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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Access networks – Optical line systems for local and access networks

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Higher speed passive optical networks – Requirements

Recommendation ITU-T G.9804.1

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Recommendation ITU-T G.9804.1

Higher speed passive optical networks– Requirements

Summary

Recommendation ITU-T G.9804.1 serves as a guide for the development of higher speed passive optical network (PON) systems, by identifying sets of applications that can be addressed by a particular system and defining the requirements for each of those systems. It is anticipated that they may have several distinct systems, such as higher speed single channel (TDMA PON), higher speed multi-channel (TWDM PON), and higher speed point to point overlay PONs.

History

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1 Scope

This Recommendation describes the general requirements of higher speed passive optical networks (HSP) that operate at speeds of over 10 Gbit/s per channel, for residential, business, mobile backhaul, and other applications. This Recommendation includes the principal deployment configurations, migration scenarios from legacy PON systems, and system requirements. This Recommendation also includes the service and operational requirements to provide for a robust and flexible optical access network supporting all access applications.

The HSP systems can meet the needs of a wide range of networks in diverse markets and is deployable in numerous applications in an efficient manner. As much as possible, this Recommendation maintains the characteristics from legacy PON systems: [b-ITU-T G.982], ITU T G.983.x, ITU-T G.984.x, ITU-T G.987.x, ITU-T G.989.x, and ITU-T G.9807.x series of Recommendations. This is to promote backward compatibility with existing optical distribution networks (ODN) that comply with those Recommendations and re-use established technical capabilities as much as possible. This Recommendation also describes smooth migration scenarios from legacy PON systems to HSP systems. Furthermore, HSP systems are expected to meet bandwidth growth and enable new revenue streams on legacy ODNs as well as supporting greenfield applications over new ODNs.

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 (2011), *Characteristics of a single-mode optical fibre cable.*

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

[ITU-T G.703] Recommendation ITU-T G.703 (2016), *Physical/electrical characteristics of hierarchical digital interfaces*.

[ITU-T G.808.1] Recommendation ITU-T G.808.1 (2014), *Generic protection switching – Linear trail and subnetwork protection*.

[ITU-T G.992.5] Recommendation ITU-T G.992.5 (2009), *Asymmetric digital subscriber line 2 transceivers (ADSL2) – Extended bandwidth ADSL2 (ADSL2plus)*.

[ITU-T G.983.1] Recommendation ITU-T G.983.1 (2005), *Broadband optical access systems based on Passive Optical Networks (PON)*.

[ITU-T G.984.1] Recommendation ITU-T G.984.1 (2008), *Gigabit-capable passive optical networks (GPON): General characteristics*.

[ITU-T G.986]	Recommendation ITU-T G.986 (2010), *1 Gbit/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.987.1]	Recommendation ITU-T G.987.1 (2016), *10-Gigabit-capable passive optical networks (XG-PON): General requirements*.
[ITU-T G.989]	Recommendation ITU-T G.989 (2015), *40-Gigabit-capable passive optical networks (NG-PON2): Definitions, abbreviations and acronyms*.
[ITU-T G.989.1]	Recommendation ITU-T G.989.1 (2013), *40-Gigabit-capable passive optical networks (NG-PON2): General requirements*.
[ITU-T G.992.5]	Recommendation ITU-T G.992.5 (2009), *Asymmetric digital subscriber line 2 transceivers (ADSL2) – Extended bandwidth ADSL2 (ADSL2plus)*.
[ITU-T G.993.2]	Recommendation ITU-T G.993.2 (2019), *Very high speed digital subscriber line transceivers 2 (VDSL2)*.
[ITU-T G.8261]	Recommendation ITU-T G.8261/Y.1361 (2019), *Timing and synchronization aspects in packet networks*.
[ITU-T G.8262]	Recommendation ITU-T G.8262/Y.1362 (2018), *Timing characteristics of a synchronous equipment slave clock*.
[ITU-T G.9700]	Recommendation ITU-T G.9700 (2019), *Fast access to subscriber terminals (G.fast) – Power spectral density specification*.
[ITU-T G.9701]	Recommendation ITU-T G.9701 (2019), *Fast access to subscriber terminals (G.fast) – Physical layer specification*.
[ITU-T G.9807.1]	Recommendation ITU-T G.9807.1/Amd.1 (2017), *10-Gigabit-capable symmetric passive optical network (XGS-PON)*.
[ITU-T J.185]	Recommendation ITU-T J.185 (2012), *Transmission equipment for transferring multi-channel television signals over optical access networks by frequency modulation conversion*.
[ITU-T J.186]	Recommendation ITU-T J.186 (2008), *Transmission equipment for multi-channel television signals over optical access networks by sub-carrier multiplexing (SCM)*.
[IEEE 802.3]	IEEE 802.3-2018, IEEE Standard for Ethernet.

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 access network (AN) [b-ITU-T G.902]: An implementation comprising those entities (such as cable plant, transmission facilities, etc.) which provide the required transport bearer capabilities for the provision of telecommunications services between a service node interface (SNI) and each of the associated user-network interfaces (UNIs).

3.1.2 Ethernet LAN service (E-LAN) [b-MEF6.1]: An Ethernet service type that is based on a Multipoint-to-Multipoint Ethernet virtual connection.

3.1.3 Ethernet Line service (E-Line) [b-MEF6.1]: An Ethernet service type that is based on a Point-to-Point Ethernet virtual connection.

3.1.4 Ethernet Tree service (E-Tree) [b-MEF6.1]: An Ethernet service type that is based on a Rooted-Multipoint Ethernet virtual connection.

3.1.5 Ethernet Virtual Connection (EVC) [b-MEF6.1]: An association of two or more UNIs that limits the exchange of Service Frames to UNIs in the Ethernet Virtual Connection.

3.1.6 jitter (timing jitter) [b-ITU-T G.810]: The short-term variations of the significant instances of a timing signal from their ideal positions in time (where "short-term" implies that these variations are of frequency greater than or equal to 10 Hz).

3.1.7 service node (SN) [b-ITU-T G.902]: A network element that provides access to various switched and/or permanent telecommunication services.

3.1.8 service node interface (SNI) [b-ITU-T G.902]: An interface which provides access to a service node.

3.1.9 user-network interface (UNI) [b-ITU-T I.112]: The interface between the terminal equipment and a network termination at which interface the access protocols apply.

3.1.10 1:1 VLAN [b-BBF TR-101]: A VLAN forwarding paradigm involving a one-to-one mapping between user port and VLAN. The uniqueness of the mapping is maintained in the Access Node and across the Aggregation Network.

3.1.11 N:1 VLAN [b-BBF TR-101]: A VLAN forwarding paradigm involving many-to-one mapping between user ports and VLAN. The user ports may be located in the same or different Access Nodes.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

Terms related to optical access architecture

3.2.1 channel group: A set of channel pairs carried over a common fibre.

3.2.2 channel pair: A set of one downstream wavelength channel and one upstream wavelength channel that provides connectivity between an optical line terminal (OLT) and one or more optical network units (ONUs).

3.2.3 channel partition: Any of operator-specified non-overlapping subsets of time and wavelength division multiplexing (TWDM) or point-to-point (PtP) WDM channels in a higher speed PON (HSP) system.

3.2.4 channel partition index: The identity of an operator-specified time and wavelength division multiplexing (TWDM) or point-to-point (PtP) WDM channel subset in a higher speed PON (HSP) system.

3.2.5 channel termination (CT): See OLT PtP WDM channel termination and OLT TWDM channel termination.

3.2.6 coexistence element: A bidirectional functional element used to connect passive optical network (PON) systems defined in different Recommendation series to the same optical distribution network (ODN).

3.2.7 dual parenting: A passive optical network protection configuration where optical network units (ONUs) are connected to two channel terminations (CTs) hosted in different optical line terminal (OLT) chassis. Typically, the OLT chassis in dual parenting are geographically remote from each other.

3.2.8 gigabit-capable passive optical network (G-PON): A PON system supporting transmission rates in excess of 1 Gbit/s in at least one direction and implementing the suite of protocols specified in ITU-T G.984.x series of Recommendations.

3.2.9 next generation PON (NG-PON): In the context of ITU-T standards development activity, a generic term referencing the PON system evolution beyond G-PON. The concept of NG-PON currently includes NG-PON1, where the ODN is maintained from B-PON and G-PON, and NG-PON2, where a redefinition of the ODN is allowed from that defined in B-PON and G-PON.

3.2.10 next generation PON 1 (NG-PON1): A PON system with a nominal aggregate capacity of 10 Gbit/s in the downstream direction. The NG-PON1 system is represented by XG-PON and XGS-PON.

3.2.11 next generation PON 2 (NG-PON2): A PON system with a nominal aggregate capacity of 40 Gbit/s in the downstream direction and 10 Gbit/s in the upstream direction, and implementing the suite of protocols specified in the ITU-T G.989 series Recommendations. An NG-PON2 system is composed of a set of time division multiple access (TWDM) channels and/or a set of point-to-point (PtP) WDM channels.

3.2.12 OLT PtP WDM channel termination: A logical function that resides at the optical line terminal (OLT) network element and terminates a single point-to-point (PtP) wavelength division multiplexing (WDM) channel in a PtP WDM system.

3.2.13 OLT TWDM channel termination: A logical function that resides at the optical line terminal (OLT) network element and that terminates a single time and wavelength division multiplexing (TWDM) channel in a TWDM system.

3.2.14 optical access network (OAN): A part of an access network whose network elements are interconnected by optical communication channels.

NOTE – An OAN may or may not extend all the way to the user-network interface (UNI), so that the user-side interface of the OAN does not necessarily coincide with the UNIs of the AN.

3.2.15 optical distribution network (ODN): 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.

3.2.16 optical distribution segment (ODS): A simple optical distribution network (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.

3.2.17 optical line termination (OLT): A network element in an ODN-based optical access network that terminates the root of at least one optical distribution network (ODN) and provides an optical access network (OAN) service node interface (SNI).

3.2.18 optical network terminal (ONT): An optical network union (ONU) supporting a single subscriber.

3.2.19 optical network unit (ONU): A network element in an ODN-based optical access network that terminates a leaf of the optical distribution network (ODN) and provides an optical access network (OAN) user-network interface (UNI).

3.2.20 optical trunk line (OTL): A passive point-to-point segment of a composite optical distribution network (ODN).

3.2.21 passive optical network (PON) system: A combination of network elements in an ODN-based optical access network that includes an optical trunk line (OLT) and one or more optical network unions (ONUs) and implements a particular coordinated suite of physical medium dependent layer, transmission convergence layer, and management protocols.

3.2.22 point-to-point) **wavelength division multiplexing ((PtP WDM) channel**: In a PtP WDM passive optical network (PON) system, PtP WDM channel refers to the pair of a downstream wavelength channel and an upstream wavelength channel providing point-to-point connectivity.

3.2.23 point-to-point wavelength division multiplexing passive optical network (PtP WDM PON): A multiple wavelength PON system that enables point-to-point connectivity using a dedicated wavelength channel per optical network union (ONU) for the downstream direction and a dedicated wavelength channel per ONU for the upstream direction.

3.2.24 radio frequency (RF) video overlay: A method for video transmission in the downstream direction in a wavelength band between 1550 nm and 1560 nm according to Recommendations ITU-T J.185 and ITU-T J.186.

3.2.25 time and wavelength division multiplexing (TWDM) channel: In a 50G TWDM passive optical network (PON) system, TWDM channel refers to the pair of a downstream wavelength channel and an upstream wavelength channel providing point-to-multipoint connectivity by using, respectively, time division multiplexing and multiple access mechanisms.

3.2.26 time and wavelength division multiplexing passive optical network (TWDM PON): A multiple wavelength PON system in which each wavelength channel may be shared among multiple optical network unions (ONUs) by employing time division multiplexing and multiple access mechanisms.

3.2.27 wavelength channel: A unidirectional (downstream or upstream) optical communications channel characterized by a single unique central frequency or a set of unique central frequencies mapped to one wavelength multiplexer (WM) tributary port.

3.2.28 wavelength multiplexer (WM): A bidirectional functional element used to multiplex /demultiplex between next generation passive optical network 2 (NG-PON2) wavelength channel pairs and channel groups.

3.2.29 10-Gigabit-capable passive optical network (XG(S)-PON): A PON system supporting nominal transmission rates on the order of 10 Gbit/s in at least one direction, and implementing the suite of protocols specified in ITU-T G.987.x series of Recommendations (XG-PON) or in the ITU-T G.9807.1 (XGS-PON), as the realization of next generation passive optical network 1 (NG-PON1).

3.2.30 10-Gigabit passive optical network (**XG-PON)**: A variant of 10-Gigabit-capable passive optical network system that operates at a nominal line rate of 10 Gbit/s downstream and 2.5 Gbit/s upstream, implementing the suite of protocols specified in ITU-T G.987.x series of Recommendations.

3.2.31 10-Gigabit passive optical network (XGS-PON): A variant of 10-Gigabit-capable passive optical network system that operates at a nominal line rate of 10 Gbit/s downstream and upstream, implementing the suite of protocols specified in ITU-T G.9807.1.

Terms related to optical parameters, optical power, losses and penalties[1]

3.2.32 attenuation: See optical path loss.

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[1] For the definition of the HSP architectural reference points mentioned within this clause, please see clause 5.2. For relationship between optical power and loss parameters, see clause5.3. For the definition of the burst mode transmitter enabled/disabled periods and the associated transient times, see clause 5.13.

3.2.33 channel spacing: The absolute difference between the nominal central frequencies of two adjacent wavelength channels in a given reference grid.

3.2.34 consecutive identical digit (CID) immunity: The longest continuous sequence of identical bits that can be present in a digital signal without causing degradation such that the system specifications are no longer met.

3.2.35 differential fibre distance: The absolute difference between the fibre distances of any two given paths between the Reed-Solomon (code) (R/S) and S/R for channel group (S/R-CG) reference points in the same ODN.

3.2.36 differential optical path loss: The absolute difference between the optical losses, expressed in decibel units, of any two given paths between the Reed-Solomon (code) R/S and S/R for channel group (S/R-CG) reference points in the same optical distribution network (ODN).

3.2.37 dispersion: A physical phenomenon comprising the dependence of the phase or group velocity of a light wave in the medium on its propagation characteristics such as optical frequency (wavelength) or polarization mode.

3.2.38 dynamic range: An optical receiver characteristic that is equal to the ratio of the receiver overload to the receiver sensitivity.

3.2.39 extinction ratio (ER): With respect to a digital on-off keying signal generated by an optical transmitter, the ratio of the average optical power level at the centre of the binary digit corresponding to the high intensity of light to the average optical power level at the centre of a binary digit corresponding to the low intensity of light. For the burst mode signal, averaging is performed over the time periods when the transmitter is enabled but excluding the associated transient times (see clause 5.13). For the continuous mode signal, averaging is performed over the entire signal string.

3.2.40 fibre distance: The overall length of fibre (and, if applicable, equivalent fibre runs representing delay-inducing components) between the Reed-Solomon (code) (R/S) and S/R for channel group (S/R-CG) reference points.

3.2.41 in-band crosstalk tolerance: The minimum value of signal-to-crosstalk ratio at the S/R for channel group (S/R-CG) (upstream direction) or Reed-Solomon (code) (R/S) (downstream direction) reference point that maintains the receiver compliance with the sensitivity requirements. The crosstalk is assumed to be polarized and aligned with the signal polarization.

3.2.42 line code: In the higher speed PON (HSP) context, a code that transforms a binary digital signal into an amplitude- and time-discrete waveform for transmission over a physical channel.

3.2.43 mask of transmitter eye diagram: A general method of transmitter pulse shape characterisation that allows the combined specification of rise time, fall time, pulse overshoot/undershoot, ringing and jitter to ensure satisfactory operation with a compliant receiver. Transmitter mask compliance is required at the appropriate reference point (S/R for channel group (S/R-CG) for downstream, Reed-Solomon (code) (R/S) for upstream).

3.2.44 mean launch optical power: An optical transmitter characteristic expressing the average optical power of an optical signal transmitted into the fibre and carrying a given digital sequence, referring to the optical power of an individual wavelength channel at the appropriate reference point (S/R-CG for downstream direction, R/S for upstream direction). When specified as a range, the minimum mean launch optical power provides the power level that the transmitter should guarantee at all times, and the maximum mean launch optical power provides the power level that the transmitter should never exceed. When applied to burst mode transmission, the term pertains to the time interval during which the transmitter is enabled and excludes possible starting and ending transient behaviour.

3.2.45 nominal central frequency: The specified frequency of a wavelength channel.

3.2.46 nominal line rate: The total number of bits that can be physically transferred per unit of time over a communication link. Nominal line rate accounts for useful data as well as for all possible protocol overheads and necessarily exceeds the effective data rate on any given protocol level.

3.2.47 optical distribution network (ODN) fibre distance class: The categorization of an ODN based on the predefined values of minimum and maximum fibre distance between the S/R-CG and any of R/S reference points.

3.2.48 ODN optical path loss class (ODN class): The categorization of an optical distribution network (ODN) based on the predefined values of minimum and maximum optical path loss over all possible paths between the S/R-CG and any of the R/S reference points and over all possible operating wavelengths of a specific PON system.

3.2.49 operating wavelength band: The spectral interval defined by its boundaries λ_{min} and λ_{max} which includes all possible central operating wavelengths for a particular application.

3.2.50 optical path loss: The reduction in the optical power of light having traversed the ODN expressed as a ratio in decibel units. This loss may be caused by the fibre, connectors, splices, splitters, wavelength couplers, attenuators, and other passive optical components.

3.2.51 optical path penalty (OPP): The apparent degradation of receiver sensitivity due to impairments from fibre transmission and apparent increase in ODN loss due to Raman depletion. The optical path penalty accounts for the effects of reflections, inter-symbol interference, mode partition noise, fibre dispersion, and fibre non-linearities.

3.2.52 optical power spectral density when not enabled (WNE-PSD): The optical power spectral density per transmitter, at any wavelength inside or outside the operating wavelength band, measured when the transmitter is not enabled and the allocated transient time has elapsed, at the appropriate reference point (S/R-CG for downstream direction, R/S for upstream direction). Measurements are averaged over time and are expressed as the total integrated power within a sliding spectral window of known width.

3.2.53 optical return loss (ORL): The total reflection at the source reference point of the optical signal propagation path, measured as a ratio of the transmitted optical power to the reflected optical power.

3.2.54 overload: A receiver parameter equal to the maximum average received optical power that produces the specified bit error ratio (BER) reference level, referring to the optical power of an individual wavelength channel at the appropriate reference point (S/R-CG for upstream direction, R/S for downstream direction) measured with the worst-case signal, but without the optical path impairments.

3.2.55 per channel out-of-band optical power spectral density (OOB-PSD): The optical PSD outside the operating wavelength band measured at the appropriate reference point (S/R-CG for downstream direction, R/S for upstream direction). Measurements are averaged over the time periods when the transmitter is enabled, or when the transmitter is not enabled but the allocated transient time has not yet elapsed, and are expressed as the total integrated power within a sliding spectral window of known width.

3.2.56 per channel out-of-channel optical power spectral density (OOC-PSD): For a transmitter in a stationary wavelength channel state, the optical PSD outside the spectral interval corresponding to the operating wavelength channel, measured at the appropriate reference point (S/R-CG for downstream direction, R/S for upstream direction). Measurements are averaged over the time periods when the transmitter is enabled, or when the transmitter is not enabled but the allocated transient time has not yet elapsed, and are expressed as the total integrated power within a sliding spectral window of known width.

3.2.57 reflectance: The reflection from any single discrete reflection point in the optical signal propagation path, which is defined to be the ratio of the reflected optical power present at a point, to the optical power incident to that point.

3.2.58 sensitivity: A receiver parameter equal to the minimum average received optical power that produces the specified bit error ratio (BER) reference level, referring to the optical power of an individual wavelength channel at the appropriate reference point (S/R-CG for upstream direction, R/S for downstream direction) measured with the worst-case signal, but without the optical path impairments.

3.2.59 service rate: The data rate with respect to the upper layer service data units (SDUs). Data rate refers to the Ethernet frame traffic, whereby destination address, source address, and frame check sequence (FCS) are included into payload, but the Ethernet preamble, delimiter, and inter-frame gap (IFG) are not. The term *maximum service rate* refers to the highest possible aggregate service rate across multiple ONUs.

3.2.60 side mode suppression ratio (SMSR): The ratio of the power of the largest peak of the transmitter spectrum to that of the second largest peak. The second largest peak may be next to the main peak, or far removed from it. Within this definition, spectral peaks that are separated from the largest peak by the clock frequency are not considered to be side modes.

3.2.61 spectral excursion: 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).

3.2.62 spectral width: The full width of the largest spectral peak, measured 15dB down from the maximum amplitude of the peak.

3.2.63 stationary wavelength channel state: An optical transmitter or receiver is said to be *in a stationary wavelength channel state*, if 1) it is fixed wavelength, or 2) it is wavelength-tunable and its transient processes associated with the execution of a wavelength channel tuning control command have completed.

3.2.64 tolerance to reflected optical power: A transmitter parameter that characterizes the maximum admissible ratio of the average reflected optical transmit power incident at the transmitter to the average optical transmit power.

3.2.65 transmitter calibration: An optical transmitter is *calibrated with accuracy* δ, if given a target transmission frequency f_0 within its tuning range, it is capable of transmitting with the spectral excursion not exceeding δ (in other words, its transmission spectrum between the -15dB cut-off points lays entirely within the spectral interval ($f_0 - \delta$, $f_0 + \delta$)).

3.2.66 transmitter power wavelength dependency: For a tunable transmitter under wavelength control, the variation of the mean launches optical power when tuning within maximum spectral excursion (MSE).

3.2.67 transmitter disable transient time: For a burst-mode transmitter, the allocated transient time on de-assertion of the TxEnable signal, measured in bit periods with respect to the transmitter nominal line rate.

3.2.68 transmitter enable transient time: For a burst-mode transmitter, the allocated transient time on assertion of the TxEnable signal, measured in bit periods with respect to the transmitter nominal line rate.

3.2.69 tuning granularity: The smallest step by which a tunable device is able to adjust the operating frequency/wavelength within the tuning range of the device. This Recommendation specifies the tuning granularity by its maximum allowable value.

3.2.70 tuning range: The spectral interval either in frequency (f_{min}, f_{max}) or wavelength (λ_{min}, λ_{max}) over which the operating frequency/wavelength of a tunable device can be adjusted by means of tuning control.

3.2.71 tuning time: The elapsed time from the moment the tunable device leaves the source wavelength channel to the moment the tunable device reaches the target wavelength channel.

3.2.72 tuning window: The difference between the highest and lowest operating frequencies/wavelengths of a tunable device, attainable by means of tuning control.

3.2.73 wavelength channel spacing: See channel spacing.

Terms related to transmission convergence layer

3.2.74 activation: A set of distributed procedures executed by the optical line terminal (OLT) and the optical network units (ONUs) that allows an inactive ONU to join or resume operations on the passive optical network (PON). The activation process includes three phases: parameter learning, serial number acquisition, and ranging.

3.2.75 activation cycle: An interval of continuous optical network unit (ONU) operation between two consecutive re-entries of the ONU state machine into the initial state.

3.2.76 attenuation level: A controlled attenuation applied to the output of an optical network unit (ONU) transmitter to shift its mean launch optical power range down.

