the respective rate class is supported; the bit value of 0 indicates the respective rate class is not supported.
38	Reserved	Each octet set to 0x00 by the transmitter, treated as "don't care" by the receiver.
39	Reserved	Each octet set to 0x00 by the transmitter, treated as "don't care" by the receiver.
40	Activation Debug Information	The octet of the form DDDD RRCS. DDDD is the activation reason code that reflects the most recent transition to O2-3 state. The Activation reason code has the following code points: 0000 – activation debug is not supported, no previous operation history is available, or the ONU is in a factory-fresh configuration. 0001 – Deactivate_ONU-ID PLOAM has been received in O2-3; 0010 – Not used for WDM PON; 0011 – Deactivate_ONU-ID PLOAM has been received in another state (that is, a state with a functional OMCC channel); 0100 – Calibration_Request PLOAM has been received in O2-3; 0101 – the ONU is being enabled after Emergency Stop (that is, after a sojourn in O7 state); 0110 – Loss of downstream synchronization (LODS) has occurred in O2-3; 0111 – Not used for WDM PON; 1000 – TOZ has expired in O2-3; 1001 – Not used for WDM PON; 1010 – TO2 has expired in O6; 1011 – TO4 has expired in O8; 1100 – TO5 has expired in O9; 1101 – ONU has lost power. Other code points reserved.

Table B.19 – Serial_Number_ONU message

Octet	Content	Description
		C is channel change flag, which is set in connection with a non-zero value of the Activation reason code to indicate that the wavelength channel has been changed, and the new value was pre-determined by the PLOAM protocol. The C flag is persistent between activation attempts, and is cleared, once the OMCC channel is established. S is a scan flag which is set to indicate the current channel (which may or may not change from the previous activation) has been found in the course of wavelength channel scanning. The S flag is persistent between activation attempts, and is cleared, once the OMCC channel is established. R – reserved; ONU sets this bit to zero.
41-48	MIC	Message integrity check computed using the default PLOAM integrity key.

B.7.3.4.2 Registration message

Information regarding Registration message is provided in Table B.20.

Table B.20 – Registration message

Octet	Content	Description
1-2	ONU-ID	ONU-ID of the message sender.
3	Message type ID	0x02, "Registration".
4	SeqNo	Repeated from downstream Request_Registration message.
5-40	Registration_ID	A string of 36 octets that has been assigned to the subscriber on the management level, entered into and stored in non-volatile storage at the ONU. Registration_ID may be useful in identifying a particular ONU installed at a particular location. The default is a string of 0x00 octets (Note).
41-48	MIC	Message integrity check computed using the default PLOAM integrity key.
NOTE – It is recommended that the Registration_ID be a string of American standard code for information interchange (ASCII) characters, justified in the lower-numbered bytes of the registration message, and with 0x00 values in unused byte positions.		

B.7.3.4.3 Acknowledgement message

Information regarding Acknowledgement message is provided in Table B.21.

Table B.21 – Acknowledgement message

Octet	Content	Description
1	ONU-ID	ONU-ID of the message sender.
3	Message type ID	0x09, "Acknowledgement".
4	SeqNo	Same as downstream sequence number. Set to the value of SeqNo in the downstream PLOAM message to which the present message provides an acknowledgement.

Table B.21 – Acknowledgement message

Octet	Content	Description
5	Completion _code	Completion code: 0x00: OK; 0x01: No message to send; 0x02: Busy, preparing a response; 0x03: Unknown message type; 0x04: Parameter error; 0x05: Processing error. Other values reserved.
6	Attenuation	Attenuation parameter represents a requested attenuation level as a part of the power levelling instruction to an ONU, or an ONU's attenuation level at the time of the message transmission as a part of the power levelling report. This is a one-octet field of the form 0000 MMMM, where MMMM is the attenuation level: 0000: Unattenuated transmission; 0001..0111: attenuation level in steps of 3dB.
7	Power levelling capability	Power levelling capability is a seven-bit bitmap of the form 0CCC CCCC, whereby a bit in the K-th least significant position indicates that the ONU supports the attenuation level of 3K dB. For example, 0000 0010 indicates support of 6dB attenuation level.
8-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the ONU-specific derived shared PLOAM integrity key.

B.7.3.4.4 Rate_Response message

Information regarding Rate_Response message is provided in Table B.22.

Table B.22 – Rate_Response message

Octet	Content	Description
1-2	ONU-ID	ONU-ID of the message sender
3	Message type ID	0x1C, "Rate_Response".
4	SeqNo	Eight-bit unicast PLOAM sequence number. Repeats the value from the downstream Rate_Control PLOAM message.
5	Operation code	Operation code: 0x00: ACK; 0x01: NACK; 0x03: Complete_u; 0x04: ROLLBACK. Other values reserved.

Table B.22 – Rate_Response message

Octet	Content	Description
6	Response code	Response code: 0x00: As long as Operation code is ACK or Complete_u; 0x01: NACK due to downstream line rate being out of supported Rx tuning range; 0x02: NACK due to upstream line rate being out of supported Tx tuning range; 0x03: NACK due to ONU not being ready to start transceiver tuning by Scheduled SFC; 0x10: ROLLBACK due to no DSYNC on current downstream wavelength channel. Other values reserved.
7-40	Padding	Set to 0x00 by the transmitter; treated as "don't care" by the receiver.
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

B.8 WDM PON ONU activation cycle

B.8.1 Causal sequence of activation events

The OLT CT controls the WDM PON ONU activation by means of exchanging upstream and downstream PLOAM messages. The outline of the activation events in their causal order is given below:

1) The activating ONU tunes its receiver to search for the downstream wavelength channel, attains synchronization to user data and management TC data and collects the system, channel and profile information, confirming the channel partition, downstream and upstream channel frequency, line rate, downstream and upstream wavelength channel ID, service type, and channel assignment. The ONU may repeat the downstream wavelength channel search as necessary.
2) Once the ONU confirms the downstream wavelength channel, it makes best effort to tune its transmitter to specified upstream wavelength channel and starts announcing its presence on the PON with a Serial_Number_ONU PLOAM message, which also contains authenticating information.
3) When the OLT CT successfully authenticates the ONU, it provides a confirmation using the Assign_ONU-ID PLOAM message.
4) The ONU completes activation and starts operation.

B.8.2 WDM PON ONU activation cycle state machine

B.8.2.1 WDM PON ONU activation states, timers and inputs

Table B.23 summarizes the ONU activation cycle states.

Table B.23 – ONU activation cycle states

ONU State/Substate		Semantics
Ref	**Full name**	
O1	Initial state	The ONU enters the Initial state (O1) when it originally powers up, or upon reactivation. The transmitter is off.
	O1/Off-Sync ≡ O1.1	The substate is the entry point to O1 state. The ONU searches for the downstream wavelength channel, attempting to achieve synchronization in **both** user data and management TC data paths. Once the downstream synchronization is attained, the ONU transitions to the O1/Profile Learning substate.
	O1/Profile Learning ≡ O1.2	The ONU collects profile information from the management TC data path, determines whether the channel is available and verifies the PON-TAG digest.
O2-3	Serial Number state	The ONU starts the discovery timer TOZ. The ONU activates its transmitter. The ONU transmits Serial_Number_ONU PLOAM message regularly, providing authenticating information, until the OLT CT confirms ONU-ID assignment. ONU returns to O1 state upon timer TOZ expiration
O5	Operation state	The ONU enters the Operation state (O5) when it receives and transmits user data and management TC data.
	O5/Operating ≡ O5.1	The substate is the entry point to O5 state. The ONU receives and transmits user data and management TC data.
	O5/Management LODS ≡ O5.3	The ONU enters this substate from the Operating (O5.1) following the loss of downstream synchronization in the management TC data path, or from the Intermittent LODS state (O6) following the restoring of downstream synchronization in the user data path. Upon entry to the Management LODS state (O5.3), the ONU starts timer TOM and keeps the communication of user data. If the downstream synchronization is restored in management TC data path, before timer TOM expires, the ONU transitions back into the Operating (O5.1). Upon timer TOM expires or following the loss of downstream synchronization in the user data path, the ONU transitions to the Intermittent LODS state (O6).
O6	Intermittent LODS state	The ONU enters this state from the Operation state (O5) following the loss of downstream synchronization in the user data path or TOM expires. Upon entry to the Intermittent LODS state (O6), the ONU starts timer TOL. If the downstream synchronization is restored in the user data path, before timer TOL expires, the ONU transitions back into the Management LODS state (O5.3). Upon timer TOL expiration, the ONU transitions to the Initial state (O1).
O7	Emergency Stop state	The ONU switches its transmitter off, but maintains downstream synchronization to both user data and management TC data paths, and parses the management TC data information.
* The substate O5.2 is specified in other PON system, but is irrelevant to WDM PON system.		

Table B.24 summarizes the ONU activation cycle state machine timers.

Table B.24 – ONU activation cycle state machine timers

Timer	Full name	State	Semantics and initial value
TOZ	Discovery timer	O2-3	Timer TOZ controls the duration of an ONU discovery attempt in the Serial Number state (O2-3), forcing a transition to the Initial state (O1) if the discovery feedback from the OLT CT is lacking.
TOM	Management synchronisation recovery timer	O5/Management LODS	Timer TOM is used to assert a failure to recover from a Management LODS condition by limiting the time an ONU can remain in the Management LODS (O5.3).
TOL	Loss of downstream synchronization (LODS) timer.	O6	Timer TOL is used to assert a failure to recover from an intermittent LODS condition by limiting the time an ONU can remain in the Intermittent LODS state (O6).

The Applicable states column in Table B.25 includes all states where the event may occur in principle, including due to protocol error. Whether an event requires processing is indicated in Table B.26.

Table B.25 – ONU activation cycle state machine inputs

Input	Applicable states	Semantics
Downstream synchronization events		
DSYNC	O1/Off-Sync; O6;	Downstream synchronization attained. The event is generated when the synchronization has been achieved in the downstream user data path.
LODS	All states and substates, except O1/Off-Sync; O6;	Loss of downstream synchronization. The event is generated when the downstream synchronization in the user data path is lost.
MDSYNC	O1/Off-Sync; O5/Management LODS	Management downstream synchronization attained. The event is generated when the synchronization has been achieved in the downstream management TC data path.
MLODS	O1/Profile Learning; O2-3; O5/Operating	Management loss of downstream synchronization. The event is generated when the downstream synchronization in the management TC data path is lost.
Internal events		
DWLCH ok to work	O1/Profile Learning;	The channel is available and the PON-TAG digest is successfully verified.
DWLCH not appropriate	O1/Profile Learning;	The channel is engaged, or the PON-TAG digest verification is unsuccessful.
Timer events		
TOZ expires	O2-3	Timer expiration
TOM expires	O5/Management LODS	Timer expiration
TOL expires	O6	Timer expiration
PLOAM events		
ONU-ID Assignment	O1/Profile Learning, O2-3, O5, O7	Assign_ONU-ID PLOAM message with matching SN received.
Deactivate ONU-ID request	O1/Profile Learning, O2-3, O5, O7	Deactivate_ONU-ID PLOAM message received
Disable SN request	O1/Profile Learning, O2-3, O5, O7	Disable_Serial_Number PLOAM message with Disable option received
Enable SN request	O1/Profile Learning, O2-3, O5, O7	Disable_Serial_Number PLOAM message with Enable option received.

Table B.25 – ONU activation cycle state machine inputs

Input	Applicable states	Semantics
Other PLOAM messages*		
System_Profile	O1/Profile Learning, O2-3, O5, O7	PLOAM message of specific type is received.
Channel_Profile	same as above	PLOAM message of specific type is received.
Key_control	same as above	PLOAM message of specific type is received.
Rate_Control	same as above	PLOAM message of specific type is received.
* Although the input events of this part do not drive the ONU state machine, their effect depends on the ONU state at the time the event occurs (the message is received).		

B.8.2.2 ONU state diagram

The WDM PON ONU activation cycle state transition diagram is graphically represented in Figure B.8.

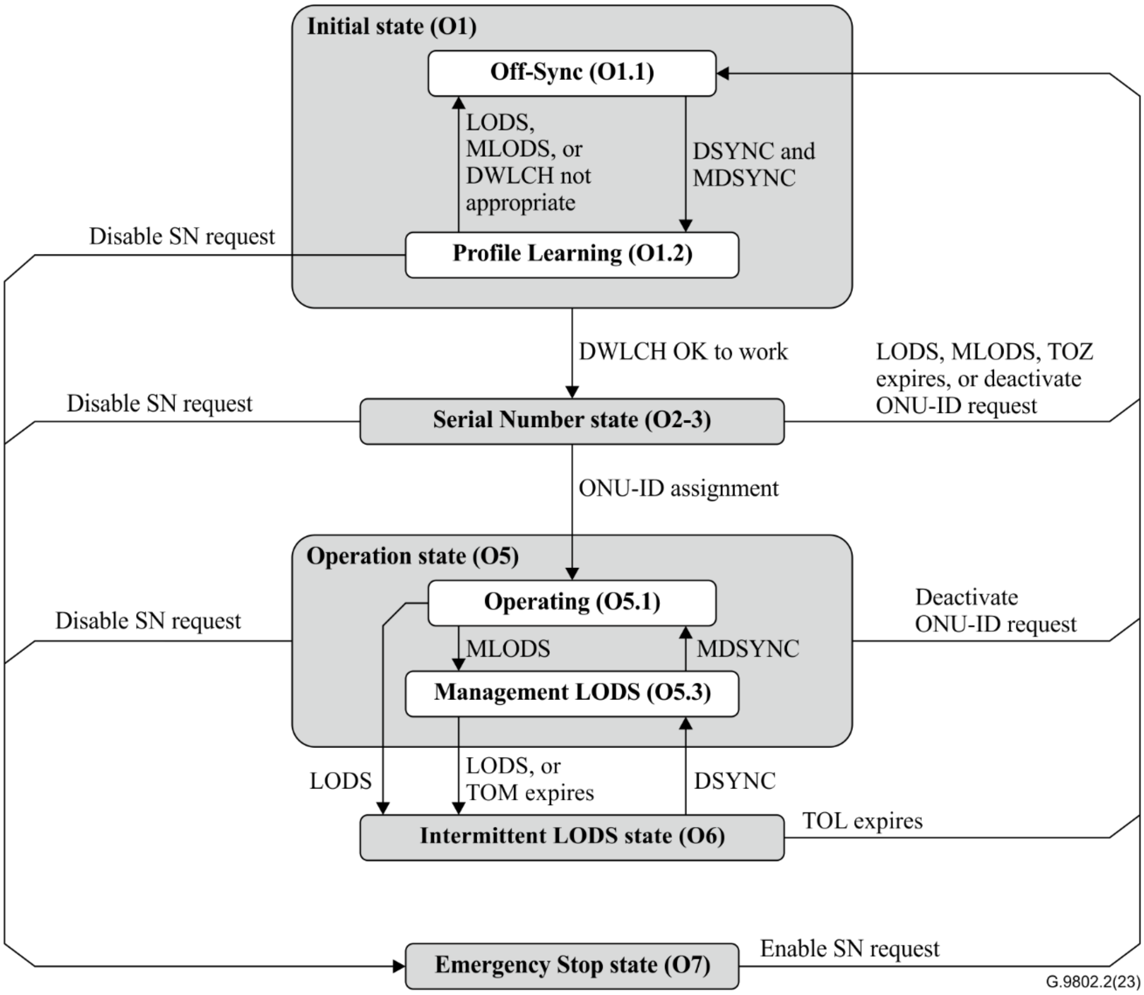


Figure B.8 – WDM PON ONU state diagram

B.8.2.3 ONU state transition table

In Table B.26 a shaded cell indicates that an event is not applicable in the given state; a dash within a cell indicates that the event is not processed (ignored) in the given state. For the receipt of the PLOAM messages that do not drive the ONU activation cycle state machine, Table B.26 only indicates whether the event is processed (plus) or ignored (dash) in the given state. The specific effects of the PLOAM message receipt are discussed in the corresponding clauses of this Recommendation. The TC layer configuration parameter sets referenced in Table B.26 are specified in Table B.27.