3.2.77 bandwidth allocation: An upstream transmission opportunity granted by the optical line terminal (OLT) for a specified time interval to a specified traffic-bearing entity within an optical network unit (ONU).

3.2.78 calibration record: A data structure which establishes an association between the wavelength channels and the corresponding values of the tuning control parameters.

3.2.79 calibration record status: A linear array which contains a calibration record accuracy indication for every available wavelength channel.

3.2.80 dynamic bandwidth assignment (**DBA)**: A process by which the optical line terminal (OLT) distributes upstream passive optical network (PON) capacity between the traffic-bearing entities within optical network units (ONUs), based on the dynamic indication of their traffic activity and their configured traffic contracts.

3.2.81 effective key length: The number of randomly generated bits of a cryptographic key. The effective key length may be less than the nominal key length of a particular cryptosystem, if a part of the key is replaced by a well-known bit pattern.

3.2.82 embedded operation, administration, and maintenance (OAM): An operation and management channel between the optical line terminal (OLT) and the optical network units (ONUs) that utilizes the structured overhead fields of the downstream XG-PON transmission convergence (XGTC) frame and upstream XGTC burst and supports time-sensitive functions.

3.2.83 equalization delay (EqD): The requisite delay assigned by the optical line terminal (OLT) to an individual optical network unit (ONU) in order to ensure that the ONU's transmissions are precisely aligned on a common OLT-based upstream frame reference. The ONU's equalization delay is assigned as a result of ranging and is subject to in-service updates in the course of burst arrival phase monitoring.

3.2.84 loose calibration: An accuracy characterization of an optical network unit's (ONU's) calibration record with respect to a given upstream wavelength channel which allows the ONU to avoid interference with any other upstream wavelength channels.

3.2.85 loose calibration bound: An upper limit for the permitted transmitter spectral excursion of optical network units (ONUs), connected to a time and wavelength division multiplexing passive optical network (TWDM PON) system, to be considered as loosely calibrated. This is determined by the physical properties of any particular implementation of a TWDM PON system.

3.2.86 one-step tuning time: The time it takes an optical network unit (ONU) to tune its transmitter over the spectral distance equal to its tuning granularity value.

3.2.87 ONU management and control interface (OMCI): An operation and management channel between the optical line terminal (OLT) and an optical network unit (ONU) that is message-based and employs an extendable management information base.

3.2.88 physical layer OAM (PLOAM): An operation and management channel between the optical line terminal (OLT) and the optical network units (ONUs) that is close to real time and is based on a fixed set of messages.

3.2.89 power levelling: A mechanism that allows an optical network unit (ONU) to change its mean launch optical power.

3.2.90 profile: A collection of parameters describing a particular object.

3.2.91 quiet window: A time interval during which the optical line terminal (OLT) suppresses all bandwidth allocations to in-service optical network units (ONUs) in order to avoid collisions between their upstream transmissions and the transmissions from ONUs whose burst arrival time is uncertain. The OLT opens a quiet window to allow new ONUs to join the passive optical network (PON) and to perform ranging of specific ONUs.

3.2.92 ranging: A procedure of measuring the round-trip delay between the optical line terminal (OLT) and any of its subtending optical network units (ONUs) with the objective to determine and assign the appropriate equalization delay, which is necessary to align the ONU's upstream transmissions on a common OLT channel termination (CT) based upstream frame reference. Ranging is performed during ONU activation and may be performed while the ONU is in service.

3.2.93 ranging grant: An allocation structure that is addressed to the default Alloc-ID of the optical network unit (ONU) and has the physical layer operations, administration, and maintenance, upstream (PLOAMu) flag set. A ranging grant does not specify a data allocation and has the GrantSize of zero.

3.2.94 requisite delay: A general term denoting the total extra delay the optical line terminal (OLT) may require an optical network unit (ONU) to apply to the upstream transmission beyond the ONU's regular response time. The purpose of requisite delay is to compensate for variation of propagation and processing delays of individual ONUs, and to avoid or reduce the probability of collisions between upstream transmissions.

3.2.95 root frequency: The nominal central frequency representing a cyclic set of frequencies that forms an upstream wavelength channel.

3.2.96 round-trip delay: A sum of round-trip propagation delay, optical network unit (ONU) response time, and any ONU requisite delay.

3.2.97 round-trip propagation delay: The total amount of time it takes an optical signal to travel from the optical line terminal (OLT) transmitter to the optical network unit (ONU) receiver and from the ONU transmitter to the OLT receiver.

3.2.98 round-trip time: The time interval, as observed by the optical line terminal channel termination (OLT CT), between the start of a downstream physical interface (PHY) frame carrying a certain bandwidth map and the start of an upstream PHY burst specified by that bandwidth map.

3.2.99 serial number grant: A type of allocation structure, addressed to a broadcast Alloc-ID and having the physical layer operations, administration, and maintenance, upstream (PLOAMu) flag set, that invites the optical network units (ONUs) in serial number state to transmit a Serial_Number_ONU PLOAM message either in band or via auxiliary management and control channel (AMCC). A serial number grant does not specify a data allocation.

3.2.100 service adapter: A functional entity responsible for encapsulating/de-encapsulating of the service data units (SDUs) belonging to the specific service type to/from the 10-Gigabit-capable PON encapsulation method (XGEM) frames.

3.2.101 status reporting DBA (SR-DBA): A method of dynamic bandwidth assignment that infers the dynamic activity status of the traffic-bearing entities within optical network units (ONUs) based on explicit buffer occupancy reports communicated over the embedded operation, administration and maintenance (OAM) channel.

3.2.102 sufficient calibration: An accuracy characterization of an optical network units (ONU's) calibration record with respect to a given upstream wavelength channel which allows the ONU to guarantee transmission within the specified maximum spectral excursion (MSE) interval of that channel.

3.2.103 traffic-monitoring DBA (TM-DBA): A method of dynamic bandwidth assignment that infers the dynamic activity status of the traffic-bearing entities within optical network units (ONUs) based on observation of idle 10-Gigabit-capable PON encapsulation method (XGEM) frame transmissions during upstream bursts.

3.2.104 transmission container (**T-CONT)**: A traffic-bearing object within an optical network unit (ONU) that represents a group of logical connections, is managed via the ONU management and control channel (OMCC), and, through its TC layer Alloc-ID, is treated as a single entity for the purpose of upstream bandwidth assignment on the passive optical network (PON).

3.2.105 tunability: In the TWDM PON and PTP WDM PON context, a property of an optical network unit (ONU) to change its wavelength.

3.2.106 TWDM PON transmission convergence (TWDM TC) layer: A protocol layer of the TWDM PON protocol suite that is positioned between the physical media dependent (PMD) layer and the TWDM PON clients. The TWDM TC layer is composed of the TWDM TC service adaptation sublayer, the TWDM TC framing sublayer, and the TWDM TC PHY adaptation sublayer.

3.2.107 TWDM TC framing sublayer: A sublayer of the TWDM PON transmission convergence layer that supports the functions of frame/burst encapsulation and delineation, embedded operation, administration, and maintenance (OAM) processing, and Alloc-ID filtering.

3.2.108 TWDM TC PHY adaptation sublayer: A sublayer of the TWDM PON transmission convergence layer that supports the functions of physical synchronization and delineation, forward error correction (FEC), and scrambling.

3.2.109 time and wavelength division multiplexing transmission convergence (TWDM TC) service adaptation sublayer: A sublayer of the TWDM PON transmission convergence layer that supports the functions of service data unit (SDU) (user data and OMCI traffic) fragmentation and reassembly, XGEM encapsulation, XGEM frame delineation, and XGEM port-ID filtering.

3.2.110 uncalibrated optical network unit (ONU): An ONU is said to be *uncalibrated* with respect to a given upstream wavelength channel if its calibration record accuracy does not satisfy the criterion for loose calibration.

3.2.111 10-Gigabit-capable PON encapsulation method (XGEM) port: An abstraction in the time and wavelength division multiplexing transmission convergence (TWDM TC) service adaptation sublayer representing a logical connection associated with a specific client packet flow.

3.2.112 10-Gigabit-capable PON encapsulation method (XGEM): A data frame transport scheme that is connection-oriented and that supports fragmentation of user data frames into variable sized transmission fragments.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

1PPS	One Pulse per Second
ACK	Acknowledgment
AES	Advanced Encryption Standard
Alloc-ID	Allocation Identifier
AMCC	Auxiliary Management and Control Channel
AN	Access Network
ANI	Access Node Interface
AWG	Arrayed Waveguide Grating
BBU	Baseband Unit
BER	Bit Error Ratio
B-PON	Broadband Passive Optical Network
CD	Chromatic Dispersion
CDN	Content Delivery Network
CE	Coexistence Element
CEx	Coexistence Element Type x (x = 1, 2, etc.)
CG	Channel Group
CID	Consecutive Identical Digits
CIR	Committed Information Rate
CO	Central Office
CP	Channel Pair
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
eCPRI	Enhanced Common Public Radio Interface
CS	Channel Spacing
CT	Channel Termination
CTI	Cooperative Transport Interface
CU	Control Unit
DBA	Dynamic Bandwidth Assignment
DBRu	Dynamic Bandwidth Report, upstream
DeMux	Demultiplexer
DF	Disable Failure
DG	Dying Gasp
DPU	Distribution Point Unit
DS	Downstream (transmission direction)
DWLCH	Downstream Wavelength Channel

DU	Distributed Unit
EDFA	Erbium-Doped Fibre Amplifier
EqD	Equalization Delay
ER	Extinction Ratio
ESMC	Ethernet Synchronization Messaging Channel
EVC	Ethernet Virtual Connection
FCAPS	Fault, Configuration, Accounting, Performance, and Security
FCS	Frame Check Sequence
FEC	Forward Error Correction
FS	Framing Sublayer
FSR	Free Spectral Range
FTTCab	Fibre To The Cabinet
FTTB/C	Fibre To The Building/Curb
FTTC	Fibre To The Cabinet
FTTCell	Fibre To The Cell Site
FTTdp	Fibre To The Distribution Point
FTTH	Fibre To The Home
FTTO	Fibre To The Office
G-PON	Gigabit-capable Passive Optical Network
HEC	Hybrid Error Correction
HSP	Higher Speed PON
ID	Identifier
IFG	Inter-Frame Gap
IPTV	Internet Protocol Television
LT	Line Terminal
MAC	Media Access Control
MDU	Management Data Unit
MDU	Multi-Dwelling Unit
MEF	Metro Ethernet Forum
MIB	Management Information Base
MIC	Message Integrity Check
MPM	Multi-PON Module
MSE	Maximum Spectral Excursion
MTU	Maximum Transmission Unit
MUX	Multiplexer
NGN	Next Generation Network
NG-PON1	Next Generation Passive Optical Network 1

NG-PON2	Next Generation Passive Optical Network 2
NT	Network Terminal
OAM	Operation, Administration and Maintenance
OAN	Optical Access Network
OC	Operation Control
OCS	Operation Control Structure
ODN	Optical Distribution Network
ODN-ID	Optical Distribution Network Identifier
ODS	Optical Distribution Segment
OLT	Optical Line Terminal
OMCC	ONU Management and Control Channel
OMCI	ONU Management and Control Interface
ONU	Optical Network Unit
OOB	Out-of-Band
OOB-PSD	Out-of-Band Power Spectral Density
OOC	Out-of-Channel
OOC-PSD	Out-of-Channel Power Spectral Density
OPEX	Operational Expenditure
OPL	Optical Path Loss
OPP	Optical Path Penalty
ORL	Optical Return Loss
OTDOA	Observed Time Difference of Arrivals
OTDR	Optical Time Domain Reflectometer
OTL	Optical Trunk Line
PDU	Protocol Data Unit
PHY	Physical interface
PIR	Peak Information Rate
PLOAM	Physical Layer Operations, Administration and Maintenance
PLOAMu	PLOAM, upstream
PMD	Physical Medium Dependent
PON	Passive Optical Network
POTS	Plain Old Telephone Service
PSD	Power Spectral Density
PtP	Point-to-Point
PtP WDM	Point-to-Point Wavelength Division Multiplexing
QoS	Quality of Service
RE	Reach Extender

RF	Radio Frequency
RRH	Remote Radio Head
RRT	Round-trip Response Time
RS	Reed-Solomon (code)
R/S	Receive/Send reference point at the interface of the ONU to the ODN
R'/S'	Reach extender interface to optical trunk line
RTT	Round Trip Time
RU	Reference Unit
Rx	Receiver
SDU	Service Data Unit
SFU	Single-Family Unit
SMF	Single Mode Fibre
SMSR	Side Mode Suppression Ratio
SN	Serial Number
SN	Service Node
SNI	Service Node Interface
SOA	Semiconductor Optical Amplifier
S/R	Send/Receive reference point at the OLT side
S/R-CP	S/R for Channel Pair
S/R-CG	S/R for Channel Group
S'/R'	Reach extender interface to optical distribution network
SR	Status Reporting (DBA method)
SR	Sleep Request (PLOAM message type)
T-CONT	Transmission Container
TC	Transmission Convergence
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TM	Traffic Monitoring (DBA method)
ToD	Time of Day
Tx	Transmitter
TWDM	Time and Wavelength Division Multiplexing
UNI	User-Network Interface
US	Upstream (transmission direction)
VBES	VLAN for business Ethernet service
VoD	Video on Demand
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network

VR	Virtual Reality
WDM	Wavelength Division Multiplexing
WNE-PSD	When Not Enabled Power Spectral Density
WM	Wavelength Multiplexer
XG-PON	Asymmetric 10-Gigabit Passive Optical Network
XGS-PON	Symmetric 10-Gigabit Passive Optical Network
XGEM	10-Gigabit-capable PON Encapsulation Method
XGTC	XG-PON Transmission Convergence

5 Conventions

5.1 Optical access concepts

This Recommendation reuses the optical access network terminology and definitions system adopted by [b-ITU-T G.987]. An example of an access network architecture satisfying the definition system shown in Figure 5-1.

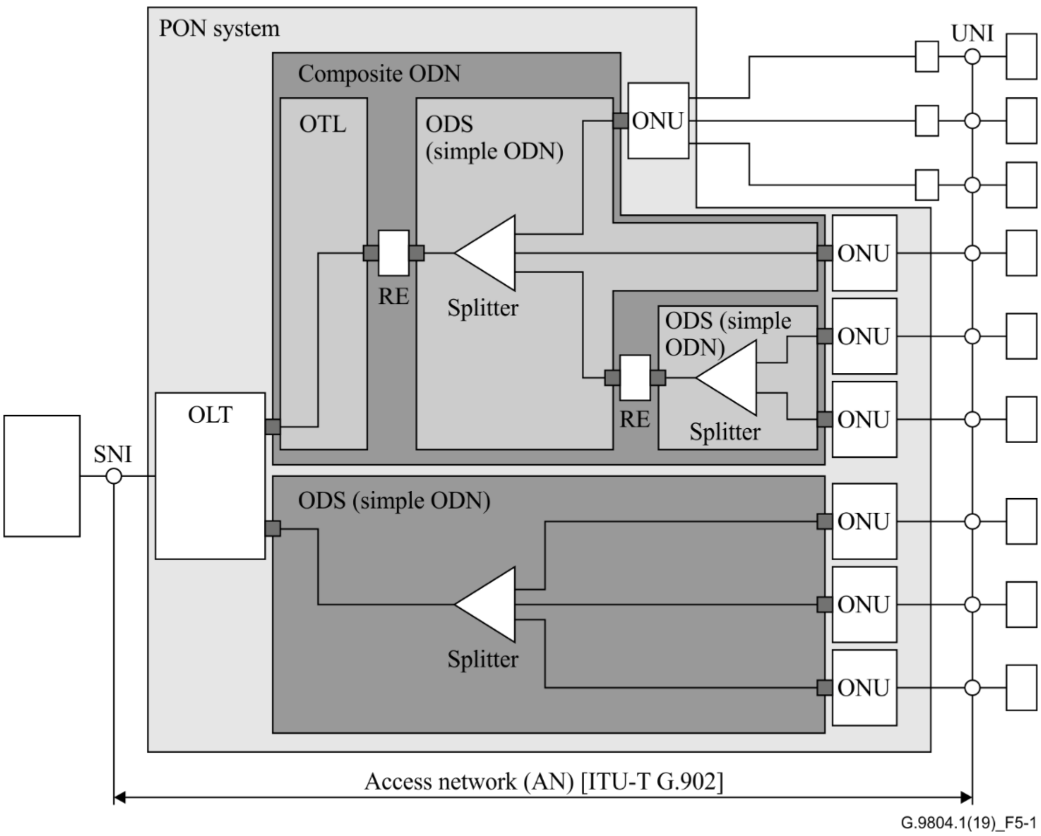


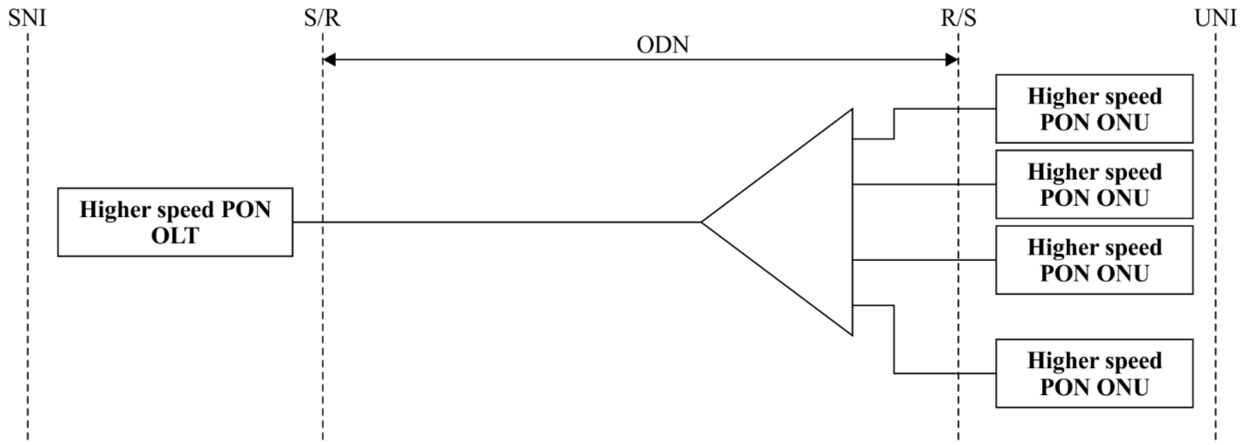
Figure 5-1 – Reference access network architecture

5.2 Higher speed PON system reference points

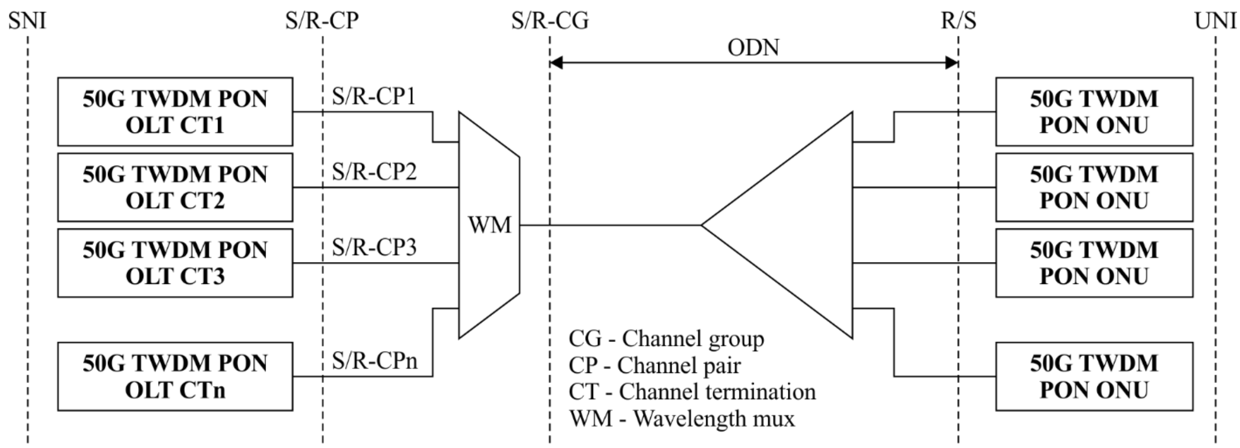
The basic architectures of higher speed PON systems can be split between time division multiplexing/time division multiple access (TDM/TDMA) based, and point-to-point (PtP) based. The general reference logical architecture and its reference points of the higher speed PON TDM/TDMA system are presented in Figure 5-2 (a).

In a higher speed multi-channel PON system, such as 50G TWDM PON, the OLT is conceptually composed of multiple OLT channel terminations (CTs) connected via a wavelength multiplexer

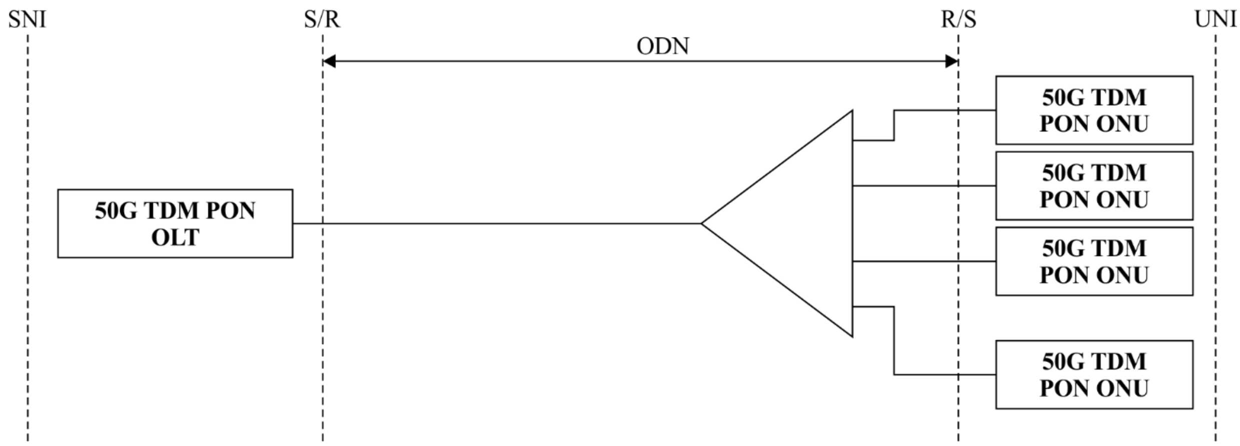
(WM). The associated reference logical architecture and its reference points are presented in Figure 5-2 (b). In a higher speed single-channel, such as 50G TDM PON, the OLT can be treated as a special case of a higher speed multi-channel PON system. The associated reference logical architecture and its reference points are presented in Figure 5-2 (c).



a) Higher speed PON TDM/TDMA system



b) 50G TWDM PON system



c) 50G TDM PON system

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Figure 5-2 – Higher speed PON reference logical architecture

5.3 Optical power and loss parameters

The relationships between optical power and loss parameters are captured in Figure 5-3.