Table B.26 – WDM PON ONU activation cycle state transition table

Events	**ONU activation cycle states**						
	Initial state O1		**Serial Number state O2-3**	**Operations state O5**		**Intermittent LODS O6**	**Emergency Stop state O7**
	Off-Sync O1.1	**Profile Learning O1.2**		**Operating O5.1**	**Management LODS O5.3**		
Power up If last operational state was O7 ==> O7 else ==> O1.1							
Downstream synchronization attained DSYNC	Both DSYNC and MDSYNC; ==> O1.2;					Stop TOL; ==> O5.3;	
Loss of downstream synchronization LODS		Discard I; ==> O1.1;	Discard I; Stop TOZ; ==> O1.1;	Start TOL; ==> O6;	Start TOL; Stop TOM; ==> O6;		–
Downstream management synchronization attained MDSYNC	Both DSYNC and MDSYNC; ==> O1.2;				Stop TOM; ==> O5.1;		
Loss of downstream management synchronization MLODS		Discard I; ==> O1.1;	Discard I; Stop TOZ; ==> O1.1;	Start TOM; ==> O5.3;			
Downstream wavelength channel is OK to work		Start TOZ; ==> O2-3					
Downstream wavelength channel is not appropriate		Discard I; ==> O1.1;					
Timer TOZ expires			Discard I; ==> O1.1;				
Timer TOL expires						{Discard V; ==> O1.1;}	
Timer TOM expires					==> O6;		
ONU-ID assignment		–	Set II; *Stop TOZ;==>* O5;				–
Directed deactivate ONU-ID request		–	–	Discard V; ==> O1.1;	Discard V; Stop TOM; ==> O1.1;		–
Disable SN request		==> O7;	Stop TOZ; ==> O7;	==> O7;	Stop TOM; ==> O7;		–
Enable SN request		–	–	–	–		Discard VI; ==> O1.1
System_Profile		+	+				–
Channel_Profile		+	+				–
Key_Control		–	–				–
Protection_ Control (FFS)		–	–	+			–
Rate_control		–	–	+	+		–

The composition of the TC layer configuration parameter sets referenced in Table B.26 is specified in Table B.27.

Table B.27 – Reference TC layer configuration parameter sets

TC layer configuration item	Parameter set						
	I	II	III	IV	V	VI	VII
System profile parameters						X	X
Channel profile parameters						X	X
ONU-ID		X	X		X	X	
Default XGEM Port-ID		X	X		X	X	

B.9 OLT and ONU timing relationships

This clause is for further study.

B.10 Performance monitoring, supervision and defects

This clause focuses on mechanisms to detect link failure and monitor the health and performance of the links. It does not cover functions that may utilize the performance monitoring information, such as station management or provisioning.

B.10.1 Performance monitoring

To facilitate troubleshooting, it is desirable that OLT channel termination and ONU maintain a variety of performance monitoring (PM) counters. The collected counter values may trigger actions ranging from threshold crossing alerts to alarms to protection switching, which are largely beyond the scope of this Recommendation.

This clause identifies mandatory and optional PM parameters, and for the PM parameters collected at the OLT CT.

Monitoring of optical parameters, for example, transmitted and received optical power, is specified in [ITU-T G.988].

Counters collected at the ONU are available to the OLT CT using OMCI.

Table B.28 summarizes performance monitoring parameters.

Table B.28 – Performance monitoring parameters

Parameter	Mandatory or optional	Description	Collected by:		Notes
			Each ONU	OLT CT	
PHY PM					
Corrected FEC bytes	M	The number of bytes that were corrected by the FEC function.	Yes, if downstream FEC is enabled.	Yes, if upstream FEC is enabled	
Corrected FEC codewords	M	Count of FEC codewords that contained errors but were corrected by the FEC function.	Yes, if downstream FEC is enabled.	Yes, if upstream FEC is enabled	

Table B.28 – Performance monitoring parameters

Parameter	Mandatory or optional	Description	Collected by:		Notes
			Each ONU	OLT CT	
Uncorrectable FEC codewords	M	Count of FEC codewords that contained errors and could not be corrected by the FEC function.	Yes, if downstream FEC is enabled.	Yes, if upstream FEC is enabled	
Total FEC codewords	M	Count of total received FEC codewords.	Yes, if downstream FEC is enabled.	Yes, if upstream FEC is enabled	
Total received words protected by BIP-32	M	Count of received 4-byte words that are included in BIP-32 check.	Yes	Yes	
BIP-32 error count	M	Count of bit errors according to BIP-32 (Note).	Yes	Yes	
PSB HEC error count	O	HEC error in any of the fields of PSB	Yes	Yes	
FS HEC error count	O	FS header HEC errors received.	Yes	Yes	
LODS PM					
Total number of LODS events	M	Counter of state transitions from O5.1/O5.3 to O6	Yes	N/A	ONU local event
XGEM PM					
Transmitted XGEM frames	M	Total number of XGEM frames transmitted.	Yes	Yes	
Received XGEM frames	M	Total number of XGEM frames received.	Yes	Yes	
Count of the number of transmitted XGEM frames with LF bit NOT set	O	Number of transmit fragmentation operations.	Yes	Yes	
Count of XGEM frame header HEC errors	M	Number of events involving loss of XGEM channel delineation.	Yes	Yes	
Count of FS frame words lost due to XGEM frame HEC error.	O	Aggregate severity measure of the loss of XGEM channel delineation events. Note that the number of lost XGEM frames is not available.	Yes	Yes	
UTILIZATION PM					
Transmitted bytes in non-idle XGEM frames	M	Measure of downstream utilization	Yes	Yes	
Received bytes in non-idle XGEM frames	M	Measure of upstream utilization	Yes	Yes	

Table B.28 – Performance monitoring parameters

Parameter	Mandatory or optional	Description	Collected by:		Notes
			Each ONU	OLT CT	
PLOAM PM					
PLOAM MIC errors	O	Counter of received PLOAM messages with MIC errors	Yes	Yes	
PLOAM timeouts	O	Retransmission count: missing, late or errored response. No response to Request_Registration, lack of ACK, etc.	N/A	Yes	
Downstream PLOAM message count	O	Count of PLOAM messages sent by OLT CT, received by ONU, either unassigned or directed to the specific ONU-ID.	Yes	Yes (unassigned)	
System_Profile message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Channel_Profile message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Assign_ONU-ID message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Deactivate_ONU-ID message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Disable _Serial_Number message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Request_Registration message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Rate_Control message count	O	Count of PLOAM messages sent by OLT CT	Yes	Yes	
Upstream PLOAM message count	O	Count of messages (other than Acknowledgement) sent by ONU, received by OLT CT.	Yes	Yes	
Serial_Number_ONU message count	O	Count of PLOAM messages sent by ONU	Yes	Yes	
Registration message count	O	Count of PLOAM messages sent by ONU	Yes	Yes	
Acknowledgement message count	O	Count of PLOAM messages sent by ONU	Yes	Yes	
Sleep_Request message count	O	Count of PLOAM messages sent by ONU	Yes	Yes	
Rate_Response message count,	O	Count of PLOAM messages sent by ONU	Yes	Yes	
Activation PM					
OMCI PM					

Table B.28 – Performance monitoring parameters

Parameter	Mandatory or optional	Description	Collected by:		Notes
			Each ONU	OLT CT	
OMCI baseline message count	O	OMCI message count	Yes	Yes	
OMCI extended message count	O	OMCI message count	Yes	Yes	
OMCI MIC errors	O	Count of received OMCI messages with MIC errors	Yes	Yes	
Energy conservation					
Time spent in each of the OLT CT/ONU low-power states, respectively	O	Time spent in each of the OLT CT/ONU low-power states, respectively	Yes	Yes	
NOTE – The BIP-32 error count is used to obtain a BER estimate only when FEC is off.					

B.10.2 Defects

This clause captures the required actions that are performed in the TC layer, as opposed to those left to the discretion of an implementer. In particular, the effects of repeated defects of the same type are an implementation matter.

B.10.2.1 Items detected at OLT channel termination

Table B.29 summarizes defects detected at the OLT CT.