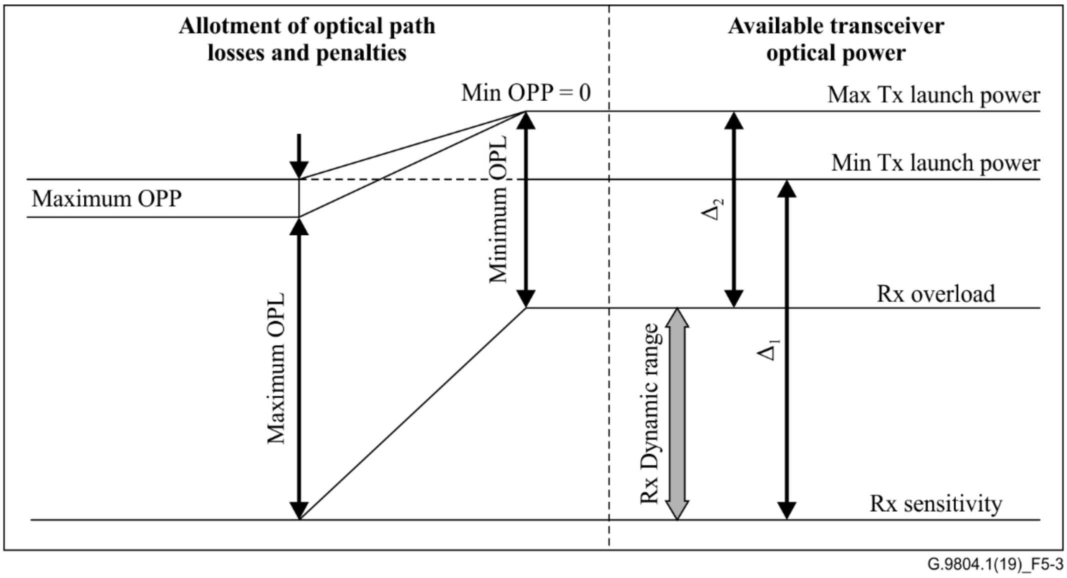

Figure 5-3 – Relationship between optical power and loss parameters

Given an ODN characterized by the maximum and minimum optical path loss and the maximum optical path penalty, the optical links is balanced if and only if the following two constraints are met (assuming logarithmic representation of the parameters):

1) The difference between the minimum transmitter mean channel launch power and the receiver sensitivity is greater than or equal to the sum of the maximum optical path loss and the maximum optical path penalty.

2) The difference between maximum transmitter mean channel launch power and the receiver overload does not exceed the minimum optical path loss.

5.4 Dynamic range, sensitivity, and overload

The concept of the dynamic range definition is illustrated in Figure 5-4. The receiver sensitivity and overload are generally understood, respectively, as the minimum and maximum average received optical power at which the bit error ratio (BER) at the receiver output remains at the specified reference level. The observed values of receiver sensitivity and overload may vary as the operating temperature and signal quality change, and the system ages. The signal quality characteristics that affect receiver sensitivity and overload may include the transmitter extinction ratio, parameters of the eye diagram, and in-band crosstalk. In this Recommendation series, receiver sensitivity and receiver overload are formally specified by their respective worst-case values, i.e., maximum sensitivity and minimum overload over the range of operating temperature and signal quality parameters, and under the end-of-life conditions.

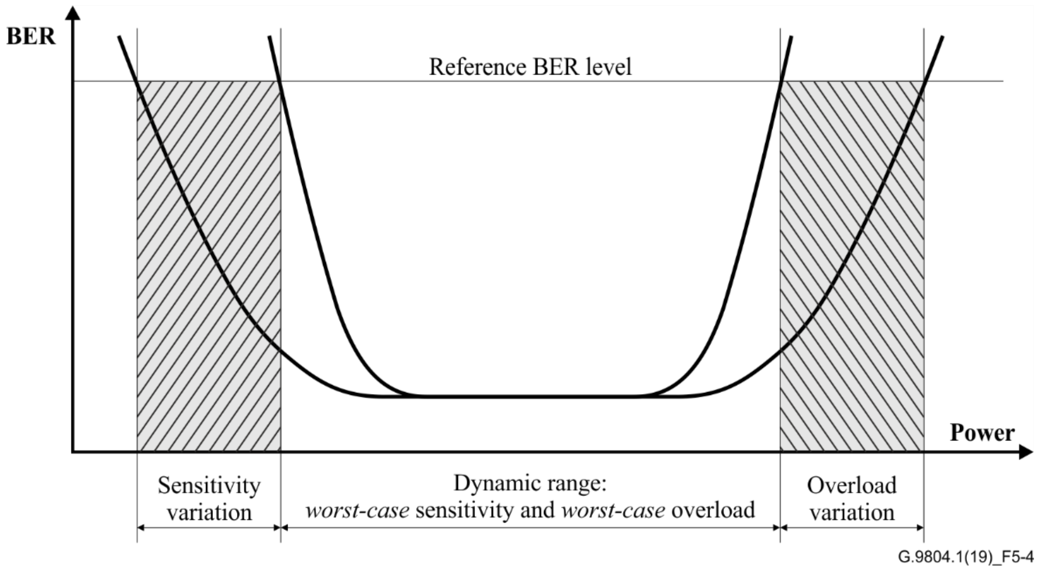

Figure 5-4 – Rx output BER as a function of received optical power, and the definition of dynamic range

5.5 Sensitivity and overload in the presence of FEC

To simplify higher speed PON (HSP) optical component verification, this Recommendation, as well as [b-ITU-T G.987.2], specifies the sensitivity and overload at the reference BER level, which corresponds to the Rx output and the forward error correction (FEC) decoder input. It is assumed that the FEC algorithms specified, respectively, for continuous mode downstream and burst mode upstream transmission are sufficiently strong to achieve the BER level of 10^{-12} or better at the FEC decoder output. See [b-ITU-T G-Sup.39] for further discussion.

5.6 Reach and distance

Like the ITU-T G.987.x series prior to it, the ITU-T G.9804.x series of Recommendations addresses the linear extent parameters of HSP using the single concept of fibre distance. An ONU is characterized by its fibre distance, and for each pair of ONUs on the same OLT PON interface, the differential fibre distance is the difference between the two individual fibre distances. Each specific physical medium dependent (PMD) layer parameter set contains a provision to support a specific maximum fibre distance. The HSP transmission convergence (TC) layer specification contains a provision to support specific ranges of maximum fibre distance and maximum differential fibre distance. These ranges can be configurable for a given system. One can expect that for each HSP deployment, the configured TC layer maximum fibre distance will match the maximum fibre distance supported by the selected PMD layer parameter set. Fibre distance concepts are illustrated in Figure 5-5.

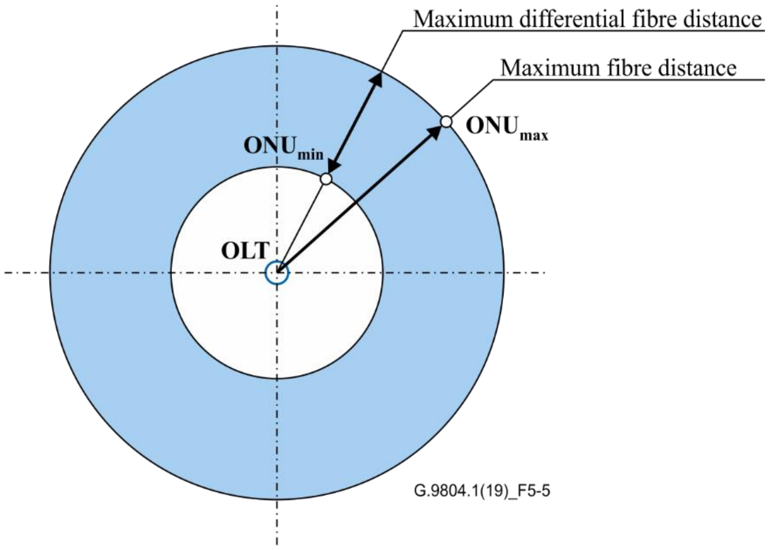

Figure 5-5 – Fibre distance concepts

5.7 Use of the term PON

Historically, the term PON was introduced to describe a point-to-multipoint fibre infrastructure composed exclusively of passive optical components. This strict-sense usage was soon naturally extended to include a fibre-in-the-loop communication system employing such an infrastructure and using time-division multiplexing to share the available digital bandwidth among many subscribers (TDM PON). As new types of PON-based systems were introduced, leveraging various TDM transport mechanisms (B-PON, G-PON, EPON) or alternative multi-access methods (WDM-PON), it became common to use the word PON with appropriate qualification in reference to the specific architectural variations. While the term remained overloaded, referring in different contexts to a network, a system, architecture or technology, all the referenced entities shared a common attribute of containing, using or relying upon a fibre infrastructure with no active (electronic) components between the central office interface and the user equipment interface. More recently, introduction of active reach extenders within the optical distribution network as defined in [b-ITU-T G.984.6] created a paradoxical situation when an infrastructural component of a G-PON system may not be entirely passive, that is, nominally, no longer a PON. Thus, it became apparent that the excessive overloading of what was once meant to be a precise term may adversely impact the clarity of a technical presentation.

This current series of Recommendations deliberately restricts the usage of the term PON to the contexts where it denotes a system, that is, a combination of network elements including at least one OLT and multiple ONUs interconnected by an ODN that implements a particular coordinated suite of physical medium dependent layer, transmission convergence layer, and management protocols. It also strives to provide a consistent, unambiguous, and extensible definition system that allows supporting efficient communication on the subject.

5.8 Use of the term ODN

In the ITU-T G.983 B-PON and ITU-T G.984 G-PON series of Recommendations (prior to [b-ITU-T G.984.6]), the term optical distribution network (ODN) refers to a passive point-to-multipoint distribution means extending from the user-facing interface of the OLT to the network-facing interfaces of the ONUs. The introduction of active reach extenders and the concept of dual-homing call for a revision of the term's scope and usage, as the fibre-based distribution network extending between the OLT and ONU interfaces may be neither point-to-multipoint nor strictly passive.

This current series of Recommendations follows the ITU-T G.987.x series, endorsing a generalized usage of the term ODN to denote a point-to-multipoint fibre infrastructure, which is not required to be entirely passive. In the contexts where the internal structure of the ODN is not a concern, it is the ODN that interconnects the OLT and the ONUs to form a PON system. In the contexts where the internal structure of the ODN is relevant, two types of ODNs can be distinguished. 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 *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. The definition allows two ODNs with distinct roots to share a common subtree, thus supporting the notions of dual-homing and protection within the definition system.

5.9 Use of the terms ONU and ONT

Throughout the ITU-T G. 9804.x series of Recommendations, as in the earlier ITU-T G.987.x series, the network element interfacing the end-user access facilities and the ODN is referred to as an ONU, or an optical network unit, irrespective of the number and type of user interfaces or the depth of fibre deployment. Historically, the term ONT, or optical network terminal/termination, has been used either interchangeably with ONU or with the particular semantics of "an ONU that is used for fibre to the home (FTTH) and includes the user port function" (see [b-ITU-T G.983.1]), or "a single-subscriber ONU" (see [b-ITU-T G.984.1] and other Recommendations of the ITU-T G.984.x series). This Recommendation follows the latter approach in defining ONT. Note, however, that while this definition captures one established trade interpretation of the term, the concept itself is not used as a part of the ITU-T G. 9804.x reference access architecture.

Outside of the scope of [ITU-T G.987], [ITU-T G.989] and ITU-T G. 9804.x series, alternative interpretations may apply and, therefore, the reader is advised to clarify the exact meaning of the term in each specific context. In particular, in some external contexts, the term ONT may be used generically to refer to any device terminating a leaf of the ODN.

5.10 Use of the terms T-CONT and Alloc-ID

A transmission container (T-CONT) is an ONU management and control interface (OMCI) managed entity representing a group of logical connections that appear as a single entity for the purpose of upstream bandwidth assignment in a PON system.

For a given ONU, the number of supported T-CONTs is fixed. The ONU autonomously creates all the supported T-CONT instances during ONU activation or upon OMCI management information base (MIB) reset. The OLT uses the ONU management and control channel (OMCC) to discover the number of T-CONT instances supported by a given ONU and to manage those instances.

The *Allocation identifier* (*Alloc-ID*) is a 14-bit number that the OLT assigns to an ONU to identify a traffic-bearing entity that is a recipient of upstream bandwidth allocations within that ONU. Such a traffic-bearing entity is usually represented by a T-CONT but may also be represented by an internal non-managed structure.

Each ONU is assigned at least its default Alloc-ID and may be explicitly assigned additional Alloc-IDs per OLT's discretion.

To activate a T-CONT instance for carrying the upstream user traffic, the OLT must map that T-CONT instance to an Alloc-ID which was previously assigned to the given ONU via the physical layer operations, administration and maintenance (PLOAM) messaging channel. Mapping of T-CONTs to Alloc-IDs is performed via the OMCC. The OMCC itself is mapped, in the upstream direction, to the default Alloc-ID. This mapping is fixed; it cannot be managed via the OMCI MIB and it should survive OMCI MIB reset.

Although in many cases there exists a one-to-one correspondence between T-CONTs and Alloc-IDs, it is the Alloc-ID, not a T-CONT, which is visible at the TC layer of the system.

5.11 Use of the terms bandwidth assignment and bandwidth allocation

The term "bandwidth assignment" refers to the distribution of the upstream PON capacity between the ONUs' traffic-bearing entities using certain isolation and fairness criteria. In static bandwidth assignment, the said criteria are based exclusively on the provisioned parameters of the traffic contracts, and the bandwidth is assigned on the timescale of the individual service provisioning. In dynamic bandwidth assignment, the activity status of the traffic-bearing entities is taken into consideration along with the parameters of the traffic contracts, and the bandwidth assignment is periodically refined.

The term "bandwidth allocation", on the other hand, denotes the process of granting individual transmission opportunities to the ONUs' traffic-bearing entities on the timescale of a single physical interface (PHY) frame. The process of bandwidth allocation uses the assigned bandwidth values as an input and produces the per-frame bandwidth maps as an output. It also accounts for PLOAM messaging and dynamic bandwidth report, upstream (DBRu) overhead requirements and the short-term disturbances associated with the creation of quiet windows for serial number acquisition and ranging purposes.

5.12 Use of the terms band and range

When used in the context of optical spectrum, both terms "band" and "range" generally denote a spectral interval in terms of frequency (f_{min}, f_{max}) or wavelength (λ_{min}, λ_{max}). Within the HSP context, the term "band" applies specifically to a spectral interval which covers all wavelength channels of a specific application (e.g., TWDM PON upstream band, narrow band option, shared spectrum band, G-PON downstream band, etc.), whereas the term "range" usually applies to a spectral interval corresponding to a single wavelength channel.

The operating bands are specified in wavelength terms as a matter of convenience for classification and reference purposes. The actual minimum and maximum wavelengths for an operating band should be calculated from the maximum and minimum wavelengths of the two outmost wavelength channels.

5.13 Transmitter enable control and associated transient times

Conceptually, TxEnable is a binary signal that controls a burst-mode ONU transmitter. The TxEnable signal must be asserted (active) for the ONU to transmit an assigned burst. The TxEnable signal is expected to be de-asserted (inactive) whenever no burst is assigned to the ONU. The transmitter enable transient time and transmitter disable transient time are the allocated time intervals which serve to accommodate any transient physical processes that may be associated, respectively, with assertion and de-assertion of the TxEnable signal. The maximum number of bits allocated for transmitter enable transient time and transmitter disable transient time are parameters of the ONU optical interface specification. Figure 5-6 shows the relationship between the level of the TxEnable signal (without loss of generality, active-high logic is assumed) and the associated transient times of the burst-mode transmitter. Within the scope of ITU-T G. 9804.x series of Recommendations, the definitions of the optical-power-related PMD parameters applicable to the burst-mode transmitters (mean launch optical power, extinction ratio, OOC-PSD, WNE-PSD) are referenced to the corresponding averaging intervals which are specified in terms of transmitter's enabled/disabled periods and the associated transient times.

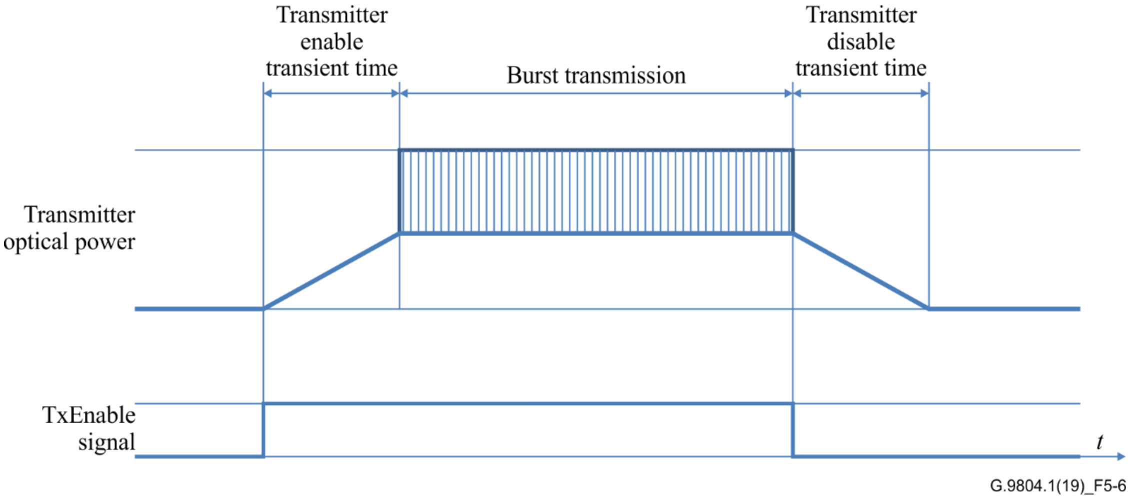

Figure 5-6 – The TxEnable signal and the associated transient times of a burst- mode transmitter

6 Architecture of the HSP

6.1 Network architecture

The optical section of a local access network system can be either active or passive and its architecture can be either point-to-point or point-to-multipoint. Figure 6-1 shows the considered architectures, which can be fibre to the home (FTTH), fibre to the cell site (FTTCell), fibre to the building/curb (FTTB/C), fibre to the cabinet (FTTCab), fibre to the distribution point (FTTdp), etc. The optical ODN is common to all the architectures shown in Figure 6-1; hence, the commonality of this system has the potential to generate large worldwide volumes.

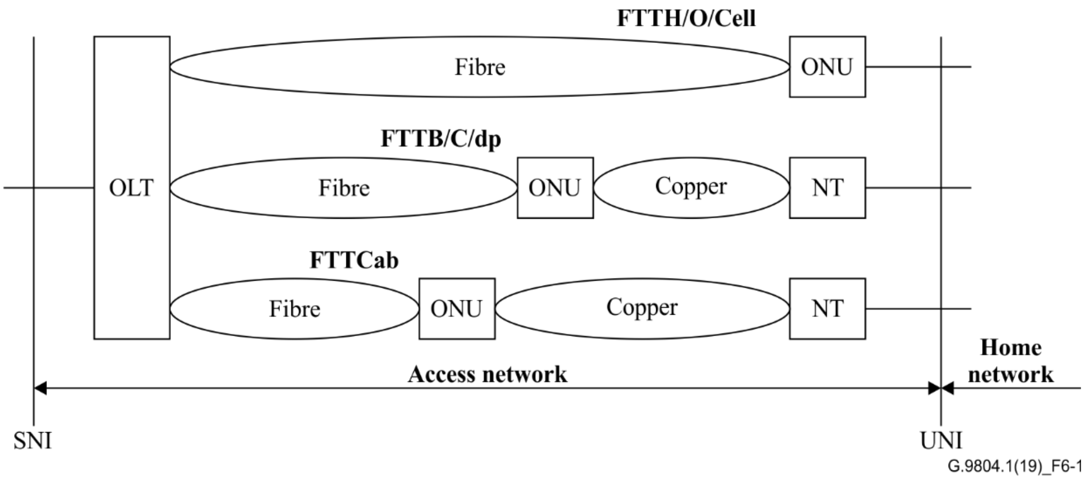

Figure 6-1 – Network architecture

NOTE – An ONU supporting FTTH has been commonly referred to as ONT, see clause 5.9.

The differences among these FTTx options are mainly due to the different services supported and the different locations of the ONUs rather than the ODN itself, so they can be treated as one in this Recommendation. It must be noted that a single OLT optical interface might accommodate a combination of several scenarios described hereafter.

Higher speed PON should extend the reach extenders capability, to produce extra optical budget to achieve longer distances and/or additional passive split at the relevant line rate combinations.

Deployment scenarios of higher speed PON are shown in Figure 6-2, with services illustrated in Table 6-1.

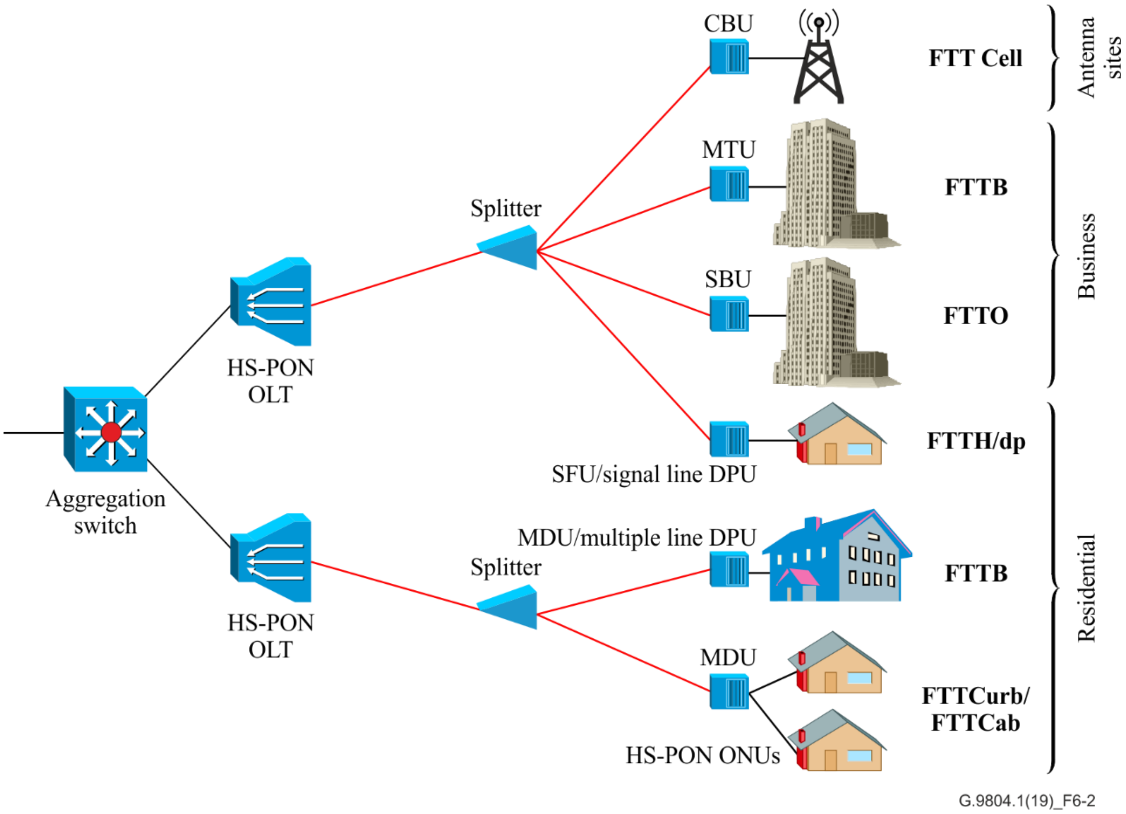

Figure 6-2 – Deployment scenarios of higher speed PON

Table 6-1 – Services categories supported in higher speed PON scenarios

Scenarios	Services categories
FTTB (for MDU-served residential users)	– Asymmetric broadband services (e.g., Internet protocol television (IPTV), digital broadcast services, video on demand (VoD), file download, etc.). – Symmetric broadband services (e.g., content broadcast, e-mail, file exchange, distance learning, telemedicine, online-games, etc.). – Plain old telephone service (POTS) – The access network must be able to provide, in a flexible way, narrow-band telephone services using either emulation (complete replication of a legacy service) or simulation (providing a service that is almost the same as the legacy service).
FTTB (for MTU-served business users)	– Symmetric broadband services (e.g., group software, content broadcast, e-mail, file exchange, etc.). – POTS – The access network must be able to provide, in a flexible way, narrow-band telephone services using either emulation (complete replication of a legacy service) or simulation (providing a service that is almost the same as the legacy service). – Private line – The access network must be able to provide, in a flexible way, private-line services at several rates.
FTTC and FTTCab	– Asymmetric broadband services (e.g., IPTV, digital broadcast services, VoD, file download, online-games, etc.). – Symmetric broadband services (e.g., content broadcast, e-mail, file exchange, distance learning, telemedicine, etc.).

Table 6-1 – Services categories supported in higher speed PON scenarios

Scenarios	Services categories
	− POTS – The access network must be able to provide, in a flexible way, narrow-band telephone services using either emulation (complete replication of a legacy service) or simulation (providing a service that is almost the same as the legacy service). − xDSL backhaul.
FTTH	− Asymmetric broadband services (e.g., IPTV, digital broadcast services, 4K and 8K video, VoD, file download, etc.). − Symmetric broadband services (e.g., content broadcast, e-mail, file exchange, distance learning, telemedicine, online-games, etc.). − POTS – The access network must be able to provide, in a flexible way, narrow-band telephone services using either emulation (complete replication of a legacy service) or simulation (providing a service that is almost the same as the legacy service).
FTTO	Fibre to the office (FTTO) addresses business ONU dedicated to a small business customer. The following service categories have been considered: − Symmetric broadband services (e.g., group software, content broadcast, e-mail, file exchange, etc.). − POTS – The access network must be able to provide, in a flexible way, narrow-band telephone services using either emulation (complete replication of a legacy service) or simulation (providing a service that is almost the same as the legacy service). − Private line – The access network must be able to provide, in a flexible way, private line services at several rates.
FTTCell	The ONU in a FTTCell scenario will have to offer connectivity to wireless base stations: − Symmetric TDM services (e.g., 2G cell site backhaul). − Symmetric/asymmetric packet-based broadband services (e.g., 3G/4G/5G cell-site x-haul). − Hot spots.
FTTdp	The ONU in a FTTdp scenario will be called a distribution point unit (DPU) that in addition to the FTTB service categories and capabilities may support: − Reverse powering capability with power supplied through the copper drop from the end-user installation. − xDSL or G.fast copper drop UNI. − FTTdp architectures involving DPU are described in [b-BBF TR-301].
PON-based 5G Mobile FrontHaul (PON-MFH)	The OLT and ONUs provide transport between the control unit (CU) and RU. Ultra-low latency with the use of cooperative DBA function and quiet window reduction for the PON. An interface (named cooperative transport interface or (CTI)) between the 5G scheduler and a PON OLT/scheduler as defined by O-RAN WG 4 group in collaboration with ITU SG15 Q2 group.

For supporting the wide range of scenarios and applications, optical parameters for the OLT and the ONU should be determined to allow an outdoor operation.

6.2 System overview

This clause and its subclauses provide an overview of higher speed PON system requirements, which are compatible with legacy power splitting ODNs. Optical technologies that specifically require wavelength filtering in the ODN are precluded from this Recommendation. However, optical technologies compatible with legacy power splitting ODNs and capable of supporting ODNs that may consist of wavelength filters only, or a combination of both wavelength and power splitters, are in scope of this Recommendation.

Requirements that are specific to particular transmission systems are given in clauses 6.2.1 to 6.2.4.

6.2.1 Common requirements

All HSP systems that are intended to operate on the established splitter-based PON infrastructure should adhere to the following:

– The system specification should provide:
  - The symmetric nominal line rate combinations per wavelength channel in the downstream and upstream directions of approximately 50 Gbit/s to ensure support of the maximum service rate of at least 40 Gbit/s.
  - The asymmetric nominal line rate combination options per wavelength channel:
    - o approximately 50 Gbit/s in the downstream and 25 Gbit/s in the upstream,
    - o approximately 50 Gbit/s in the downstream and 12.5 Gbit/s or 10 Gbit/s in the upstream.
  - Simultaneous support of the ONUs with different asymmetric upstream nominal line rate combination options on the same wavelength channel via TDMA. Supporting additional 50 Gbit/s nominal line rates through TDMA in the upstream direction is for further study.

– Support the maximum fibre distance of at least:
  - 20 km for general applications,
  - 10 km for wireless applications that are latency sensitive (e.g., 5G).

– Support using fibre types described in [ITU-T G.652] and [ITU-T G.657].

– Operate over ODNs comprised of fibres, connectors, splitters, and optionally wavelength selective devices.

– For TDMA based systems, use of a common TC layer, which should support:
  - maximum fibre distance of 60 km,
  - maximum differential fibre distance of up to 40 km,
  - configuring the maximum differential fibre distance with a 20 km step,
  - support a minimum 1:256 split ratio.

− The capability to provide non-service-affecting scheduled maintenance by limiting the service outage to in-service ONUs to 50ms or less.

− The OLT power management capability.

6.2.2 50G TDM PON system requirements

50G TDM PON systems supports a single wavelength channel pair operating in TDM/TDMA mode and satisfying the line rate requirements of clause 6.2.1.

6.2.3 50G TWDM PON system requirements

The 50G TWDM PON system supports:

− Multiple wavelength channel pairs multiplexed on the same fibre, each operating in TDM/TDMA mode and satisfying the rate requirements of clause 6.2.1.

– The tunable ONUs capable of operating on any of the available wavelength channel pairs under the OLT control.

– The capability to support services with distinct characteristics on the same fibre by assigning them to different wavelength channels.
– The pay-as-you-grow capability to increase the overall capacity on the fibre by providing additional wavelength channel pairs with increasing demand.
– The capability to natively avoid service-affecting ONU activation on service-critical wavelength channels, by allowing activation on a proper subset of available wavelength channels.
– The capability to provide wavelength service protection by limiting the service restoration time in case of OLT card failure to 50 ms or less.
– The capability to support the ONU service rates in excess of the maximum service rate of an individual wavelength channel through wavelength channel bonding.
– The load balancing capability across available wavelength channels.
– The capability to employ multi-wavelength techniques for rogue ONU mitigation.

6.2.4 Higher speed point-to-point WDM PON (PtP WDM PON) system requirements

The system requirements of higher speed point-to-point WDM PON (PtP WDM PON) system are for further study.

6.3 Network reference configurations

The higher speed PON systems comprise one or more wavelength channel pairs which are separated in the wavelength domain. Basic architectures can be split between TDM/TDMA based, and point-to-point based. The higher speed PON TDM/TDMA system comprising a single wavelength channel pair is the single channel TDM PON. The higher speed PON TDM/TDMA system comprising more than one wavelength channel pairs is the TWDM PON. TWDM PON system supports ONU tunability, wavelength channel bonding, and makes use of a wavelength multiplexer at the OLT. The operational principles of TDM and TDMA apply in an individual wavelength channel pair in both higher speed PON TDM/TDMA systems. The higher speed PON point-to-point systems are non TDMA based and typically have multiple wavelength channel pairs.

A high-level and simple reference configuration of a single channel TDM PON is depicted in Figure 6-3.

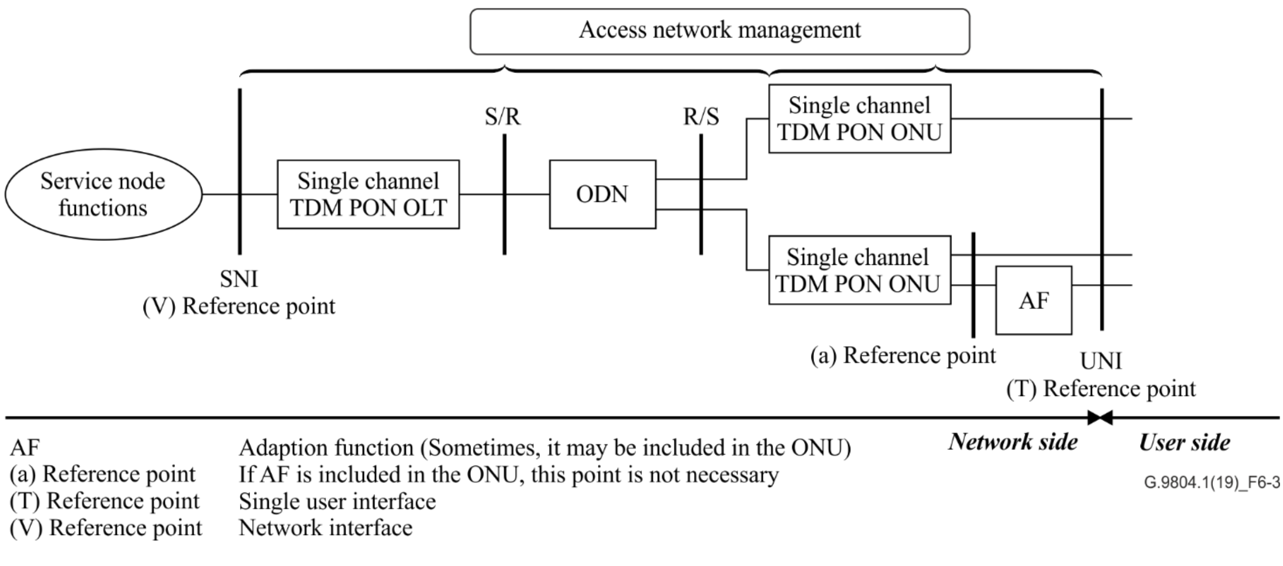

Figure 6-3 – High-level reference configuration of single channel TDM PON

Figure 6-4 depicts the functional optical access network architecture and reference points that apply to single channel TDM PON systems with legacy systems coexistence. The ODN consists of the splitter and the coexistence element (CEx) and, optionally, reach extenders may also be used in the ODN. The optical technologies specified for single channel TDM PON systems shall be compatible with legacy power splitting ODNs (that is an ODN that may contain power splitters and a coexistence element). The interface at reference points S/R and R/S at single channel TDM PON OLT and single channel TDM PON ONU optical port is defined as $IF_{50G\ TDM}$. This is a PON-specific interface that supports all the protocol elements necessary to allow transmission between the OLT and the ONUs.

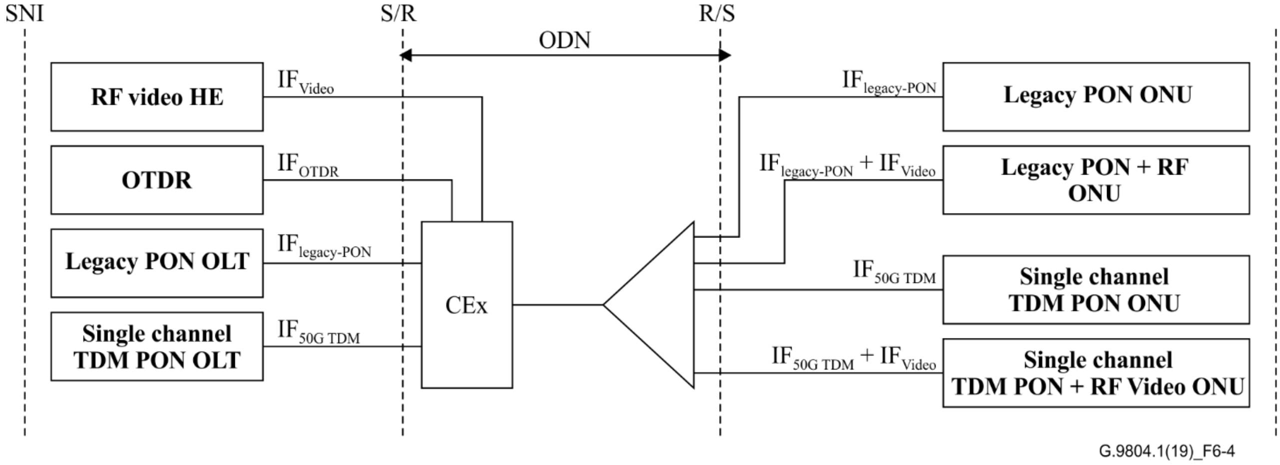

Figure 6-4 – Functional reference architecture and points for single channel TDM PON system coexistence with legacy systems

7 Migration scenarios

G-PON (ITU-T G.984.x series of Recommendations), XG-PON (ITU-T G.987.x series of Recommendations), XGS-PON (ITU-T G.9807.x series of Recommendations), 10G-EPON (IEEE 802.3av standard) and TWDM PON (ITU-T G.989.x series of Recommendations) have been standardized, and some of them have now been widely deployed worldwide. With the ever-increasing bandwidth demand from consumer and business applications, the most general requirement for HSP is to provide higher bandwidth than these legacy PON systems. In addition, given the major investments spent in time and money on deploying these legacy PON systems (including the fibre infrastructure), HSP must be able to protect these investments by ensuring seamless and smooth migration capability for subscribers to high speed PON systems.

There are several migration scenarios to meet the needs of different service providers. These reflect recognition that differing service introduction strategies might affect the requirements for the high speed PON specifications.

PON brownfield scenario in this Recommendation refers to the deployment scenario where a PON system has already been deployed and network operators decide to leverage this existing fibre infrastructure to offer higher bandwidth carrier services, using HSP systems on this legacy fibre infrastructure.

Some subscribers on an existing PON system might require an upgrade to such higher speed tier service and it might be beneficial to move these subscribers over to the HSP system, while other subscribers remain on the legacy PON. It is likely that two or three PON generations will continue to coexist for a relatively long time.

In a slightly different migration scenario, it may be desirable to replace an existing PON with HSP completely in a 'full migration' scenario. In this case, it would still be useful to operate both legacy PON and HSP systems at the same time on the ODN and update customers one at a time. The timeframe for this type of full migration upgrade is generally much shorter.

The general requirements for this scenario are as follows:

– Coexistence between legacy PON and HSP on the same fibre must be supported for the case that the fibre resource is not necessarily abundant,

– Service interruption for the ONUs that do not undergo an upgrade should be avoided or minimized,

– HSP must support/emulate all legacy PON services in the case of full migration,

– Legacy PON systems include GPON, XG-PON, XGS-PON 10G-EPON and TWDM PON.

PON greenfield scenario in this Recommendation refers to the deployment scenario where PON had not been previously deployed in the object area. In this scenario, the requirement of coexistence with legacy PONs is not necessary. Upgrading the access network to FTTx infrastructure is a significant investment for service providers and takes a long time to fully realize. When HSP technology becomes mature, it may be desirable to use HSP systems to replace legacy copper-based infrastructure or to deploy in a brand-new development area for the benefit of higher bandwidth, higher splitting ratios, and other capabilities.

7.1 Coexistence

The smooth migration from one PON technology to another on the same ODN provides for an enhanced customer experience by minimizing the disruption of the existing optical plant. Coexistence facilitates a smooth migration from legacy PON to HSP systems. Without this coexistence capability, customers may have to wait longer to move their service and all customers on an ODN may experience unacceptable service disruption if parts of the passive infrastructure must be exchanged/reconfigured. The coexistence of two PON generations could enable a flexible migration and/or on-demand deployment of new PON connections without service interruption. For maximum flexibility, HSP systems must allow the coexistence with XG(S)-PON or GPON on the same ODN.

To facilitate coexistence, an HSP system must be capable of reusing existing legacy PON optical power splitters and ideally operate in usable spectrum not occupied by legacy PONs in a particular deployment. However, an HSP system could re-use the spectrum allocated to legacy PON systems if it is not coexisting with those legacy PON systems on the fibre used to deploy the HSP system. It should also be noted that certain approaches facilitate the reuse of spectrum by using a common wavelength band that can include multi-rate receivers. HSP systems must allow coexistence over the whole, end-to-end ODN including coexistence over the feeder fibre by use of a CEx (or equivalent WDM), as shown in Figure 7-1(a). Besides, higher speed TDMA system such as 50G TDM PON can use a multi-PON module integrated in the OLT PON port when coexisting with a legacy PON system, as shown in Figure 7-1(b). The end-to-end ODN of HSP is delimited by R/S to S/R reference points which are analogous to R/S to S/R as defined in [ITU-T G.984.1] and [ITU-T G.987.1]. HSP systems support power-based splitting ODNs. Appropriate filtering must be installed in ONUs to eliminate optical interference between the coexisting generations of PON. Furthermore, any interference due to fibre non-linearity should also be considered in the crosstalk analysis.

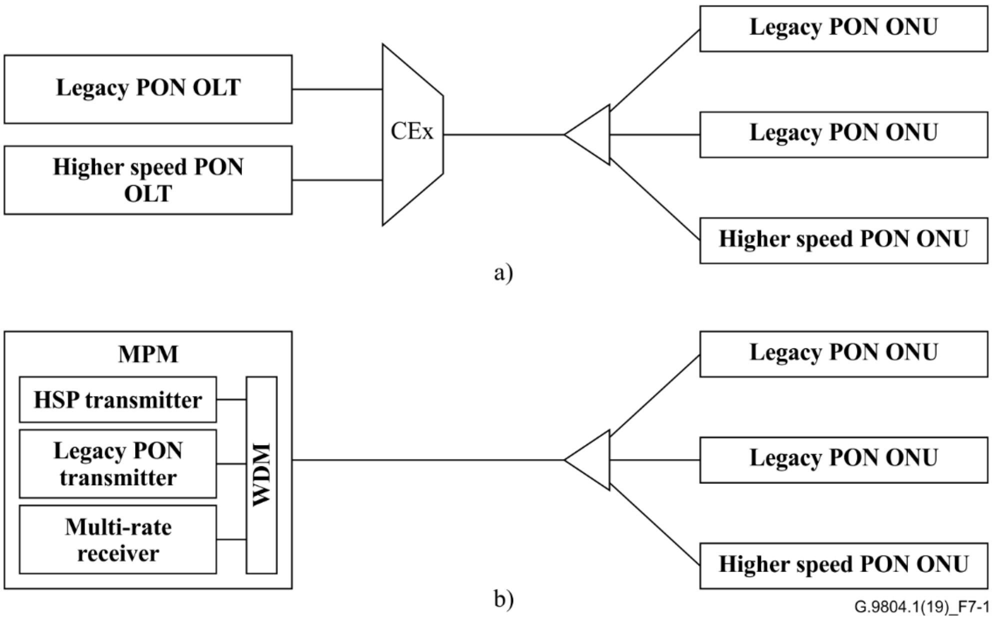

Figure 7-1 – ODN co-existence scenario (a) with CEx device, (b) higher speed TDMA system with multi-PON module

The coexistence of HSP systems with legacy RF-video overlay must be supported. RF-video overlay defined in [ITU-T J.185] or [ITU-T J.186] will continue to be used into the foreseeable future to support video delivery. Many legacy PON deployments use RF-video overlay for video delivery; therefore, coexistence will enable easy migration to HSP systems. This requirement should not increase system complexity when RF-video overlay is not required.

7.2 Migration path options

HSP systems must allow a technology migration on existing infrastructure without any prolonged service interruption. It must be capable of upgrading single customers on demand.

In order to realize the migration path there are three options which differ in the level of flexibility:

− **Straight two-step full migration to HSP**: this covers two-step straight full migrations in line with the PON generation order from GPON to XG(S)-PON and then to HSP. This requires a full migration from GPON to XG(S)-PON before starting with the HSP upgrade. The two-step full migration option could be realized by removing all the GPON from the ODN and re-using the GPON wavelength windows to enable HSP technology coexisting with XG(S)-PON. The scenario has a double co-existence at any one time of two PON technologies.

− **Direct migration to HSP**: a direct migration covers a path from GPON to HSP. Migration requires an HSP system that can coexist with GPON, a double PON technology coexistence.

− **All-embracing migration to HSP**: the highest level of flexibility is realized by an HSP system that enables coexistence of GPON, XG(S)-PON and HSP. The all-embracing option is the most challenging due to limited optical spectrum and reduced inter-band guard band among the three PON technologies. Operationally, a triple coexistence is required to be managed by support systems, technician tools, and increased OLT port and ONU type inventory.

In any migration case including co-existence, the legacy ONU and OLT must remain unchanged and should not require any additional wavelength filters to protect them against HSP signals. In the event that extra filtering is required, this should preferably be at the OLT where access may be easier and not the ONU to avoid truck rolls to many locations of the ONU. The attenuation of any additional devices, i.e., the CEx supporting coexistence, must also remain similar to that introduced by WDM1r devices in order not to compromise the legacy optical budget. Whichever migration scenario is chosen, it must be possible to migrate a customer from legacy PON to HSP through a replacement of the ONU.

7.3 Migration to 50G TDM PON

In the context of 50G TDM PON, it must support a migration path from XG(S)-PON to 50G TDM PON, and a migration path from 10G-EPON to 50G TDM PON. The upstream wavelength of asymmetric 10G-EPON system is narrowed in 1270 nm ± 10 nm in this case.

In the transition period, to get simultaneous XG(S)-PON working with 50G TDM PON, a WDM function should be included in the network, either an independent device CEx or embedded in a multi-PON module (MPM) as illustrated in Figure 7-2, and Figure 7-3.

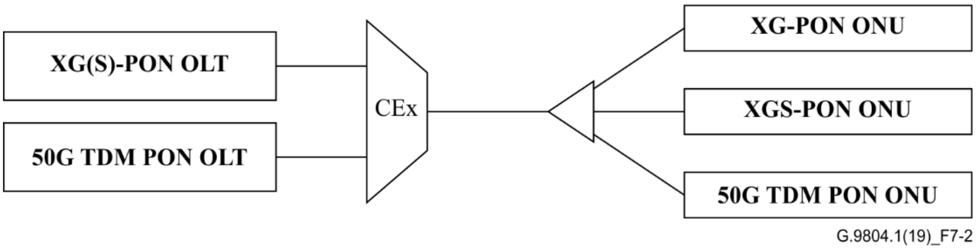

Figure 7-2 – Coexistence of XG(S)-PON and 50G TDM PON by independent CEx device

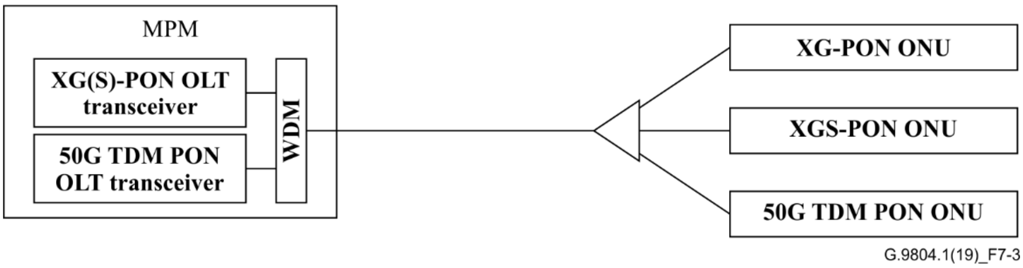

Figure 7-3 – Coexistence of XG(S)-PON and 50G TDM PON by MPM method

In the transition period, to get a simultaneous 10G-EPON working with a 50G TDM PON, a WDM function should be included in the network, via independent device CEx or embedded in an MPM module as illustrated in Figures 7-4 and 7-5.