Table B.29 – Defects detected at the OLT CT

Type		Description			
		Detection conditions	Actions	Cancellation conditions	Actions
LOS	Loss of signal	The OLT CT did not receive any expected transmissions in the upstream (complete PON failure) for four consecutive frames.	At the discretion of the OLT CT; may require additional diagnostic to determine whether PON has been lost, and ultimately lead to protection switching event.	When the OLT CT receives upstream transmission.	–
SUFi	Start-up failure of ONU$_i$.	The OLT CT detects the ONU's serial number, but the ONU fails to complete the bring-up sequence.	Send Deactivate_ONU-ID PLOAM message.	The ONU is ranged successfully.	

Table B.29 – Defects detected at the OLT CT

Type		Description			
		Detection conditions	Actions	Cancellation conditions	Actions
DFi	Disable failure of ONU.	The ONU responds to an attempt to disable the ONU using its serial number (with one or more Disable_Serial_Number PLOAM messages) which may have been preceded by a failed attempt to deactivate the ONU (with one or more Deactivate_ONU PLOAM messages). Note that the OLT CT can detect this condition only if it continues to provide upstream bandwidth allocations to the ONU.	Mitigating action at OLT CT discretion. May include rogue ONU diagnostic procedures. The offending ONU-ID and the associated Alloc-IDs may have to be blocked from re-allocation.	The offending ONU is successfully re-activated and remains positively controlled, or is prevented from transmitting upstream.	
LOPCi	Loss of PLOAM channel with ONU$_i$.	Generic defect indicating breakage of the PLOAM protocol: persistent MIC failure in the upstream; lack of acknowledgements or proper PLOAM responses from the ONU. Persistent means that the same irregular condition is observed consecutively at least three times.	Mitigating action at the OLT CT discretion; may include ONU re-authentication, ONU deactivation or disabling, or execution of rogue ONU diagnostic procedures.		–

B.10.2.2 Items detected at ONU

Table B.30 summarizes defects detected at the ONU.

Table B.30 – Defects detected at the ONU

Type		Description			
		Detection conditions	Actions	Cancellation conditions	Actions
LODS	Loss of downstream synchronization.	The ONU downstream synchronization state machine in the Hunt or Pre-Sync states. (See clause B.8.2.)	Provide necessary visual indication and user-side interface signalling. Execute appropriate transition of the ONU activation state machine.	The ONU downstream synchronization state machine in the Sync or Re-Sync states.	Execute appropriate transition of the ONU activation state machine.

B.10.2.3 Urgent ONU status snapshot record

To facilitate post-mortem diagnostics, the ONU supports recording a snapshot of relevant ONU status information, defects and failure conditions. The information is collected and stored by the ONU when communication channel with the OLT CT is compromised or unavailable.

The urgent status snapshot record is made as a part of the dying gasp (DG) sequence, and any time the transmitter is being switched off by the ONU software. It can be retrieved either remotely on site or in the lab upon ONU replacement. The urgent status snapshot record is stored in non-volatile memory to ensure it survives ONU reactivation, warm and cold reboot, power cycle, and power loss.

The storage is expected to accommodate at least ten urgent status snapshot records and to be reasonably protected against accidental erasure and unauthorized access.

B.11 WRP Security

This clause discusses threat model characteristics for the WRP operating environment, and specifies authentication, data integrity and privacy protection aspects of the system.

B.11.1 Threat model for WRP

WRP security is intended to protect against the following threats:

1) An attacker could connect a malicious device at various points on the infrastructure (e.g., by tampering with street cabinets, spare ports or fibre cables). Such a device could intercept and/or generate traffic. Depending on the location of such a device, it could impersonate an OLT CT or alternatively it could impersonate an ONU.
2) A malicious user in first scenario could record packets transmitted on the passive optical network (PON) and replay them back onto the PON later, or conduct bit-flipping attacks.

Passive optical networks (PONs) are deployed in a wide variety of scenarios. In some cases, the ODN, the optical splitter, or even the ONUs may be installed in a manner considered to be physically secure or tamper-proof.

To accommodate these scenarios in an economical manner, activation of some of the WRP security features is optional, as indicated in the clauses below.

B.11.2 Authentication

The WRP system supports three mechanisms for authentication. The first mechanism is based on the use of Registration_ID. It is executed in the course of ONU activation and may be repeated throughout the duration of the activation cycle, i.e., until the ONU's next entry into the Initial state (O1). The registration-based authentication mechanism provides a basic level of authentication of the ONU to the OLT CT. It does not provide authentication of the OLT CT to the ONU. Support of the registration-based authentication mechanism is mandatory in all WRP devices. The two other authentication mechanism provide secure mutual authentication to both OLT CT and ONU. One of them is based on an ONU management and control interface (OMCI) message exchange (see Annex C). The other is based on an IEEE 802.1X message exchange and provides a wide range of extensible features (see Annex D). Support for OMCI-based and IEEE 802.1X-based authentication mechanism is mandatory for implementation at the component level, but optional from an equipment specification perspective. In other words, the transmission convergence (TC) layer implementation will have the capability to support both secure mutual authentication methods, but equipment constructed using these TC-layer implementation may choose not to support them.

It is within the discretion of an operator to require support of one or both secure mutual authentication mechanisms at the equipment specification stage, and to employ any or none of the authentication methods, including the basic registration-based authentication, when the system is in service.

Upon authentication failure, the OLT CT may undertake measures to restore functionality and to prevent a potential security breach, which may include repeating authentication using the same or an alternative mechanism, blocking upstream and downstream traffic, deactivating or disabling the offending ONU, or executing the rogue ONU diagnostic procedures.

B.11.2.1 Registration-based authentication

The registration-based authentication mechanism can provide authentication of ONU to OLT CT, but not vice versa. Its support is mandatory for all WRP systems. To maintain full functionality, this method requires:

– that a Registration_ID be assigned to a subscriber at the management level;
– that the Registration_ID be provisioned into the OLT CT and be communicated to the field personnel or to the subscriber directly;
– that the ONU support a method for entering the Registration_ID in the field (specification of such a method being beyond the scope of this Recommendation);
– that the field personnel or the subscriber in fact enter the Registration_ID into the ONU.

The Registration_ID is stored at the ONU in a non-volatile storage. It is retained through ONU re-activation and power cycle, until explicitly reset by the field personnel or the subscriber.

B.11.2.1.1 The OLT CT perspective

The OLT CT must support ONU authentication based on the reported Registration_ID, as well as the MSK and derived shared key calculation procedure based on the reported Registration_ID (see clause B.11.3).

The OLT CT requests the Registration_ID from the ONU in the following situations:

– As a final handshake upon completion of a secure mutual authentication procedure, by sending a Request_Registration message to the ONU.
– At any time throughout the ONU's activation cycle at its own discretion, by sending a Request_Registration message to the ONU.

If at the time of Registration_ID receipt from the ONU, there is no valid secure mutual association (SMA) between the OLT CT and the ONU (i.e., in the course if secure mutual authentication has not been executed or has failed), the OLT CT:

– must compute the master session key (MSK) and derived shared keys based on the reported Registration_ID;
– may perform authentication of the ONU based on the reported Registration_ID.

It is up to the operator to specify whether registration-based authentication is performed and how the result is used. Failure of registration-based authentication shall not prevent the OLT CT from maintaining management level communication with the ONU, but may have an effect on how the OLT CT further handles the ONU and, in particular, on subsequent provisioning of services.

Registration-based authentication is not performed and the registration-based MSK and derived shared keys are not calculated, if at the time of the Registration_ID report there exists a valid SMA between the OLT CT and the ONU.

Once the OLT CT transmits a Request_Registration message to the ONU while expecting to use the reported Registration_ID for shared key derivation, it refrains from sending to that ONU other PLOAM or OMCI messages with ONU-specific MIC (see clauses B.11.3.2 and B.11.3.3) until after the Registration_ID is received and the registration-based MSK and derived shared keys are calculated.

Once the OLT CT completes calculation of the registration-based MSK and derived shared keys for a particular ONU, it immediately commits those keys as active.

At the start of the ONU's activation cycle, the OLT CT discards any active registration-based MSK and derived shared keys.

B.11.2.1.2The ONU perspective

The ONU must be able to perform calculation of the MSK and derived share keys based on the Registration_ID.

The ONU computes the registration-based MSK and derived shared keys upon power up (initially, using the well-known default Registration_ID (see clause B.7.3.4.2), and each time the Registration_ID changes. The computed values are stored for future use. As the registration-based key set may be required at any time, the ONU may benefit by storing the registration-based MSK and derived shared keys separately from the MSK and derived shared keys based on secure mutual authentication.

ONU reports Registration_ID to the OLT in the following situations:

– At any time during the ONU's activation cycle, in response to a Request_Registration message.

The events that cause registration-based key re-computation are asynchronous to the physical layer operations, administration and maintenance (PLOAM) channel events. The ONU is expected to have the registration-based MSK and derived shared keys available at the time it reports its Registration_ID to the OLT CT.

If there is no valid SMA between the OLT CT and the ONU, the ONU commits the set of shared keys based on the reported Registration_ID immediately upon sending the Registration PLOAM message.

The ONU retains the Registration_ID and the stored registration-based MSK and derived shared keys between activation cycles and between power cycles.

B.11.2.2 Secure mutual authentication options

Two secure mutual authentication mechanisms are defined: OMCI-based authentication (Annex C), and IEEE 802.1X-based authentication (Annex D). These mechanisms authenticate the OLT CT to the ONU as well as the ONU to the OLT CT. The support of both secure mutual authentication mechanisms is optional on the system level.

If secure mutual authentication is supported by the system and is employed by the operator, the OLT CT initiates the secure mutual authentication procedure using an appropriate mechanism upon completion of the ONU activation procedure before user data traffic is transmitted, and subsequently may initiate re-authentication at any time, subject to the operator's policies and discretion.

In the course of execution of a secure mutual authentication procedure, the OLT CT and the ONU compute the secure master session key (MSK) and a set of secure shared keys applicable for specific management and operation tasks.

Both the OLT CT and the ONU discard the MSK and derived shared keys obtained in the course of secure mutual authentication at the start of the ONU's activation cycle along with the other TC layer parameters.

B.11.3 Key derivation

The mathematical details of the MSK and derived shared key calculation are shared by the OLT CT and the ONU.

The ONU computes the registration-based MSK and derived shared keys upon power up (initially using the well-known default Registration_ID (see clause B.7.3.4.2), and each time the Registration_ID changes.

The OLT CT computes the registration-based MSK and derived shared keys each time when the ONU reports its Registration_ID to the OLT CT in response to the Request_Registration PLOAM message, but only when there is no valid mutual security association between OLT CT and ONU.

Both the OLT CT and the ONU compute the secure MSK and derived shared keys each time a secure mutual authentication procedure using either the OMCI-based or the IEEE 802.1X-based mechanism is executed.

B.11.3.1 Cryptographic method

The secure key derivation procedure employs the cipher-based message authentication code (CMAC) algorithm specified in [b-NIST SP800-38B] with the advanced encryption standard (AES) encryption algorithm [b-NIST FIPS-197] as the underlying block cipher.

The AES-CMAC function takes as its inputs:

– block cipher key *K*;

– the information message *M*; and

– the bit length of the output *Tlen*,

and produces the message authentication code *T* of length *Tlen* as an output. The notation for invocation of the AES-CMAC function is:

$$T = \text{AES-CMAC}\ (K, M, Tlen) \qquad \text{(B-1)}$$

For the purposes of this Recommendation, the block size of the underlying block cipher and the bit length of the AES key are 128 bits. This version of the block cipher is referred to herein as AES-128.

B.11.3.2 Master session key

The master session key (MSK) is a 128-bit value that is shared between the OLT CT and the given ONU as a result of an authentication procedure, and which serves as a starting point for the derivation of all of the other secret keys used in subsequent secure communications.

For the registration-based key derivation, the MSK is obtained from the ONU Registration_ID:

$$\text{MSK} = \text{AES-CMAC}\ ((0x55)16, \text{Registration\_ID}, 128) \qquad \text{(B-2)}$$

Here $(0x55)_{16}$ denotes a default key composed of the hex pattern 0x55 repeated 16 times, and Registration_ID is the 36-byte value transmitted in the Registration PLOAM message. Note that the Registration PLOAM message may carry either an ONU-specific Registration_ID, or a well-known default value.

When the key derivation is triggered by the success of secure mutual authentication, the procedure to obtain the MSK depends on the specific authentication mechanism.

B.11.3.3 Derived shared keys

The session key (SK) binds the MSK to the context of the security association between the OLT CT and ONU. The SK, which is used for subsequent key derivations, is obtained using the following formula:

$$\text{SK} = \text{AES-CMAC}\ (\text{MSK}, (\text{SN} \mid \text{PON-TAG} \mid 0x53657373696f6e4b), 128) \qquad \text{(B-3)}$$

where the information message, which is 24 bytes long, is a concatenation of three elements: the ONU serial number (SN) as reported in octets five to 12 of the upstream Serial_Number_ONU PLOAM message (clause B.7.3.4.1), the PON-TAG as reported in octets 12 to 19 of the downstream System_Profile PLOAM message (clause B.7.3.3.7), and the hexadecimal representation of the ASCII string "SessionK".

The OMCI integrity key (OMCI_IK) is used to generate and verify the integrity of OMCI messages. The OMCI_IK is derived from the SK by the following formula:

$$\text{OMCI\_IK} = \text{AES-CMAC}\ (\text{SK}, 0x4f4d4349496e746567726974794b6579, 128) \qquad \text{(B-4)}$$

Here the information message parameter of the AES-CMAC function is 128 bits long, and is the hexadecimal representation of the ASCII string "OMCIIntegrityKey".

The PLOAM integrity key (PLOAM_IK) is used to generate and verify the integrity of FS layer unicast PLOAM messages. The PLOAM_IK is derived from the SK by the following formula:

$$PLOAM\_IK = AES\text{-}CMAC\ (SK, 0x504c4f414d496e7465677274794b6579, 128) \qquad (B\text{-}5)$$

Here the information message parameter of the AES-CMAC function is 128 bits long, and is the hexadecimal representation of the ASCII string "PLOAMIntegrityKey".

For downstream unassigned ONU-ID PLOAM messages and for unicast PLOAM messages exchanged in the course of ONU activation prior to availability of the registration-based MSK, the default PLOAM_IK value is used, which is equal to $(0x55)_{16}$, the subscript indicating the multiplicity of repetition of the specified hex pattern.

B.11.4 Integrity protection and data origin verification for PLOAM

For the PLOAM messaging channel, sender identity verification and protection against forgery is achieved with the use of the 8-byte message integrity check (MIC) field of the PLOAM message format.

B.11.4.1 Cryptographic method

The MIC field of the PLOAM message format is constructed using the cipher-based message authentication code (CMAC) algorithm specified in [b-NIST SP800-38B] with the 128-bit Advanced encryption standard (AES-128) encryption algorithm [b-NIST FIPS-197] as the underlying block cipher (see Figure B.9).

The parameters and the notation for invocation of the AES-CMAC function are described in clause B.11.3.1.

B.11.4.2 MIC calculation

Given the 40 bytes of the PLOAM message content and the PLOAM integrity key PLOAM_IK, the sender and the receiver can calculate the MIC field as follows:

$$PLOAM\text{-}MIC = AES\text{-}CMAC\ (PLOAM\_IK, Cdir \mid PLOAM\_CONTENT, 64) \qquad (B\text{-}6)$$

Where C_{dir} is the direction code: C_{dir} = 0x01 for downstream and C_{dir} = 0x02 for upstream, and *PLOAM_CONTENT* denotes octets 1 to 40 of the PLOAM message.