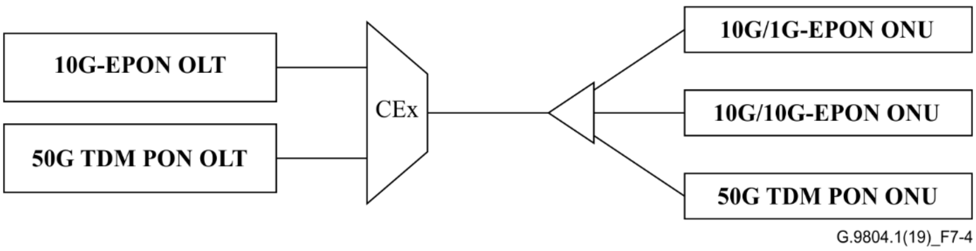

Figure 7-4 – Coexistence of 10G-EPON and 50G TDM PON by independent CEx device

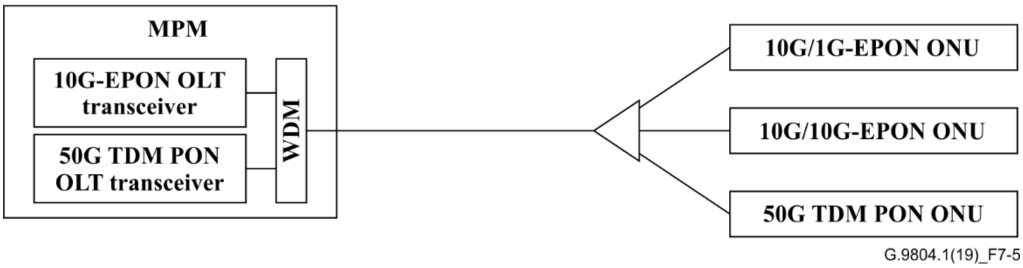

Figure 7-5 – Coexistence of 10G-EPON and 50G TDM PON by MPM module

The hybrid co-existence mixing WDM and 2.5G to 50G multi-rate receiver has been mentioned as a possible path for triple co-existence, as shown in Figure 7-6. To extend the benefit of the GPON system legacy both at the system and optical path loss, while opening an affordable migration path for the ITU-T PON legacy, triple co-existence has been found of interest to operators. Pure WDM triple co-existence requires identifying additional unique wavelength pair, which has been found to be too challenging on the condition that it does not interfere with the legacy ITU-T PON in the already crowded O-band, Figure 7-6 describes a hybrid WDM TDM triple co-existence alternative. In this architecture, coexistence between GPON and higher line rates is implemented through WDM, while XG(S)-PON and HSP will be secured through TDM upstream wavelength sharing.

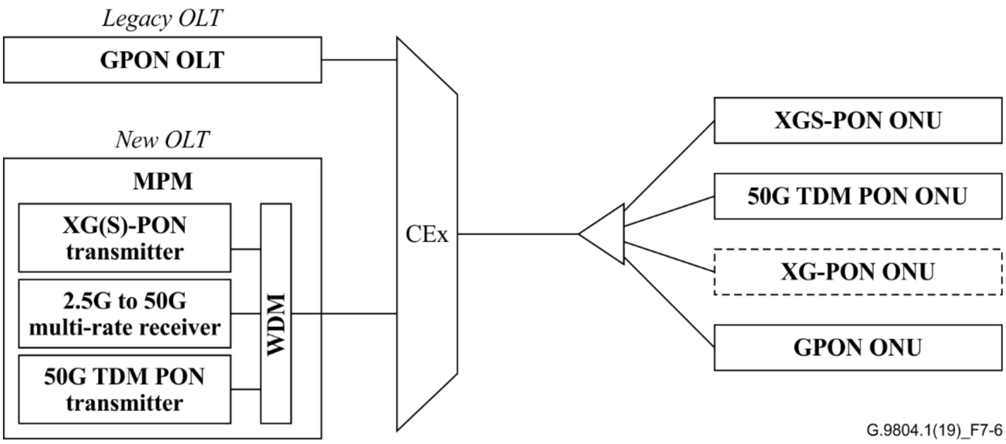

Figure 7-6 – Co-existence scenario of three generation PON systems by mixing WDM and multi-rate receiver

The co-existence scenario of three generation PON systems by pure WDM is shown in Figure 7-7. In this scenario, each generation PON system runs over its own wavelength band. Gigabit PON could be 1G-EPON or GPON (with reduced wavelength band), while 10G PON could be 10G-EPON or XG(S)-PON. Hence this scenario requires the identification of an additional unique wavelength pair that does not interfere with the legacy PON systems.

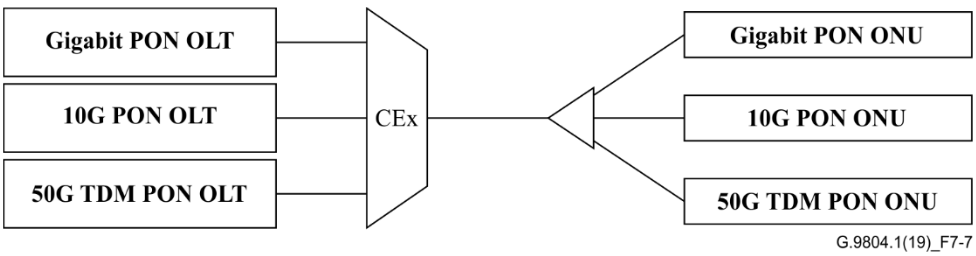

Figure 7-7 – Coexistence scenario of three generation PON systems by pure WDM

8 Service requirements

8.1 Service specific requirements

Higher speed PON systems are required to fully support various services for residential subscribers, business customers, mobile and fixed backhauling, and other applications through its high quality of service and high bit-rate capability. Further, higher speed PON system may achieve better delay and jitter performance. Higher speed PON system must support legacy services, such as POTS and T1/E1 using emulation and/or simulation, high speed private line (framed and unframed), and emerging packet-based services. The emulation option delivers packet-formatted traffic through the PON network, i.e., between the OLT and ONU, and possibly through some level of aggregation, then converts back to the relevant legacy format to hand it off to the legacy network. The simulation option is an end-to-end packet delivery starting at customer premises equipment (CPE) terminal adaptation device or ONU, to the higher speed PON access and the next generation network (NGN) packet network. An Ethernet packet size up to 9000 bytes must be supported. If jumbo frames beyond 2 000 bytes are used for non-delay-sensitive services on the same PON, the delay-sensitive services and packet network synchronization shall not be degraded by jumbo frame transport. For mobile backhaul service (especially for 5G), time of day signal distribution (as supported in the earlier [ITU-T G.984], [ITU-T G.987], [ITU-T G.989], [ITU-T G.9807.x series) and low signal transfer delay time should be supported.

In order to support the wireless transport requirements, including observed time difference of arrivals (OTDOA) based location services, the ONUs within HSP system should maintain time of day (ToD) synchronization to specified accuracy. The exact specifications can be found in [ITU-T G.8273.2], on the order of one hundred nanoseconds.

8.2 User node interfaces (UNIs)

UNI is defined as the interface that includes the following conditions:

– Interconnection between the access network and the customer,

– Described by a well-known standard,

– Includes a physical layer aspect.

Some UNIs are provided via an adaptation function, so it is not mandatory that the ONU support those interfaces.

Example of UNIs, physical interfaces and services that they provide are shown in Table 8-1.

Table 8-1 – Examples of UNI and services

UNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
10Mbps/100Mbps/1Gbps/10Gbps/25Gbps Ethernet [IEEE 802.3]	10/100/1000/10G/25G BASE	Ethernet, or Ethernet based eCPRI (see [b-eCPRI])
MoCA 2.0	–	
1Gbps/10Gbps Fibre UNI	–	Ethernet
[b-ITU-T Q.552]	–	POTS
V.35	–	–
G.hn	–	–
VDSL2 [ITU-T G.993.2], ADSL2+ [ITU-T G.992.5], G.fast [ITU-T G.9700] and [ITU-T G.9701]	xDSL	xDSL

Table 8-1 – Examples of UNI and services

UNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
[ITU-T G.703]	DS3, E1, E3	PDH
[b-ATIS 0900102] and [b-ATIS 0600107]	T1, DS0, DS1, DS3	PDH
	OC3 – OC192, STM1- STM64	SDH/SONET
CPRI/OBSAI (Open Base Station Architecture Initiative)	Option2, Option3 Option7, Option8, Option10	Wireless fronthaul
WLAN	IEEE802.11x	Wireless LAN
1PPS	1PPS	Synchronizing interface
NOTE 1 – There are many other services accommodated in HSP systems, but those services do not have specified UNIs. NOTE 2 – Each item in the "Physical interface" column is illustrated by the corresponding entry in the "UNI" column. NOTE 3 – The column labelled "Service" shows which services can be supported by the physical interface.		

8.3 Service node interfaces (SNIs)

SNI is defined as the interface that includes the following conditions:

– Interconnection between the access network and the service node,

– Described by a well-known standard,

– Includes a physical layer aspect.

Example of SNIs, physical interfaces and services that they provide are shown in Table 8-2.

Table 8-2 – Examples of SNI and Services

SNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
1GE/10GE/25GE/40GE/50GE/ 100GE/200GE/400GE – [IEEE 802.3]	1G/10G/25G/40G/50G/100G/ 200G/400G BASE	Ethernet, or Ethernet-based eCPRI (see [b-eCPRI])
[ITU-T G.703]	PDH	DS3, E1, E3, DS1, DS0
[b-ITU-T G.957]	STM-1, 4, 16, 64	E1, E3, DS1, DS3, GFP, E4, STM-n, DS0
[b-ATIS 0600107]	PDH	DS0, DS1, DS3
SDH/SONET	SDH/SONET	OC3 – OC192
OTN [ITU-T G.872 and ITU-T G.709]	OTU1, OTU2, OTU3	OTN
CPRI/OBSAI (Open Base Station Architecture Initiative)	Option2, Option3, Option7, Option8	

Table 8-2 – Examples of SNI and Services

NOTE 1 – There are many other services accommodated in HSP systems, but those services do not have specified SNIs. NOTE 2 – Each item in the "Physical interface" column is illustrated by the corresponding entry in the "SNI" column. NOTE 3 – The column labelled "Service" shows which services can be supported by the physical interface.

8.4 Access node interfaces (ANIs)

Flexible system configurations are required to improve equipment utilisation and lower capital and inventory costs. To this end, higher speed PON systems must support flexible and agnostic interfaces to the optical access network to enable the OLT network element to accommodate multiple access technologies. This objective may be achieved by using pluggable interfaces.

8.5 Latency

Higher speed PON must accommodate services (e.g., voice, internet, wireless transport and advanced video) with certain latency requirements (a maximum signal transfer delay between OLT SNI and ONU UNI). This clause describes the latency requirements for these services.

8.5.1 Latency for voice service and internet services

It is expected that unidirectional latency between OLT SNI and ONU UNI would need to be less than 1.5 ms for voice service and internet services.

8.5.2 Latency for wireless transport services

Unidirectional latency between OLT SNI and ONU UNI for wireless transport network is for further study. Descriptive information for 5G transport services can be found in [b-ITU-T G-Sup.66].

8.5.3 Latency for advanced video services

New services such as virtual reality (VR) video streaming and interactive VR video are potential services requiring low latency. Figure 8-1 shows how PON is used to transport video services. The maximum round trip time (RTT) between the user and the content delivery network (CDN) server should be less than 20 ms and 8 ms to have a good viewing experience for basic VR streaming and interactive VR services, respectively. When employing PON system as access part of end to end transportation link, it is estimated that bidirectional latency between OLT SNI and ONU UNI would need to be less than 2 ms for interactive VR service, assuming a wired connection between ONU and set-top box. If the connection is via wireless connection, the latency allowed for PON may be further reduced.

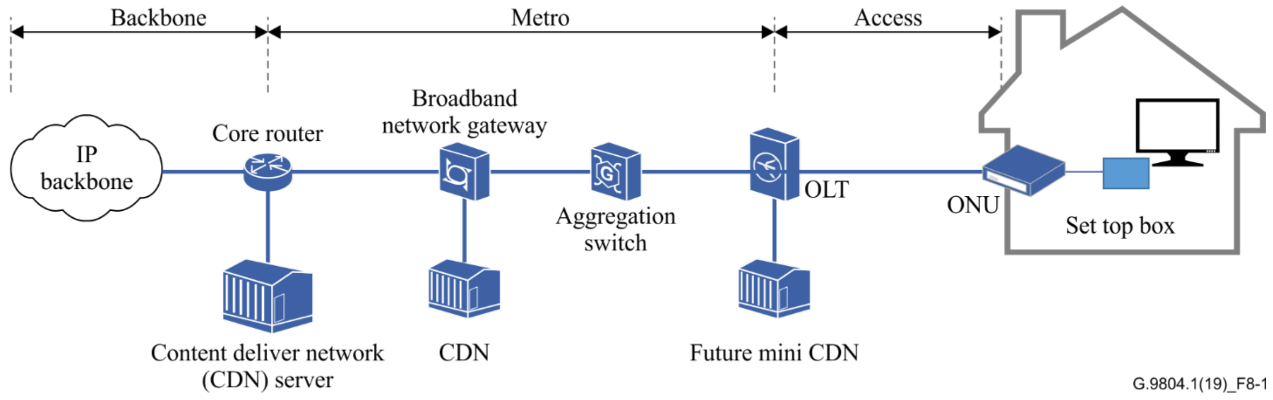

Figure 8-1 – Architecture of video services over PON

8.6 Synchronization features and quality

Network operators are motivated to leverage the higher speed PON infrastructure and systems to deliver high bandwidth to mobile cell sites. This requires accurate synchronization and timing delivery to the cell sites. Typically, T1 or E1 interfaces have been used for backhaul and these provide the necessary synchronization and timing references. However, it is increasingly important to provide accurate synchronization and timing over packet interfaces (e.g., Ethernet) especially to the cell sites where no T1/E1 interface is available driven by 3G/4G/5G wireless.

Higher speed PON OLTs for this application must be able to receive a high-quality timing clock as well as to serve as master timing source for the ONUs. The ONUs must be able to distribute the accurate timing/synchronization to the cell sites to meet the cell site frequency/phase/time synchronization requirement.

For this purpose, higher speed PON shall provide a function to transfer the accurate phase/time information between OLT and ONUs considering the propagation delay and the processing delay between them. Additional inaccuracy incurred in the PON section shall be much less than the reference accuracy to leave margin for other network sections. A summary of the synchronization requirements for different wireless technologies was provided in Table A.II.1 of [ITU-T G.9807.1 Amd1].

The mechanisms, for instance as specified in [ITU-T G.8261] and [ITU-T G.8262], for distributing accurate timing to the 3G/4G/5G cell sites are for further study depending on the performance and economics. In view of the extra complexity in delivering timing to applications such as mobile backhaul, the additional functionality might be limited to specific "CBU" ONUs.

Aspects of clock propagation, frequency and time of day synchronization scenarios, and Ethernet synchronization messaging channel (ESMC) messages transport over PON with IEEE 1588v2, can be respectively referred to in Appendices A.IV, A.V and A.VI of [ITU-T G.9807.1, Amd1].

8.7 System flexibility

Leveraging next generation fibre infrastructure across many market segments, such as business, residential, and mobile backhaul will improve the system attractiveness. Therefore, higher speed PON systems must offer functionality suitable for residential (MDU/SFU), business, and mobile backhaul customers and applications. Moreover, system flexibility must also be made possible by supporting different customer types on the same PON in a flexible way, which otherwise might need to be served separately using for example, point-to-point fibre deployment.

Like legacy PON systems, higher speed PON must provide simultaneous access to packet-based services, such as high-speed Internet access, IPTV and voice over Internet protocol (VoIP), as well as legacy services, such as POTS voice and T1/E1. In addition, a higher speed PON must provide access to carrier-grade metro Ethernet services, such as point-to-point, multipoint-to-multipoint and rooted-multipoint EVC services, also known as E-Line, E-LAN and E-Tree, respectively, defined by the Metro Ethernet Forum (MEF) in its MEF Carrier Ethernet 2.0 for business customers. These varieties of services present a broad range of quality of service (QoS) characteristics; therefore, they require systems to provide appropriate traffic management mechanisms.

For the POTS telephone services, higher speed PON must support POTS voice quality with guaranteed fixed bandwidth to meet the low-delay and low-jitter requirements. Similarly, higher speed PON must support TDM services such as E1/DS1s for business customers, and mobile backhauling applications with guaranteed fixed bandwidth to meet low-delay, low-jitter and strict timing requirements.

To provide access to a variety of packet-based services, such as IPTV, VoIP, L2/L3 VPNs and high-speed Internet access, higher speed PON must provide at least four classes of services to map UNI flows. It is desirable for higher speed PON to provide at least six classes of services to map UNI flows. Higher speed PON must also support drop precedence within at least two traffic classes.

In addition to priority-based classes of services, as indicated above and also specified in [BBF TR-156], higher speed PON ONUs must support rate-controlled services (e.g., CIR/PIR) with policing and shaping function in addition to the priority-based traffic management, for instance for business applications and mobile backhaul. Business customer ONUs must also support industry specification at UNI ports, such as [MEF 10.1]. However, it is not required for the higher speed PON to provide full media access control (MAC) address learning for the whole metro-Ethernet network. The higher speed PON will utilize the Metro Ethernet network capability to provide full Ethernet services.

Higher speed PON must support any mix of residential, business, and mobile backhaul traffic within the same PON as illustrated in Figure 6-2. It must also support a mix of consumer and business users within a multiple subscriber ONU. Higher speed PON must support a mix of rate based (including CIR/PIR provisioning, policing, shaping, etc.) and priority-based traffic management within the same PON and same ONU.

Higher speed PON must support N:1 VLAN, 1:1 VLAN and access to VLAN for business Ethernet service (VBES) service on the same PON.

9 Physical layer requirements

9.1 System capacity

HSP systems shall be capable of offering significantly more capacity per user than legacy PON systems.

A 50G TDM PON system, which operates over a single wavelength channel, shall be able to support a nominal line rate per fibre of approximately 50 Gbit/s in the downstream direction and up to approximately 50 Gbit/s in the upstream direction. A 50G TDM PON ONU shall be able to support the maximum service rate of approximately 40 Gbit/s. Note that depending on the target application (e.g., FTTH, FTTB, mobile backhaul, mobile fronthaul) and specific deployment requirements, an ONU may support a lower service rate. The 50G TDM PON systems shall be able to support ONUs with the maximum service rate. Within a single fibre, the 50G TDM PON systems shall also support diverse service rate mixes ranging from the maximum service rate to service rates as low as 1000 Mbit/s, thereby enabling efficient sharing of the common infrastructure. A 50G TDM PON ONU is required to offer a full 10 GigE or 25 GigE interfaces to the customer. Furthermore, the system shall support an upgrade to higher service rates without foreseeable technology roadblocks or bottlenecks.

A 50G TWDM PON system, which operates over multiple wavelength channels, shall be able to support a nominal line rate per wavelength channel of approximately 50 Gbit/s in the downstream direction and up to approximately 50 Gbit/s in the upstream direction. Typically, a 50G TWDM PON

ONU shall be able to support the channel maximum service rate of at least 40 Gbit/s. Within each wavelength channel, the 50G TWDM PON system shall support the same requirements with respect to service rate diversity, infrastructure sharing, a full 10 GigE interface, a full 25 GigE interface, and a service rate upgrade as the 50G TDM PON system. An advanced 50G TWDM PON ONU supporting wavelength channel bonding shall be able to support service rates in excess of the maximum service rate for a single channel.

The system capacity of PtP WDM PON is for further study.

HSP system capacity requirements are driven by the various access services that could be delivered by such systems. The envisaged services drive the need for different sustained and peak data rates, as well as different symmetry ratios between upstream and downstream data rates. For example, business services or mobile backhaul will require sustained and symmetric data rates or higher, whilst residential customers may be less bandwidth demanding and require the available peak bandwidths for short durations only. Overall, a move to more symmetric services is anticipated and HSP systems that increase the level of service rate, e.g., between 2:1 and 1:1 (downstream: upstream) service rates, are desirable. Furthermore, HSP systems must efficiently deliver service mixes consisting of services with both low and high levels of symmetry, which can be as high as 1:1 and as low as 100:1. HSP system will thus enable the provisioning of services that are tailored to meet different customers' needs over a common infrastructure.

Example of services demanding higher data rates include serving MDUs, enterprise connectivity, distributed eNodeB, and mobile transport. In addition, a higher speed PON may be cost effective and increase mobile capacity of the wireless infrastructure to introduce a distributed architecture. In supporting distributed architecture, it may be beneficial to leverage HSP systems to support the high-speed transport (e.g., eCPRI with a rate of 25.784 Gbps) between distributed unit (DU) and reference units (RUs).

It is impossible to precisely predict what service evolution will occur over the next decade given the number of unknown factors and the many global markets and deployment models. Therefore, HSP systems must be scalable enough to support any reasonably expected outcome, provided such extensions cannot threaten any legacy (e.g., generate unaffordable crosstalk, act as alien/rogue devices).

9.2 Fibre characteristics

This Recommendation is based on deployment using the fibre types described in [ITU-T G.652], which is widely used for legacy PON systems. Newer fibre types exhibiting low-bend radius characteristics defined in [ITU-T G.657] should also be compatible for HSP deployments.

9.3 Optical loss budget

HSP systems must be able to operate on legacy ODN.

9.4 Split ratio

Optical distribution networks exploiting power splitters are typically deployed these days with a split ratio in the range of 1:16 to 1:128.

Support for a higher number of ONUs per ODN enables a high degree of infrastructure sharing and node consolidation if used in conjunction with longer reach. However, it is recognized that it may be necessary to trade-off the sharing gain against increasing system complexity and power budget limitations. In some deployment scenarios the physical split ratio may be increased by using reach extension for enhanced loss budget.

9.4.1 Split ratio of 50G TDM PON

As many network operators have constructed their ODN infrastructure with 1:32 to 1:64 split for legacy TDM PONs, 1:64 split (subject to the overall loss budget) shall be the minimum requirement for 50G TDM PON to allow the coexistence described in clause 7. A generic splitter deployment of 50G TDM PON is shown in Figure 9-1(a).

In this model, a single-split architecture is a special case, where m = 64 and n = 1 and no splitter is needed at the access node. Some network operators expressed their interest in extending the split beyond 1:64 (e.g., 1:128 to 1:256) to improve 50G TDM PON overall economics compared to legacy PON.

The higher splitter ratio allows to extend PON in the backhaul section as shown in Figure 9-1 (b) and/or to extend PON towards the end users as shown in Figure 9-1 (c) to provide flexible splitter configurations and efficiently support a variety of deployment scenarios. Considering these options, the 50G TDM PON TDMA control function should support a 256-way (or possibly more) logical split. Physical split in the optical layer must be carefully selected to take into account the maturity and cost-effectiveness of optical devices. Reach extension can be used to increase the loss budget, and thus realize a higher split in the physical layer, especially in the cases presented in Figures 9-1 (b) and (c), in addition to extending the system nominal reach.