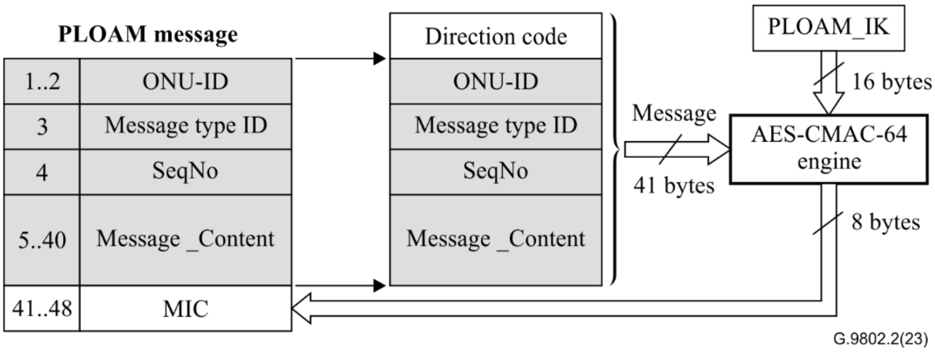


Figure B.9 – PLOAM integrity protection

B.11.5 Integrity and data origin verification key switching

B.11.5.1 Use of the default key

At the start of ONU activation, the PLOAM integrity key for the given ONU is set to the default value of $(0x55)_{16}$, which is used for PLOAM message exchange while no MSK is available. Once the ONU communicates its Registration_ID to the OLT CT, the basic MSK is established and all the derivative shared keys are obtained. The OMCI integrity key does not require an explicit default, as no OMCI exchange takes place prior to MSK establishment.

The certain types of the upstream and downstream unicast PLOAM messages (such as the Serial_Number_ONU PLOAM message, the Deactivate_ONU-ID PLOAM message, the Request_Registration and Registration PLOAM messages) are always protected by a MIC that is generated with the default PLOAM integrity key. These messages, therefore, can be successfully transmitted even if the OLT CT and ONU have not established or no longer agree on the dynamically derived keys. See PLOAM message formats for individual PLOAM message types in clauses B.7.3.3 and B.7.3.4 for the details of the default PLOAM integrity key applicability.

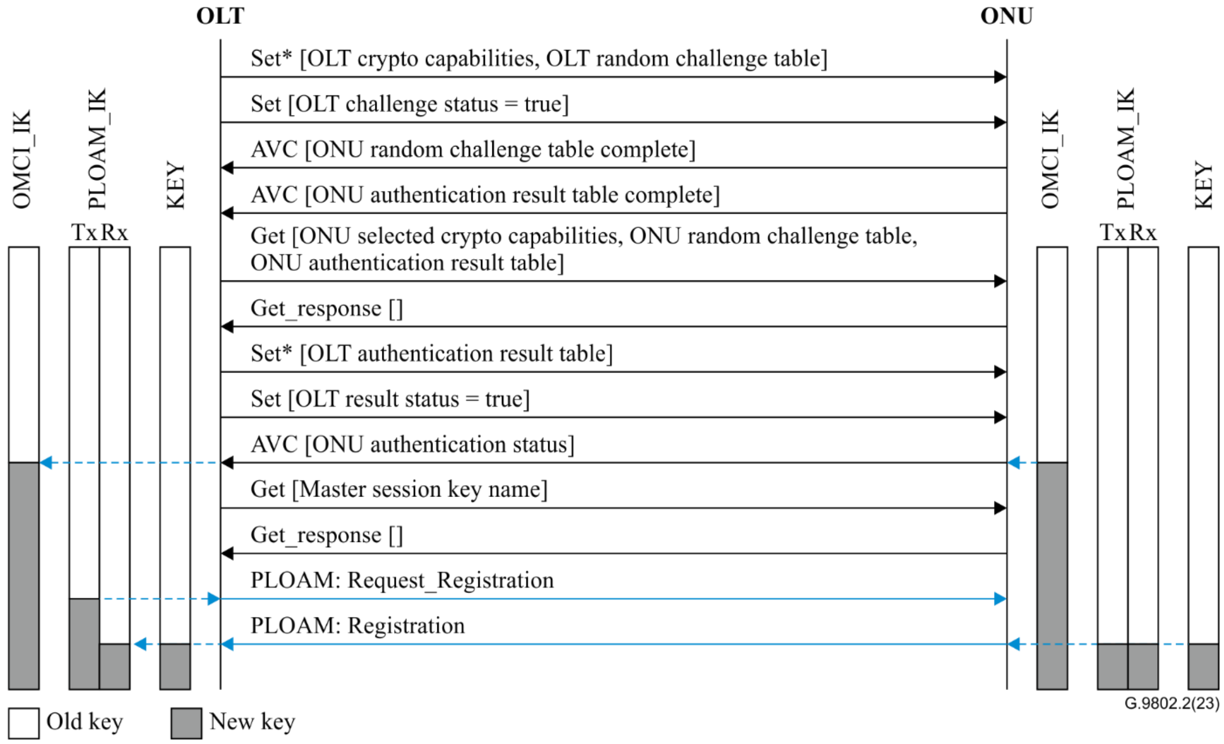
B.11.5.2 Key switching for OMCI-based secure mutual authentication

The following description refers to the Enhanced security control attributes and procedures specified in clause 9.13.11 of [ITU-T G.988].

The authentication is implemented as a three-step symmetric-key-based challenge-response procedure in the OMCC channel followed by a PLOAM handshake in the form of Registration_ID exchange.

The OLT CT initiates the OMCI-based authentication at its discretion by writing the OLT CT random challenge table attribute. From this point to the completion of the authentication procedure, the OLT CT refrains from sending to the ONU any OMCI messages unrelated to authentication.

The ONU generates a random challenge of its own, computes the response to the OLT CT challenge, and initiates the secure MSK and derived shared key calculation procedure. Once computed, the secure keys are stored for future use.



NOTE 1 – Set* indicates multiple set operations as needed to fill the table.

NOTE 2 – Unless explicitly specified otherwise, the messages are exchanged over the OMCC channel.

Figure B.10 – OMCI-based secure mutual authentication procedure

Upon receipt of the ONU's response to OLT CT's random challenge along with the ONU random challenge table (see Figure B.10), the OLT CT unilaterally verifies the ONU's authentication status. If the unidirectional ONU-to-OLT authentication fails, further execution of the authentication procedure is aborted. If the unidirectional ONU-to-OLT authentication succeeds, the OLT CT calculates the MSK and the derivative shared keys, storing them for future use. Once the key calculation is completed, the OLT CT proceeds with execution of the authentication procedure by writing the OLT CT authentication result table and OLT CT result status to the ONU.

Upon receipt of the OLT CT's response, the ONU verifies the OLT CT's authentication status and fills in the ONU authentication state attribute. The ONU transmits an attribute value change (AVC) on the ONU authentication state attribute. If the unidirectional OLT-to-ONU authentication has failed, a message integrity check (MIC) on the AVC message is generated using the previously active OMCI_IK. If the unidirectional OLT-to-ONU authentication has succeeded (and thus the mutual authentication has succeeded as well), the MIC field on the AVC message is generated with the new OMCI_IK. The new OMCI_IK is committed active at the ONU.

When the OLT CT receives the AVC on the ONU authentication state from the ONU, it checks whether the MIC field has been generated using the old OMCI_IK or the new OMCI_IK. If the old OMCI_IK was used by the ONU, the OLT CT discards the previously calculated key material. If the new OMCI_IK was used by the ONU, the OLT CT commits the new OMCI_IK as active. The OLT CT then initiates a PLOAM handshake by generating a downstream Request_Registration PLOAM message to the ONU. The purpose of the handshake is to delineate the activation of the secure shared keys in case of authentication success, or to obtain the registration-based MSK and derived shared keys in case of authentication failure. The Request_Registration PLOAM message is protected, by definition, using the default PLOAM_IK. Upon transmission of the Request_Registration message, the OLT CT commits the new PLOAM_IK as active on transmit.

Once the ONU receives the downstream Request_Registration PLOAM message, it generates an upstream Registration PLOAM message, which is protected, by definition, using the default PLOAM_IK. Upon transmission of the Registration message, the ONU commits the new PLOAM_IK and KEK as active.

Once the OLT CT receives the upstream Registration PLOAM message from the ONU, it commits the PLOAM_IK and KEK as active on receive, thus completing the key switching procedure.