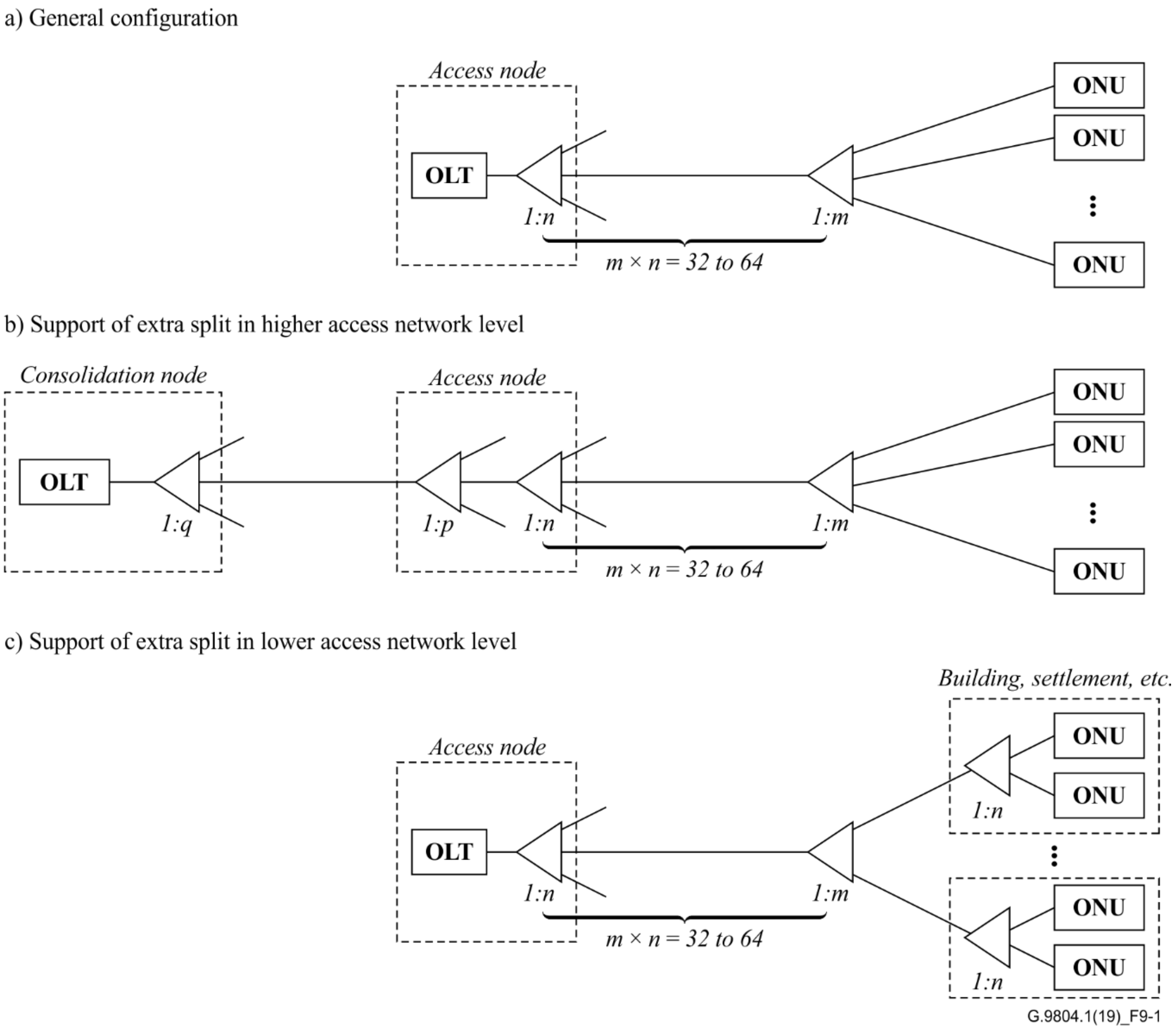

Figure 9-1 – 50G TDM PON splitter architecture options

9.4.2 Split ratio of 50G TWDM PON

50G TWDM PON systems may run over legacy power split ODNs, wavelength routing, or combinations of wavelength routing and power splitting. 50G TWDM PON systems should be flexible enough to support cost effective deployments over a variety of ODNs. 50G TWDM PON OLTs must support a split ratio of at least 1:256. Specific application and network engineering choices may require higher split ratios; therefore, the 50G TWDM PON OLT core design should not preclude supporting higher split ratios.

9.4.3 Branch capability of high speed PTP WDM PON

High speed PTP WDM PON systems may run over legacy power split ODNs. The branch capability of high speed PTP WDM PON is for further study.

9.5 Fibre distance

HSP system must support the maximum fibre distance of at least 20 km.

In addition, HSP TC layer needs to support the same requirements as XG-PON and NG-PON2, starting with the maximum fibre distance of 60 km. HSP TC layer also needs to support the maximum differential fibre distance of up to 40 km. HSP TC layer also needs to be able to configure the maximum differential fibre distance with a 20 km step.

9.6 Optical spectrum issues and availability

Access networks largely employ ITU-T G.652 single mode fibres (SMF). As is well known, the characteristics of SMF are wavelength dependent. Figure 9-2 shows the attenuation of SMF over wavelength range of interest along with the defined ITU-T bands. The attenuation of an optical signal is lowest in the C-Band and lower L-Band.

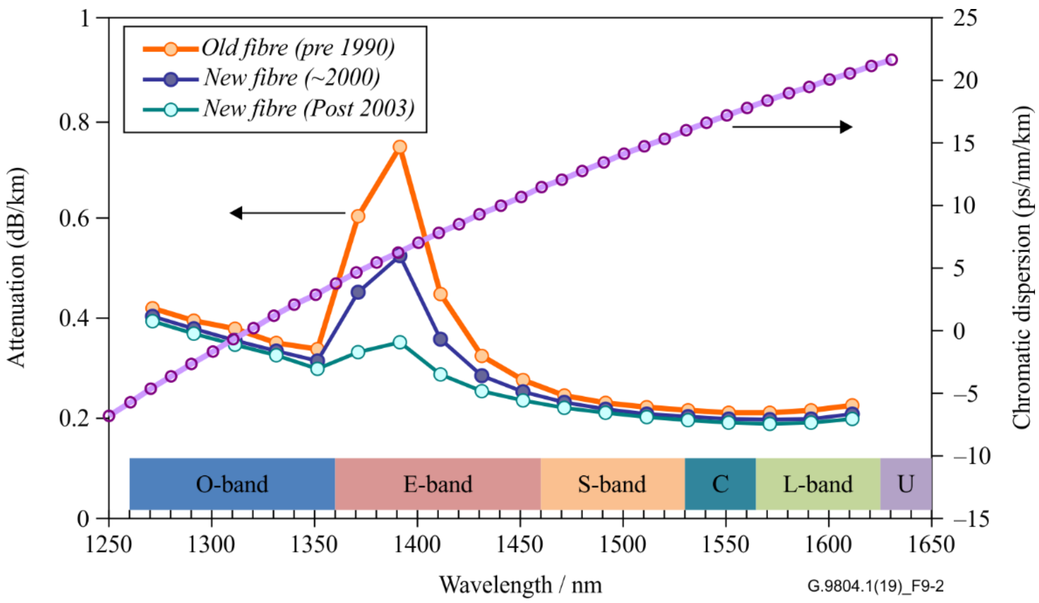

Figure 9-2 – Single mode fibre attenuation and chromatic dispersion

Chromatic dispersion (CD), which can limit system reach as signal line rates increase, is also wavelength dependent with a zero value at ~1310 nm for SMF. The wavelength variation of CD is also shown in Figure 9-2.

One further aspect concerning the wavelength options concerns the availability of opto-electronic components. For example, commonly available erbium doped fibre amplifiers (EDFAs) work in the C and L bands, whereas, semiconductor optical amplifiers (SOAs) can be made to work in any of the bands of interest. However, semiconductor optoelectronic components vary in terms of performance depending on the operating wavelength, e.g., laser temperature performance or photodiode responsivity.

Wavelength plans (Figure 9-3) of the legacy PON systems that HSP systems may need to co-exist with must be considered relative to migration and co-existence requirements.

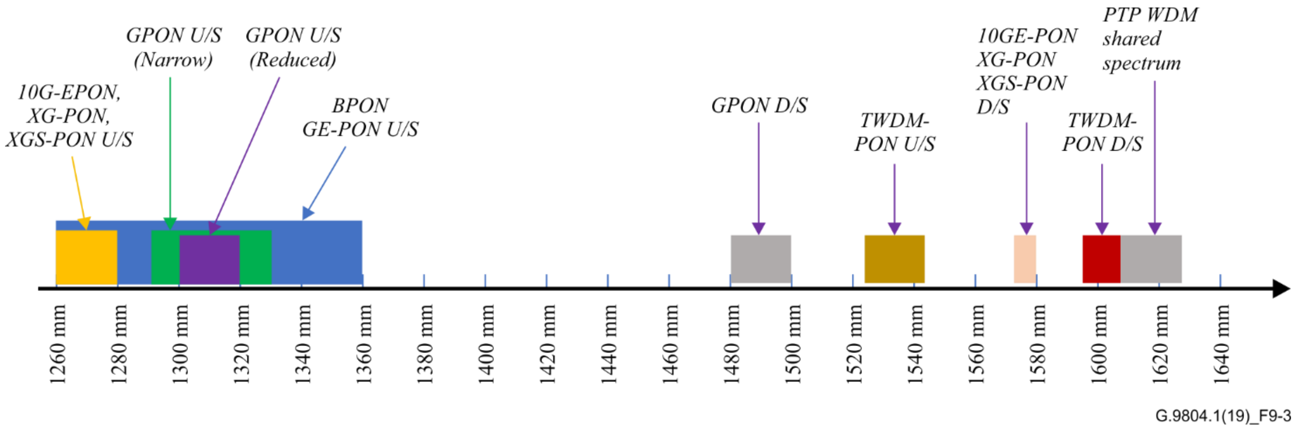

Figure 9-3 – Wavelength plans of legacy PON systems

A further factor that limits the available spectrum are the legacy filter characteristics built in to deployed systems in both the OLT in the upstream direction and the ONU in the downstream direction. The concentration of legacy TDM PON signals in the O-band is also the spectrum targeted for higher speed PON wavelengths due to the lower dispersion penalty in the O-band. Triple coexistence of GPON, XG(S)PON, and HSP becomes a significant challenge with shorter guard bands available between the legacy PON technologies. In the downstream direction, coexistence with RF-video must consider filters that require wider guard bands due to higher launch powers and could occupy most of the C-band where the fibre loss is low and EDFA optical amplifiers could be used.

10 System level requirements

10.1 Authentication/encryption

Like legacy PON system, HSP is a shared-medium based system in which all the ONUs on the same PON receive the full data. Accordingly, countermeasures must be taken to avoid impersonation/spoofing and snooping.

To protect against impersonation/spoofing, authentication mechanisms must be standardized. The HSP system must implement the mechanisms, while the run-time activation of the mechanisms must be subject to dynamic control as determined by the operator. They shall include, but will not be limited to:

- Authentication of ONU serial number and/or a registration ID used for the ONU registration process,
- Authentication of customer premises equipment (CPE), based on IEEE 802.1X,
- A strong authentication mechanism is required.

A low complexity, but secure authentication method is also necessary for the recovery from the "sleep" mode when the power saving function is used.

To protect against snooping at the ONUs, all unicast data in the downstream direction shall be encrypted with a strong and well characterized algorithm, e.g., advanced encryption standard (AES). Therefore, HSP shall also provide a reliable key exchange mechanism that is necessary to start an encrypted communication. The HSP system must implement the upstream encryption and the associated key exchange. The HSP system must provide means to control upstream encryption in run-time, per operator discretion.

10.2 Dynamic bandwidth assignment (DBA)

The HSP OLT shall support DBA for the efficient sharing of upstream bandwidth among the connected ONUs and the traffic-bearing entities within the individual ONUs based on the dynamic indication of their activity. The dynamic activity indication can be based on the following three methods:

- Status reporting (SR) DBA employs the explicit buffer occupancy reports that are solicited by the OLT and submitted by the ONUs in response,
- Traffic monitoring (TM) DBA employs OLT's observation of the actual traffic amount in comparison with the allocated upstream transmission opportunities,
- Cooperative (CO) DBA employs the upstream scheduling information provided by the OLT-side external equipment, such as a CU/DU in a wireless transport system.

The DBA definition comprises the reference model that specifies the ideal bandwidth assignment among the contending upstream traffic-bearing entities under the given traffic load conditions. To allow for effective numerical comparison of the DBA implementations, the standard contains the suggested measures of discrepancy between a DBA implementation and the reference model. To guarantee multi-vendor interoperability, the standard specifies the formats of the SR DBA status enquiries and buffer occupancy reports and the associated protocol.

10.3 Dual-rate support

The OLT of 50G TDM or OLT CT of 50G TWDM PON supports dual line-rates (nominally 25 Gbit/s or 10 Gbit/s) in the upstream direction. This enables compatibility for ONUs with two asymmetric rate combinations co-existing on the same ODN.

10.4 Colourless ONUs of 50G TWDM PON and PtP WDM PON

In the context of 50G TWDM PON and PtP WDM PON, in order to facilitate flexibility and reduce operational expenditures due to inventory management, deployed ONUs must be 'colourless', i.e., they are not specific to a certain wavelength. Colourless ONUs does not require the management of multiple ONU types that scale in number with the number of wavelengths used on the PON. This significantly reduces the provisioning time and cost compared to ONUs which are fixed wavelength.

10.5 Spectral flexibility of 50G TWDM PON and PtP WDM PON

An efficient approach to support various deployment scenarios and network applications is to utilize a degree of spectral flexibility in the 50G TWDM PON and PtP WDM PON system. Such flexibility can enable the support of different customer types and PON systems on the same ODN in a flexible way. There are diverse access applications that drive the need for a range of sustained and peak rates, different delay/jitter requirements, as well as different downstream/upstream ratios, all parameters which when combined lead to various launched power and sensitivity. Furthermore, the NG-PON2 system should allow the use of spectral flexibility to enable capacity upgrades in a progressive or modular way as demand grows. Flexible channel counts for both TWDM and PtP WDM (e.g., 4, 8, 16) should be supported to facilitate capacity increase. Additionally, spectral flexibility must facilitate a range of co-existence scenarios that avoid interference with legacy systems and subsequently enable new wavelength bands when these legacy systems are decommissioned.

To meet the above requirements, the 50G TWDM PON and PtP WDM PON system must offer the possibility to access multiple wavelengths, groups of wavelengths, or wavelength bands that can be physically and logically separated and driven independently, either by a single OLT or by multiple independent OLTs, with fully independent operation. This requirement should not increase complexity in system not requiring such flexibility options.

10.6 Rogue and alien ONU/OLT detection and mitigation

HSP systems should be able to monitor transmissions at the OLT and ONU to guard against ONUs or OLTs that exhibit rogue behaviour and detect the presence of alien light sources (e.g., an ONU transmitting in another ONU's timeslot. TWDM-based HSP systems should support wavelength monitoring to identify when an ONU is transmitting in another ONU's wavelength band or an OLT transmitting in another OLTs wavelength band. It is suggested to follow the rogue ONU prevention, detection, isolation and mitigation guidelines defined in [b-ITU-T G-Sup.49]. Further considerations may be required for the OLT.

10.7 Reach extender requirements

HSP systems must also be capable of reaching 60 km with reach extenders if needed. Preferably this could be achieved whilst maintaining passive outside plant, however, it is recognized that this may be technically challenging so options for mid-span reach extenders may be needed.

Use of a reach extender should not necessitate that the OLT nor the ONU be different or modified. Thus, HSP systems must provide PMD and TC layers capable of working transparently with and without reach extender. Mid-span reach extenders must be remotely manageable through an OLT to enable configuration and monitoring functions for maintenance and fault location. Additionally, reach extender-based scenarios must also be compatible with co-existence scenarios, resilience, and redundancy options.

Furthermore, being remotely located in the outside network, the reach extender should have minimal power requirements and must be able to operate over outdoor temperature ranges. The environmental requirements for RE are provided in clause 10.11.

10.8 Power reduction

Power saving in telecommunication network systems has become an increasingly important concern in the interest of reducing operational expenditure (OPEX) and reducing the network contribution to greenhouse gas emission. HSP systems must be designed in the most energy-efficient way. This applies to the OLT side and even more to the ONU side since the energy consumption is not shared at the ONU except for FTTC/B. In some instances, the primary objective of the power saving function in access networks is to maintain the lifeline service(s), such as a voice service, if possible, using a backup battery when electricity service goes out. A lifeline interface must be sustainable for at least eight hours after mains power outage, and options such as allowing four hours of talk time while an ONU is in sleep mode for an extended period (e.g., one week) should be offered. Therefore, the HSP system shall support improving energy efficiency whilst maintaining compatibility with the service requirements, based on the mechanisms derived from [b-ITU-T G-Sup.45]. The secondary goal is to always reduce power consumption. It is also an important requirement that service quality and the user experience should not be sacrificed.

In the context of 50G T(W)DM-PON, watchful sleep modes are the options that can offer various levels of power saving during the normal mode of operation. In addition, when the mains outage happens, power shedding should be activated for the power saving capability. Realizing that detailed values may vary for 50G T(W)DM-PON, [b-ITU-T G-Sup.45] compares the efficiency of each power saving technique as well as the level of service impact.

In the context of 50G TWDM PON, for time and wavelength division multiplexing (TWDM) channels, the mechanisms to attain better power savings at the ONU side, shall include the watchful sleep mode, which allows network operators to adjust the balance between the impact on the performance and the power-saving effect. Mechanisms at the OLT side shall include the wavelength re-tuning. Control protocols for realizing these mechanisms shall be supported in an NG-PON2 system. The OLT-port sleep mode can offer power savings because when there is less traffic in the TWDM PON system (4 Type W wavelengths) as shown in Figure 10-1, all the OLT-ports will keep working even though the total traffic could be accommodated by a single OLT-port. However, by connecting all the ONUs to the same OLT-port (CT1) with the use of wavelength re-allocation, the other OLT-ports (CT 2, CT 3 and CT 4) can be forced into sleep mode as shown in Figure 10-2.

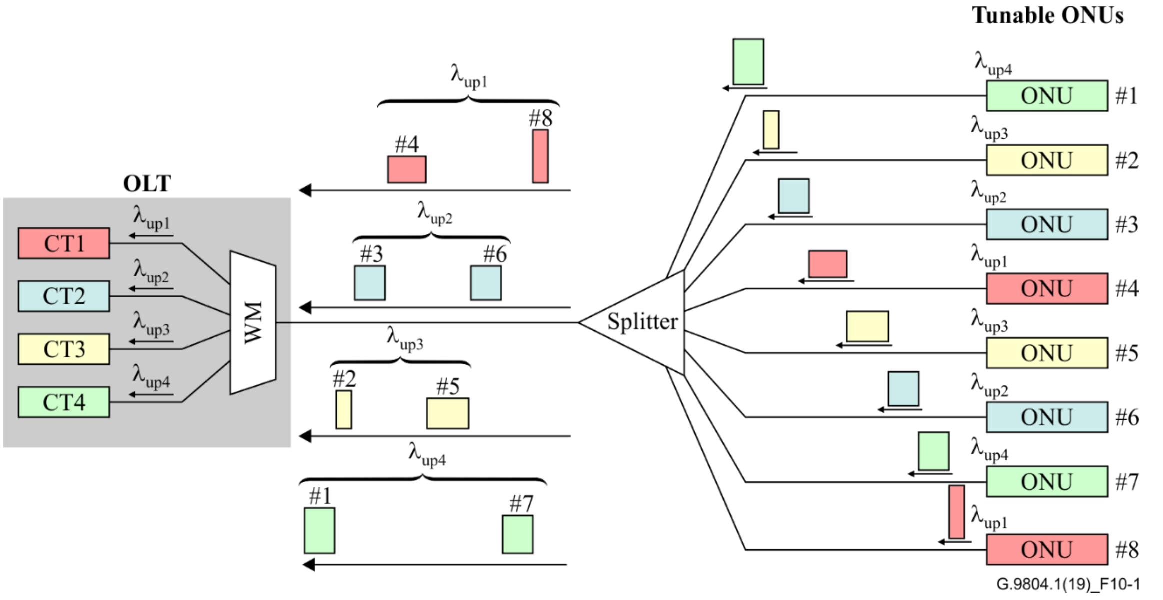

Figure 10-1 – Example of TWDM PON OLT-port sleep mode (before starting sleep mode)

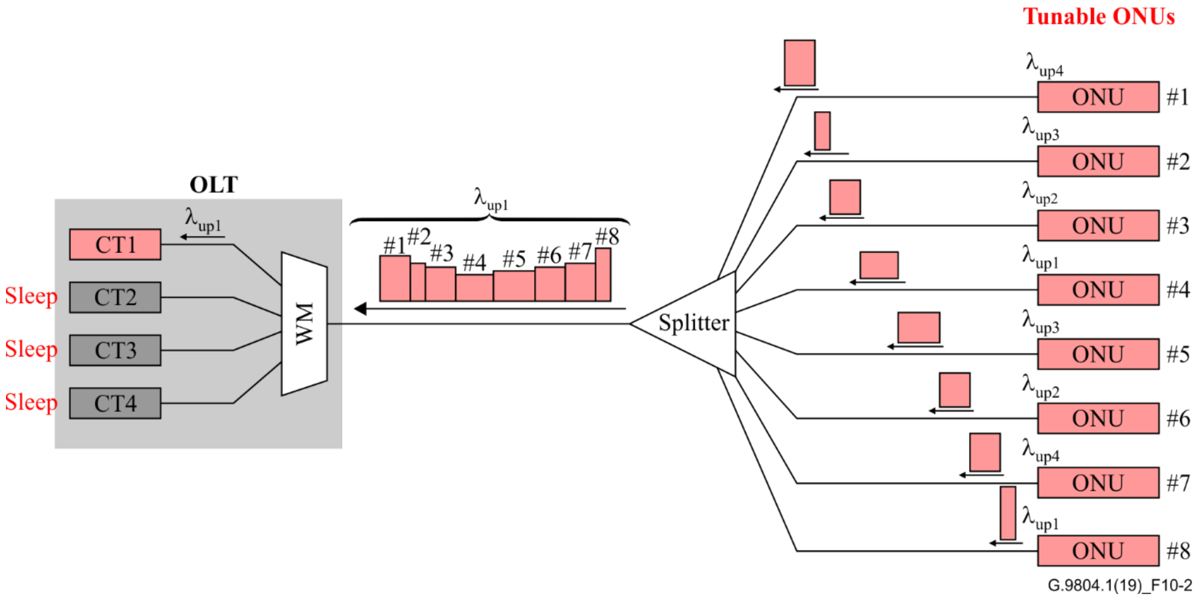

Figure 10-2 – Example of the TWDM PON OLT-port sleep (CT 2, CT 3 and CT 4 are in sleep mode)

In the context of PtP WDM PON, for PtP WDM channels, mechanisms to address power reduction capabilities at the ONU side shall include:

– The silent start function to reduce power in the standby state and to reduce risks upon resuming operation, see [ITU-T G.986],

– A sleep mode to reduce power when the traffic is low or when there is zero traffic.

Methods to address power reduction capabilities for both OLT and ONU sides shall include:

- Line-rate switching to reduce the power when traffic and service parameters permit, for link or service sets that do not allow the use of sleep mode.

10.9 PON supervision and OAM functions

While it is most important to minimize capital expenditure in the initial stage of FTTH deployment, it is becoming more important to reduce operational expenditure as well as to optimize the balance between capital expenditure and operational expenditure according to the full deployment of FTTH. The goal of PON supervision is to reduce the operational expenditure of the PON systems, without significantly increasing the capital expenditure by including as much test and diagnostic capability as possible without compromising the available bandwidth for services. Test and diagnostics must be non-service affecting. Current G-PON's capability of basic testing and diagnostics, which operates at the PON and data layers, with reporting back of alarms and events, shall be taken as a basis for HSP.

High levels of security are required from HSP systems and these systems must be at least as secure as XG-PON, XGS-PON and NG-PON2. In multiple service applications, enhanced security may be required to distinguish between data services in the OLT and ONUs that require more secure authentication. The HSP ONUs must be remotely manageable and support auto-configuration functions. The HSP system must provide full fault, configuration, accounting, performance, and security (FCAPS) management capability for the ONU.

The ability to reliably differentiate between optical and electrical faults and establish if the faults are in the ODN or in the electronics is a key operator requirement. Inference can usually be made from the presence (i.e., power or equipment failure), or absence (i.e., fibre failure), of the ONU dying gasp alarm. Special care will have to be taken about power supply monitoring in case of reverse powered distribution point unit (DPU). Several key points for the supervision of HSP can be summarized as follows:

HSP systems would benefit from an ability to detect and locate ODN faults automatically and autonomously. This is especially critical for the feeder section between the serving central office (CO) and the first-stage splitter, the length of which can be up to 60 km if a RE is used.

End-to-end performance monitoring up to the Ethernet layer: End-to-end performance monitoring enables operators to diagnose and register where customer traffic may have been dropped or throttled. Higher layer tools, such as Ethernet performance monitoring, need to support the capability of monitoring and the verification of ingress and egress traffic flows in PON network elements.

Proactive versus reactive repair: PON systems with their monitoring and control systems will allow operators to decide on the utilization of proactive or reactive fault repairs in most fault cases. It is of course up to the operators to decide how to use PON status reports.

Coexistence of HSP with legacy PON via CEMx: It is desirable to immediately localize any problems in the case of legacy PON and HSP coexistence. Interworking of the supervision function between legacy PON and HSP is one possibility here, but further studies are necessary.

In the context of 50G TWDM PON, the TWDM channels in the NG-PON2 system must support DBA for efficient sharing of bandwidth.

10.10 Provisioning and management

It is highly desirable from the network operation perspective to manage an HSP system, i.e., an OLT together with its ONUs, as a single entity, with ONUs being managed via OLTs, wherever possible. Therefore, HSP shall support full PON real-time management through ONU management and control functions, where concepts and approaches implemented for legacy PON (e.g., OMCI) should be reused as much as possible. For dual managed ONUs, HSP shall optionally support collaborative

ONU management partition between HSP OMCI and remote configuration mechanisms for all types of ONU accommodated.

Given the significant effort already expended in defining a converged management framework across optical access systems, ONU management in HSP systems must be based on OMCI ([ITU-T G.988]) suitably augmented with HSP specific MEs.

PtP WDM OLT CTs, unless intended for protection, should be independent from one another, in line rates and modulation format. The replacement of one CT by another combination on the given point to point wavelength channel must be individual by conception.

The boundaries of types of PtP WDM tributary units will be defined in PMD and TC documents.

10.11 OLT and ONU environmental and physical requirements

Outdoor operation may be needed in many of the envisaged applications for HSP systems; thus, RE and ONUs shall operate over outdoor temperature ranges. The following are informative examples of environmental requirements:

– ATIS-0600010.01.2008: (Class 4 unprotected environment)
–40°C to either +46°C ambient plus solar loading, or +70°C ambient

– Telcordia GR-487
–40°C to either +46°C ambient plus solar loading, or +70°C ambient

– ETSI ETS 300 019-1-4: (Class 4.1E: Non-weather protected locations – extended)
–45°C to +45°C ambient plus solar loading

Optionally, the OLT should also be able to operate over the extended outside temperature range.

10.12 Eye safety

With the capacity increases and demands on enhanced loss budgets, it is expected that an HSP system could launch significantly higher total power into the feeder fibres when compared to previous PON generations. All necessary mechanisms must be provided to ensure that no eye damage can be caused to end users unaware of the risks associated with a fibre termination inside the home or customer premises, including labelling and safety locking mechanisms if necessary. The system must meet all applicable requirements for the classification, service group designation, and accessibility to ensure the safe operation and servicing of the optical fibre communication system at each node. Since the HSP system could co-exist with other PON generations, the total optical power resulting from one wavelength (TDM PON) or all the different wavelengths (TWDM PON and PtP WDM PON) on the fibre must be within the safe operation range specified at each location.

The HSP elements need to conform to the following specific classes defined in [IEC 60825-2], respectively:

- Class 1M for OLT,
- Class 1 for ONU,
- Class 1M for RE.

10.13 Interoperability

The optical access equipment implemented under the HSP suite of ITU-T Recommendations is expected to be fully interoperable as far as OLT and ONU are concerned, and support open, standards-based interfaces for any external functions.

10.14 Transport of wireless fronthaul links over the access system

To achieve a fronthaul transport solution over the access system, three fronthaul protocols should be taken into consideration: namely eCPRI, CPRI, OBSAI and ETSI-ORI.

HSP systems are required to fully support the various fronthaul services for mobile applications. Furthermore, for these mobile applications, HSP must achieve:

- The capability to support a fixed and continuous symmetrical bandwidth allocation capacity compatible with any fronthaul bit rate between 614.4 Mbit/s to 25.78125 Gbit/s.
- The fronthaul latency considered applies to the round-trip time between SNI to UNI to SNI. It is required to be less than 200 µs including the fibre propagation time. A more stringent delay requirement is preferred when fronthauling legacy base station equipment.
- The accuracy of the measurement of the round-trip delay on the transmission medium (including fibre, ONT and OLT) shall meet the following requirement of ±16.276 ns. Between two periodic measurements of the round-trip delay by base band unit, the variation of the transmission medium must not exceed ±16.276 ns.
- Preferably, the fronthaul latency for upstream and downstream should be symmetrical. An asymmetrical trip delay between the upstream and downstream fronthaul transmission medium (including fibre, ONT and OLT), should impact the accuracy of the timing calculation between the user equipment and base band units. The fronthaul transmission medium time difference shall not exceed 65 ns.
- The maximum contribution $df/f0$ of jitter from the fronthaul link to the radio base station frequency accuracy budget must not exceed ±2 ppb (2.10-9). The remote radio head (RRH) clock shall be traceable to the baseband unit (BBU) clock. This implies that the fronthaul link must not introduce any constant frequency error. The link timing accuracy for the transport system will be specified with concrete values which will be defined in a further study.
- The extended outside temperature range may be needed in many of the envisaged fronthaul applications for the ONU, with a similar requirement as that already expressed in clause 10.11.
- Optionally, the OLT should also be able to operate over the extended outside temperature range and compact packaging based on pluggable receptacle footprint.
- Optionally, an antenna site management interface could be transported over the access system.
- Optionally, an additional synchronization signal (e.g., a GPS signal) could be transported over the access transmission.
- Optional capability to support the multiplexed transport of fronthaul protocols (e.g., CPRI over OTN).

11 Resilience and protection on ODN

PON resilience will become more important in supporting mobility applications, business applications and high value consumer applications, such as IPTV, especially in the node consolidation scenario. Node consolidation/bypass creates a high number of subscriber lines on the highly centralized access node. Failures in the shared portions of the PON will impact multiple customers and services. Consequently, the capability to offer improved service availability figures in HSP systems will become increasingly important.

A redundancy mechanism is required to avoid service disruption to potentially thousands of users in the event of fibre cable or equipment failure. Besides the usual hardware redundancy requirements at the OLT and in the backhaul transmission equipment (towards the metro/core), networks may require feeder and/or OTL line redundancy options to avoid large scale customer outages. Full redundancy for business services may also require end-to-end type C protection.

Individual operators need to determine the best resilience architecture for their specific market and geography. HSP systems must support the resilience options defined in clause 14 of [ITU-T G.984.1] including duplex and dual parenting duplex system configuration as well as the extensions described in Appendices II and III of [ITU-T G.984.1]. For PON redundancy, use cases and guidelines are defined in [b-ITU-T G-Sup.51]. These resilience schemes should be options available on the HSP scenarios whether they use mid-span reach extenders or not. Different types of service and specific offerings will require different recovery speeds. These may range from a few tens of milliseconds, for critical and important services such as protected leased lines, up to the order of minutes for residential applications. Note that support for resilience options should not increase the cost of such systems if deployed without resilience options.

The protection architecture of HSP should be considered as one of the means to enhance the reliability of the access networks. However, protection shall be considered as an optional mechanism because its implementation depends on the realization of economical systems. It is also likely to use other methods, such as using alternative access technologies, e.g., mobile system, for backup for better economics. Further information on protection switching can be found in [ITU-T G.808.1].

Figure 11-1 shows an example of fibre path diversity ensuring resilience against cuts in the most vulnerable part of the access network. The redundant feeder fibre could terminate at a diverse CO location, or at the same CO location as the primary OLT.

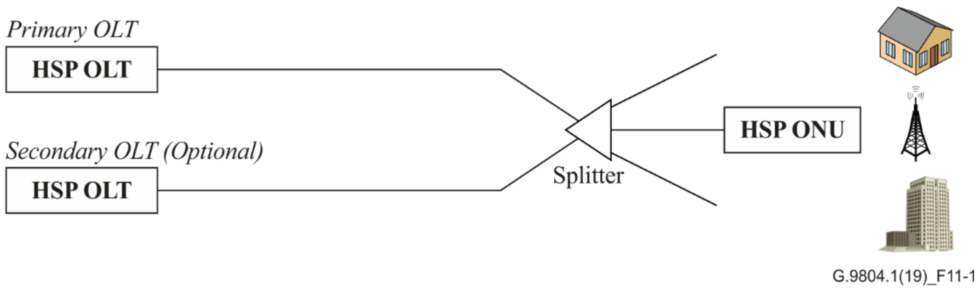

Figure 11-1 – HSP resilience scenario

Redundant splitters, especially in the highest level of hierarchy, may also be deployed and should be supported. Typically, redundancy requirements become less stringent for the customer premises, unless the end customer is, for example, a large-scale enterprise or premium user. In the redundant architecture, rapid restoration may be required. For instance, service interruption time must be less than 50 ms for enterprise or premium users.

Clauses 11.1 to 11.3 show examples of network protection in the case of multi-wavelength access systems.

11.1 Type B protection

Transceiver faults occur frequently in some scenarios and feeder fibre faults may occur in other scenarios. In type B protection, OLTs or OLT channel terminations (CTs) and feeder fibres are protected.

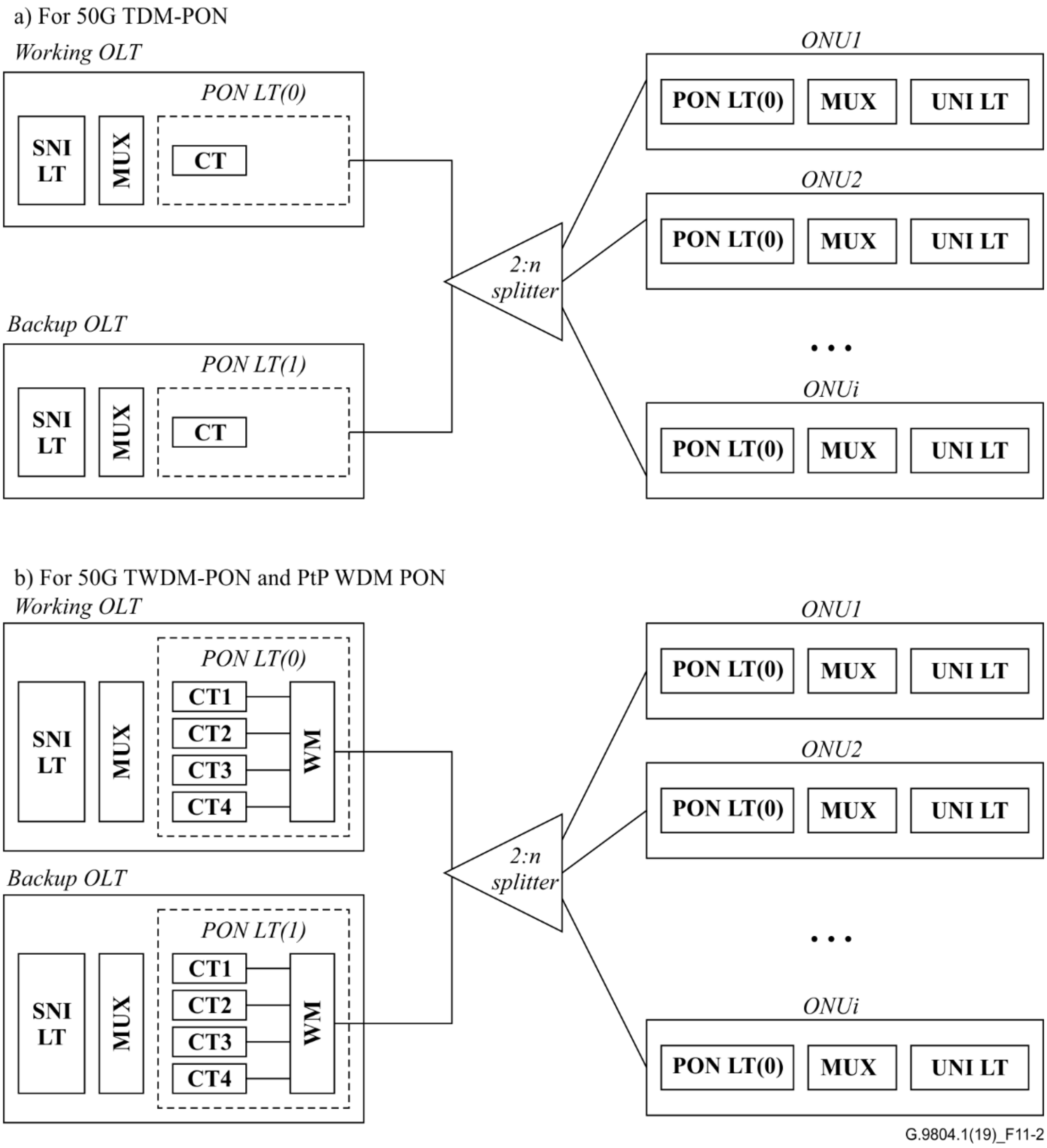

Figure 11-2 – Type B protection – 1:1 model with dual parenting

Figure 11-2 shows the 1:1 model of type B protection with dual parenting. The recovery procedure is the same as for type B protection of GPON/XG-PON. The backup OLT is a copy of the working OLT. Backup OLT or all backup OLT CTs must be turned off until the protection switchover occurs.

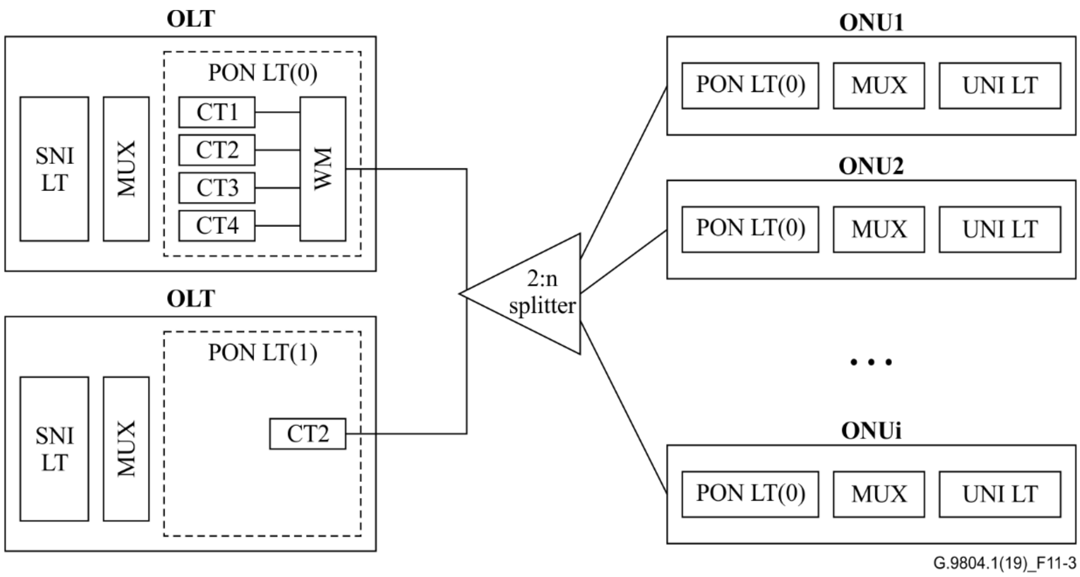

Figure 11-3 – Type B protection – 1:1 model with single backup CT

As shown in Figure 11-3, the backup OLT includes a designated OLT CT to protect the working OLT CTs, which applies to 50G TWDM PON and PtP WDM PON. When a protection switchover is triggered, the ONUs tune to the wavelength pair supported by the backup OLT CT. The backup OLT CT must be turned off until the protection switchover occurs.

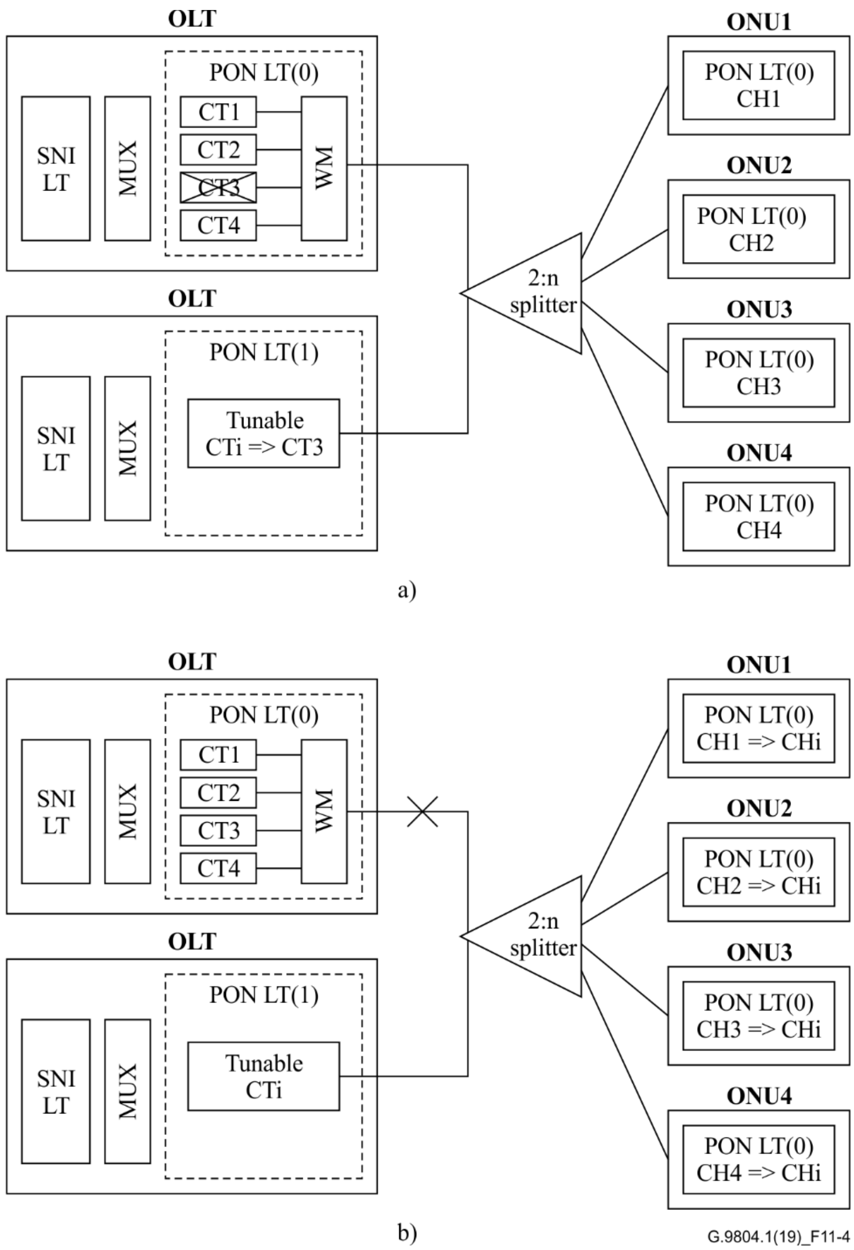

Figure 11-4 – Type B protection – 1:n model (a) CT failure, (b) feeder fibre failure

Figure 11-4 shows the architecture of 1:n type B protection, which applies to 50G TWDM PON and PtP WDM PON. The backup OLT consists of an OLT CT with a tunable transceiver to protect all working OLT CTs. When a working OLT CT fails, the backup OLT CT tunes its wavelength channels to protect the failed OLT CT, as shown in Figure 11-4(a). The ONUs associated with the failed working OLT CT can remain unchanged. When the feeder fibre from a working OLT CT fails as shown in Figure 11-4(b), all ONUs must tune to the wavelength channels supported by the backup OLT CT.