B.11.5.3 Key switching for IEEE 802.1x-based authentication

Once the IEEE 802.1x-based mutual authentication or re-authentication process has completed, the OLT CT and the authenticated ONU have a 200 ms grace interval to compute the new set of derived shared keys. Within this interval, a sender should either remain silent or continue to use the old integrity key and switch to the new one as soon as it detects the new key in the received message, or at the end of the grace interval, at the latest. While the new key is being computed, a receiver continues checking the received messages with the old key. When the new key becomes available, the receiver should start checking messages with both old and new keys and switch to using the new key only once the new key check is successful, or at the end of the grace interval, at the latest.

B.11.5.4 MIC failure considerations

If MIC failure is caused by random transmission errors, then it is likely a rare event that can be correlated with the observed bit error ratio (BER) level. A persistent MIC failure, on the other hand, is likely caused by an integrity key mismatch at the transmitter and receiver and may indicate either a security threat or a malfunction of the authentication and key generation procedure. In case of persistent message integrity check failure, of which the OLT CT learns either directly (upstream MIC failure) or through the lack of expected management traffic flow from the ONU (downstream MIC failure), the OLT CT recognizes a loss of PLOAM channel ($LOPC_i$) defect or a loss of OMCC channel ($LOOC_i$) defect for a given ONU and has to select, at its discretion, the appropriate mitigation actions. These mitigation actions may include repeating authentication using the same or an alternative mechanism, blocking upstream and downstream traffic, deactivating or disabling the offending ONU, or executing a rogue ONU diagnostic procedure.

B.12 Power management

WRP will provide the best user and network energy efficiency experience combining sleep periods behaviours when the link is idle (derived from the ITU-T PON watchful sleep and [b-IEEE 802.3az]), plus line rates switching during low duty periods according to the actual payload to be conveyed, enabling the logic at its ends to adapt the clock rate to the necessary throughput.

B.12.1 Sleep mode

During sleep modes bi-directional connectivity between both ends of the link will be temporarily lost.

This clause is for further study.

B.12.2 Line rate switching

Line rate switching (LRS) is optional, since not all of the payload to be conveyed can support LRS when no similar hierarchy of line rates are applicable (e.g., lowest rate only ONUs) or when the interfaces cannot support any variation in payload (e.g., incompatibility with CPRI based fronthaul).

LRS protocol is required to support unidirectional switching, to also provide the best efficiency for asymmetric traffic.

A classical figure of merit widely used in network planning to start upgrading any link was 85% of the capacity. Therefore, the following thresholds over an observing period (OP) are considered:

- Switching from low speed to its next step will occur when the effective payload crosses the threshold of 85% of its capacity.
- Reversely the switching down will occur when the effective payload (EP) is lower than 85% of this lower speed link capacity.

The LRS state machine is shown in Figure B.11 using the 85% capacity threshold as an example.

NOTE – The term "effective payload" excludes idle patterns from actual payload.

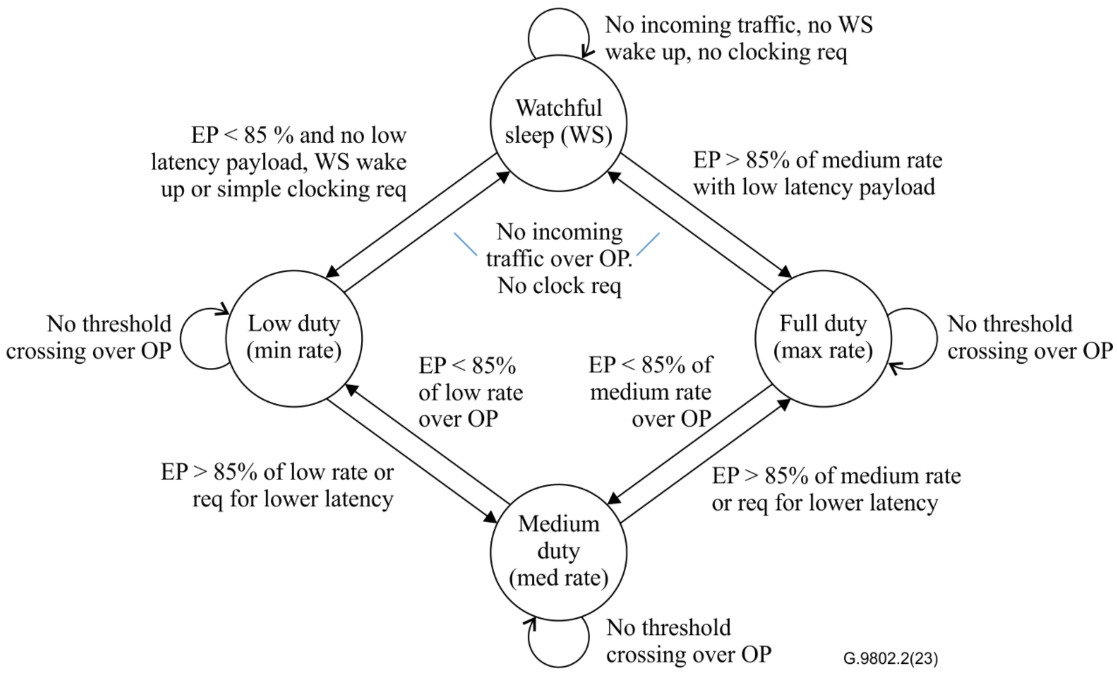


Figure B.11 – LRS state machine

B.13 System protection

This clause is for further study.

Annex C

Secure mutual authentication via OMCI

(This annex forms an integral part of this Recommendation.)

This is the same as Annex C of [ITU-T G.987.3].

Annex D

Secure mutual authentication using IEEE 802.1X

(This annex forms an integral part of this Recommendation.)

This is the same as Annex D of [ITU-T G.987.3].

Annex E

Transcoded mode management channel implementation

(This annex forms an integral part of this Recommendation.)

A transcoder byte replacement mechanism can be used for 64B/66B framing 25Gbit/s Ethernet transmission in WDM PON system, realizing the multiplexing of WDM PON management data and user data. The 64B/66B line coding and corresponding code format for 25G are specified in clause 49, clause 107 and clause 113 of [b-IEEE 802.3].

At the transmitter, the framed WDM PON management TC data and user data are transmitted to the transcoder. The 64B/66B coding bytes transformed from preamble are sequentially replaced by framed WDM PON management TC data.

At the receiver, the transcoder sequentially extracts the framed WDM PON management TC data from the bytes corresponding to preamble and passes them to the management TC framing sublayer. The default values of the original bytes corresponding to preamble will be recovered.

Different control codes in block type field are used to indicate the control character of the control block. For preamble, three control codes defined in clause 49.2.4.4 [b-IEEE 802.3] can take values of 0x78, 0x33 or 0x66. Three block type fields are defined below showing their respective data and control character mapping implementation:

1) A block type field of 0x78 ($S_0D_1D_2D_3/D_4D_5D_6D_7$): consists of a Start byte (S_0), seven free bytes from D_1 to D_7, where D_1 is the identifier followed by six bytes used as framed WDM PON management TC data carrier;
2) A block type field of 0x33 ($C_0C_1C_2C_3/S_4D_5D_6D_7$): consists of four valid control characters (C_0 to C_3), a start byte S_4, three free bytes from D_5 to D_7, followed by 4 bytes in the next block. Here D_5 is the identifier. D_6, D_7 and four bytes from the next block are used framed WDM PON management TC data carrier;
3) A block type field of 0x66 ($O_0D_1D_2D_3/S_4D_5D_6D_7$): consist of and a valid O code, three free bytes from D_5 to D_7, followed by 4 bytes in the next block. Here D5 is an identifier. D_6, D_7 and four bytes from the next block are used as framed WDM PON management TC data carrier.

If no user data is transmitted (i.e., none of 0x78/0x33/0x66), the pure control represented control code 0x1E ($C_0C_1C_2C_3/C_4C_5C_6C_7$, as IDLE) will be transformed to 0x78 in the transmitter of the transcoder. The value of parameter C of the corresponding identification byte D_0 will be set as "1", and the management data replacement will be continued as in the case block type field is 0x78.