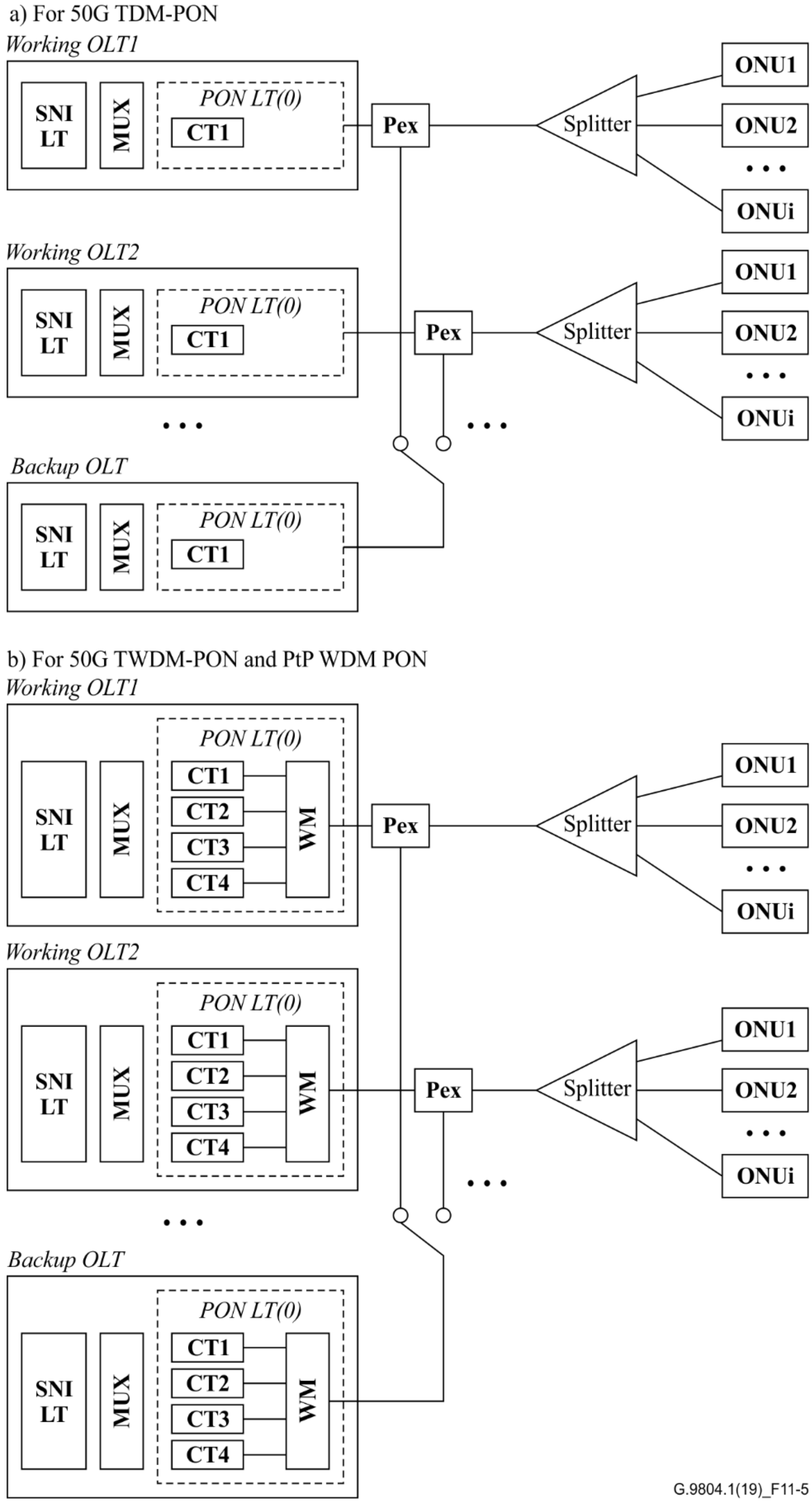

Figure 11-5 – Type B protection – 1: n model with dual parenting

Figure 11-5 shows the 1:n type B protection with dual parenting. The backup OLT supports the same wavelength channels as the working OLTs. When any failure occurs in a working OLT or a feeder fibre, the backup OLT continues the PON operation with the associated ONUs.

11.2 Type C protection

In the context of 50G TDM PON, for type C protection, which is a full duplex system (1+1 model), the ONU has two fixed transceivers as shown in Figure 11-6. Accordingly, recovery from failure at any point is possible by switching to the standby facilities.

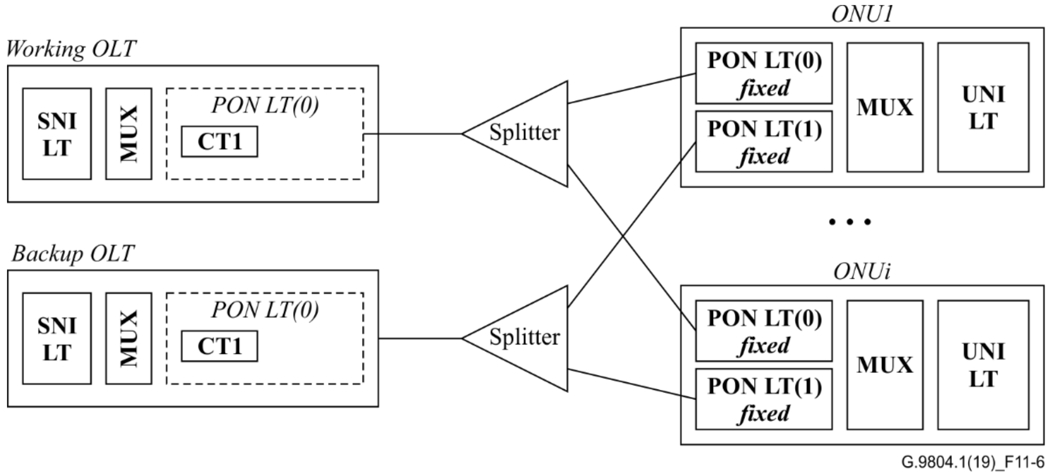

Figure 11-6 – Type C protection – 1+1 model for 50G TDM PON

In the context of 50G TWDM PON or PtP WDM PON, for type C protection, which is a full duplex system (1+1 model), the ONU has two tunable transceivers as shown in Figure 11-7. Accordingly, recovery from failure at any point is possible by switching to the standby facilities. To simplify protection management and for fast service configuration, the same wavelength configuration of the working TWDM channel and the backup TWDM channel is recommended. In Figure 11-8, the ONU chooses one tuneable wavelength transceiver plus one fixed wavelength transceiver for backup. In this case, a dedicated wavelength of the tuning range for the backup PON port is allocated to protect the working PON. In addition, if the ONU adopts a two MAC chipsets architecture in type C protection, the ONU can simultaneously activate to both the working OLT PON and the backup OLT PON via two PON MACs and two transceivers. The service recovery time could be less than 50 ms.

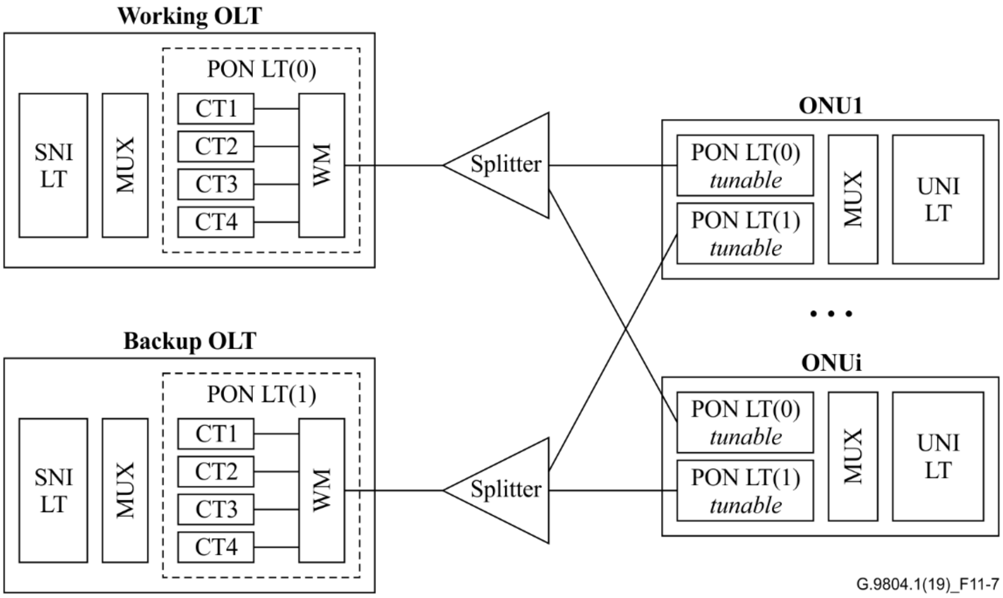

Figure 11-7 – Type C protection – 1+1 model with two tunable transceivers in ONUs

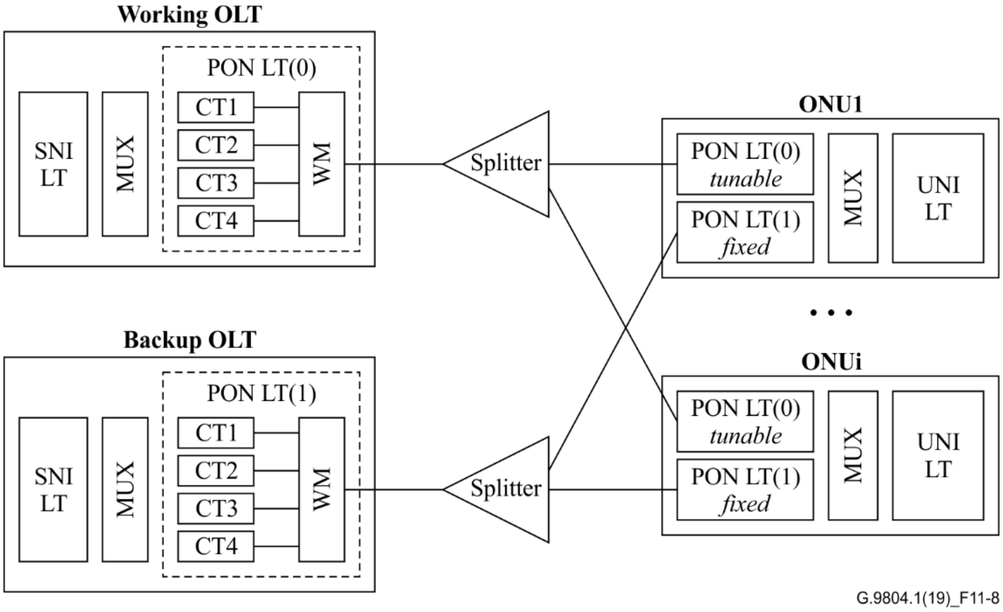

Figure 11-8 – Type C protection – 1+1 model with one tunable transceiver and one fixed transceiver in ONUs

11.3 Type W protection (for 50G TWDM PON and PTP WDM PON)

In type W protection, which is the newly defined category in this Recommendation, only the OLT (or OLT CT) is protected. In some cases, type W protection is achieved by using wavelength tuning in ONUs.

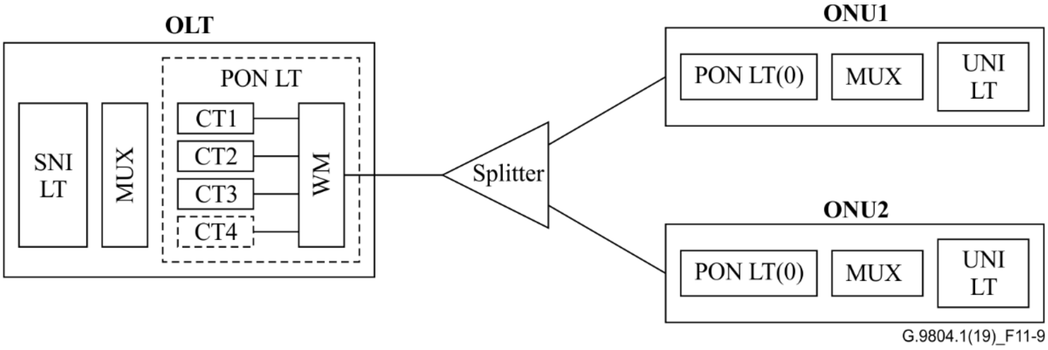

Figure 11-9 – Type W protection – 1:n model with backup OLT CT

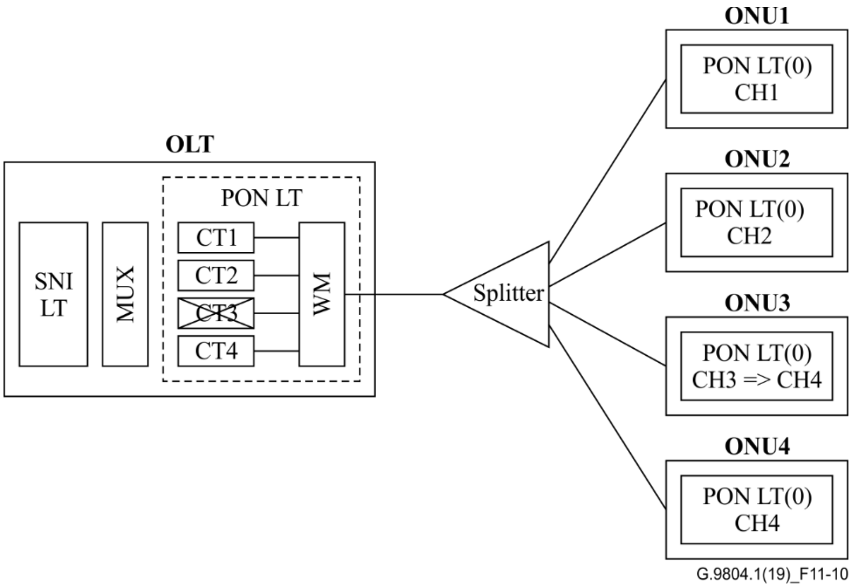

Figure 11-10 – Type W protection – 1:n model with all active OLT CTs

The 1:n model of type W protection is shown in Figure 11-9. In the 50G TWDM PON system, one of the OLT CTs is configured to be the backup OLT CT for other working OLT CTs. CT4 in Figure 11-9 is set to be the backup OLT CT. When any failure occurs in a working OLT CT, the affected ONU tunes to the associated backup TWDM channel based on the pre-configuration information stored in the ONU.

Figure 11-10 shows another 1:n model of type W protection. This protection feature is inherent in the nature of 50G TWDM PON ONU wavelength tunability. All OLT CTs are active during operation. Each OLT CT can protect the other OLT CTs. If an OLT CT fails, its ONUs tune to wavelengths associated with other OLT CTs. In Figure 11-10, OLT CT3 fails and it is protected by OLT CT4. In another approach with a shorter protection time, the backup channels can be pre-configured in the ONUs. When a failure occurs, the affected ONUs can tune to the backup channels without waiting for the OLT instructions.

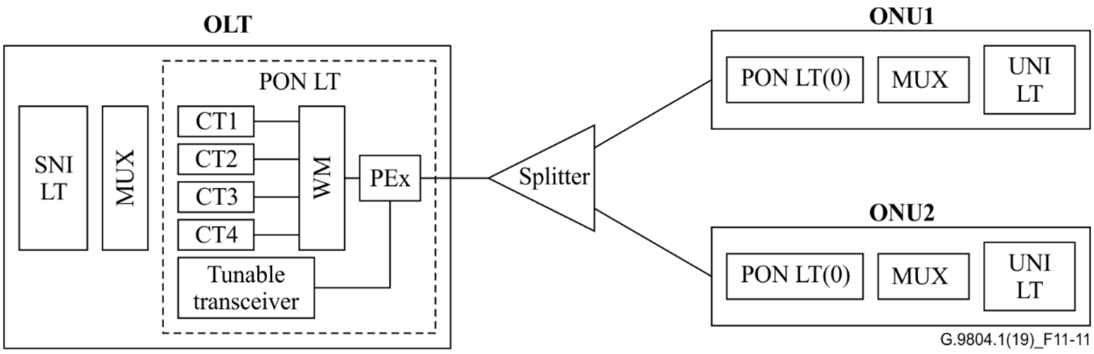

Figure 11-11 – Type W protection – (n+1):n model

The (n+1):n model of type W protection is shown in Figure 11-11. A dedicated OLT CT with a tunable transceiver is configured to be the backup OLT CT. When a working OLT CT fails, the backup OLT CT (tunable transceiver) tunes to the same wavelength channel as the working OLT CT. In order to avoid rogue OLT behaviours, the backup OLT CT tunes its wavelengths only after recognizing the working OLT CT failure. The model does not require any ONU operation in protection switchover.

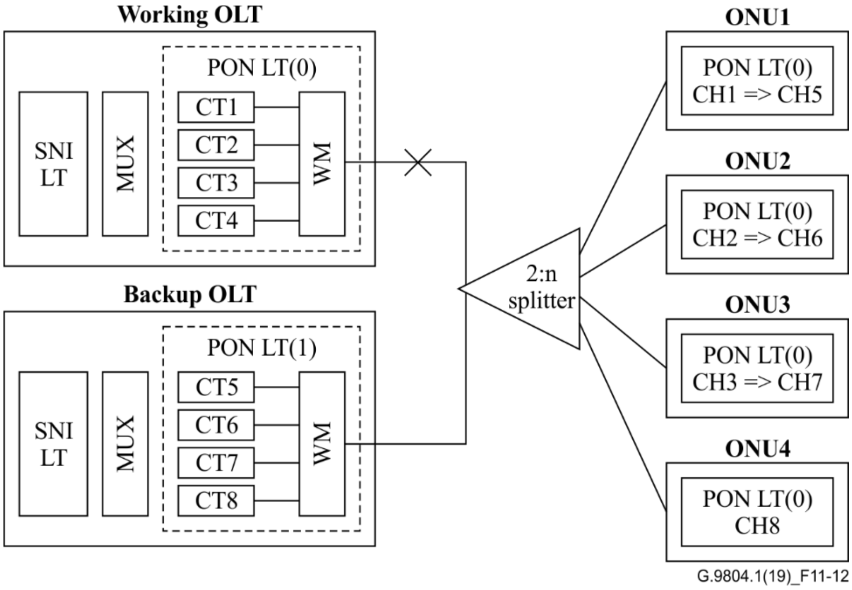

Figure 11-12 – Type W protection – 2n:n model with dual parenting

Figure 11-12 shows the architecture of 2n:n type W protection with dual parenting. The OLT CTs are divided into two groups: a working group and a backup group. When faults occur to the working group, the backup group can protect the transmission by instructing the affected ONUs to tune their wavelengths into the wavelengths of the backup group. This architecture has the same feature as type B protection as its OLT and feeder fibre are duplicated. Note that the major difference between the type B protection in Figure 11-2 and the 2n:n type W protection in Figure 11-12 is that the backup group in the 2n:n type W protection can be active to carry extra traffic with wavelengths other than those of the working group when no fault occurs, while the backup group in type B protection stands by with the same wavelengths as the working group.

11.4 Protection category

The protection category is summarized in Table 11-1. Categorization criteria are based on the subject to be protected. For type A, only a feeder fibre is protected while type B offers protection for an OLT (or OLT CTs or OLTs) and feeder fibres. Type C is referred to as a full duplex system, which protects the OLT, a feeder fibre, drop fibres and ONUs. Type W is the new category which offers protection only for an OLT CT (or OLT). In some cases, type W uses wavelength tuning in ONUs for protection.

Table 11-1 – Protection category

Type	Sub category	Dual parenting	Protected subject	ONU tuning	Extra equipment for protection	Figure number
A	1:1	No	Feeder fibre	No	Spare fibre [ITU-T G.983.1] Optical switch and 2:n splitter [b-ITU-T G-Sup.51]	Not shown
B	1:1	No	OLT and feeder fibre	No	Backup OLT, 2:n splitter, and extra feeder fibre	9-3 (with one OLT)
		Yes				9-2
	1:n	No	OLT CT and feeder fibre	No	Backup OLT CT, 2:n splitter and extra feeder fibre	9-4
		Yes	OLTs and feeder fibres	No	Backup OLT, 2:n splitters, 1:n optical switch and extra feeder fibres	9-5 (with fibre added)
C	1+1	No	OLT, feeder fibre, drop fibres and ONUs	No	Backup OLT, 2:n splitters, extra feeder fibres, extra drop fibres and extra LTs (ONUs).	9-6 9-7
W	1:n	No	OLT CT	Yes	None	9-8 9-9
	(n+1):n			No	Tunable TRx, 2:n splitter, and extra fibre	9-10
	2n:n	Yes	OLT	Yes	Backup OLT, feeder fibre	9-11

Appendix I

OLT resilience configuration of 50G TWDM PON

(This appendix does not form an integral part of this Recommendation.)

I.1 OLT resilience configuration

The time and wavelength division multiplexing passive optical network optical line terminal

(TWDM PON OLT) can be configured to protect line card faults. Figure I.1 shows the OLT resilience configuration with individual port design. An OLT is formed by taking one port from each line card and aggregating the ports using a 4x1 wavelength multiplexer/demultiplexer (Mux/DeMux). When faults occur in a line card, the corresponding wavelength channel pair is impaired. The other three wavelength channel pairs maintain transmission. The OLT can instruct the affected optical network units (ONUs) to tune to the wavelengths supported by the other OLT ports.

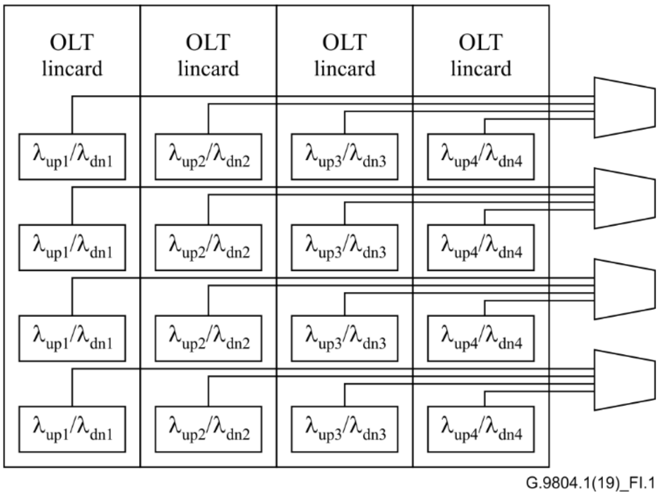

Figure I.1 – OLT resilience configuration with individual port design

Figure I.2 shows the OLT resilience configuration with integrated port design. An NxN component (e.g., 4x4 AWG, wavelength router) is used to rearrange the wavelength pairs. The wavelength pairs of an OLT are from/to different line cards. Faults to a line card only impair one wavelength pair in an OLT. The OLT can protect transmission by tuning the ONU wavelengths.

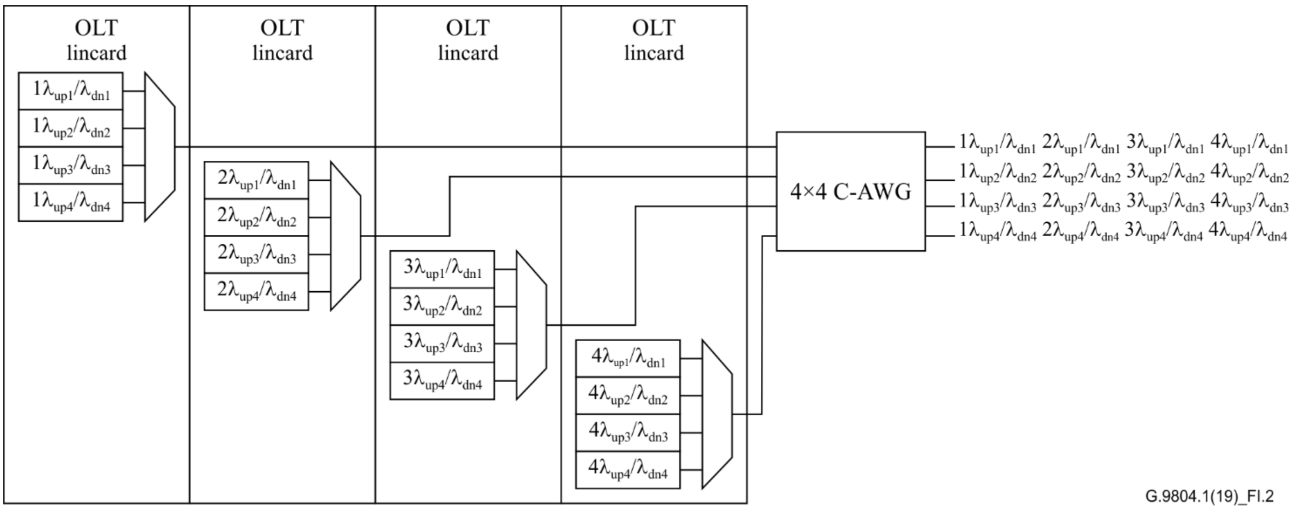

Figure I.2 – OLT resilience configuration with integrated port design

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