Therefore, in the receiver, when control block has a block type field of 0x78, and the value of parameter C of the corresponding identification byte is "1", the 7 bytes from D_1 to D_7 will be extracted sequentially and passed to the management TC framing sublayer. The default values of the original bytes corresponding to preamble will be recovered.

The D_0 identifier indicates the feature of the replaced WRP management data in respective block, the identification byte is specified in Table E.1.

Table E.1 – Identification byte of the control block identifier

Octet	Parameter	Description
1-2 (LSB)	AB	00 – framed WDM PON management TC data is included in the following 6 bytes 01 – synchronization pattern is included in the following 2 bytes, the other bytes are reserved 10 – disabled 11 – IDLE
3	C	0 – original control code 1 –transformed control code from 0x1E
4-8	DEFGH	Reserved.

Annex F

Services with 25G eCPRI over Ethernet

(This annex forms an integral part of this Recommendation.)

The interface of eCPRI is specified in [b-eCPRI]. PHY and media access control (MAC) layer of 25G eCPRI services are 25G Ethernet based. clause 108 of [b-IEEE 802.3] specify the Reed-Solomon forward error correction (RS-FEC) for 25GBASE-R PHYs. In order to support codeword alignment in the receive direction, the 25GBASE-R RS-FEC shall periodically insert codeword markers into the stream of transcoded blocks as the first 257 bits of every 1024th RS-FEC codeword. The distance between the beginning of successive codeword markers is therefore 20480 257-bit transcoded blocks, equivalent to 81920 64B/66B blocks. The transmitted codeword marker is a 257-bit block, constructed of four alignment markers followed by a zero bit. Each alignment marker is built from eight octets. Figure F.1 shows the processing of RS-FEC function in the physical coding sublayer (PCS) sublayer.

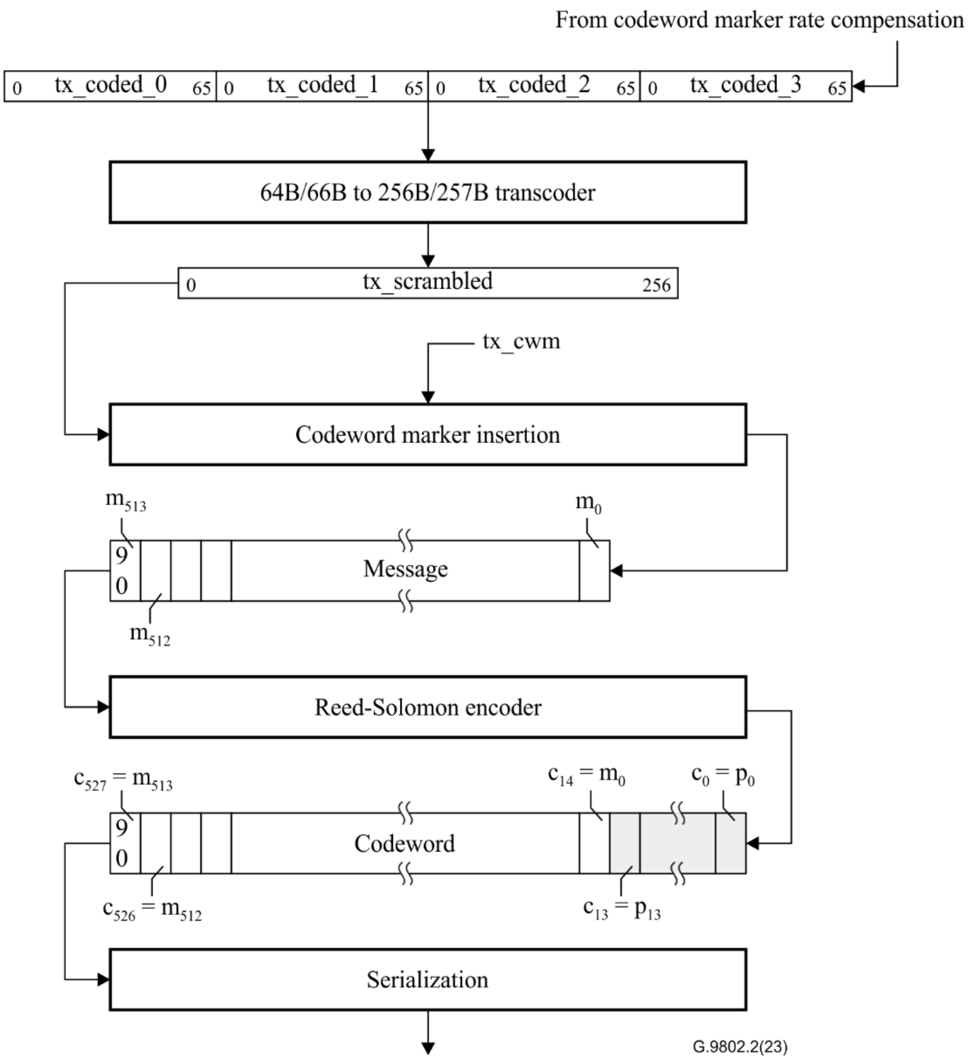


Figure F.1 – Processing of PCS sublayer

For 25G eCPRI, there is only one lane, so one alignment marker is used, and the other three alignment makers are filled with fixed pattern but not used. For WDM PON system that supports 25G eCPRI, these unused bits can be used to management channel. In order to keep as close to the standardized 25G BASE-R PHY as possible, the alignment marker is insistent with the alignment marker of PCS lane 0 specified in [b-IEEE 802.3], and the other three 64-bit blocks are used as management channel. Thus, the maximal amount of WDM PON management information to be sent is 192 bits per codeword maker. As the management channel of WDM PON system is not always working, the first 2 bits of these 192 bits are used as message indicator and the remaining 190 bits are OAM content. Figure F.2 shows the format of codeword marker for WDM PON system.

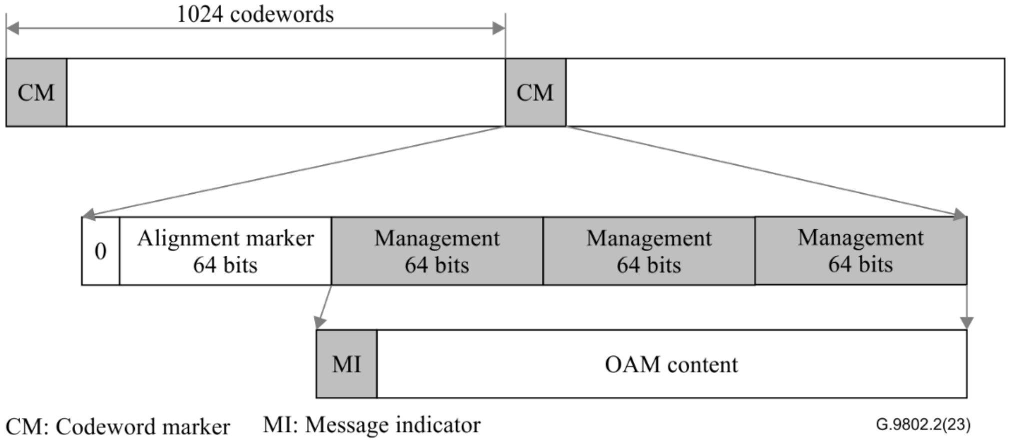


Figure F.2 – Codeword marker for WDM PON system

MI (message indicator) is a 2-bit field that indicates whether the OAM content field is valid. It has following encoding:

– 00: the OAM content is invalid;

– 01: reserved;

– 10: reserved;

– 11: the OAM content is valid.

For WDM PON system with 25G eCPRI or other 25GE based services, codeword marker is inserted every 1024 RS (528,514) [b-IEEE 802.3] codewords. At the transmitter side, the PCS receives 81920 64B/66B blocks and transcodes them to 20480 257-bit transcoded blocks, and generates one codeword marker. The codeword marker with alignment marker, message indicator and message content are encoded together with received data blocks. At the receive side, the PCS can realize the codewords synchronization based on the 64 bits alignment marker.

Annex G

Hybrid error control (HEC) decoding and scrambler sequence codes

(This annex forms an integral part of this Recommendation.)

This is the same as Annex A of [ITU-T G.987.3].

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