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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

Amendment 1

Recommendation ITU-T G.9804.1 (2019) – Amendment 1

Recommendation ITU-T G.9804.1

Higher speed passive optical networks – Requirements

Amendment 1

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.

Amendment 1 includes additional requirements for higher speed PONs.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.9804.1	2019-11-22	15	11.1002/1000/14024
1.1	ITU-T G.9804.1 (2019) Amd. 1	2021-08-06	15	11.1002/1000/14628

Keywords

Higher speed PON, 50G TDM PON, 50G TWDM PON, requirement.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

Recommendation ITU-T G.9804.1

Higher speed passive optical networks – Requirements

Amendment 1

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.9804.1 (2019).

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 passive optical network (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.

Amendment 1 of this Recommendation includes the following new requirements or modifications:

1) Slicing requirements for higher speed PON,

2) Elimination of 10 Gbit/s upstream rate requirement,

3) Optional flexible forward error correction (FEC) requirement in the upstream direction.

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*.

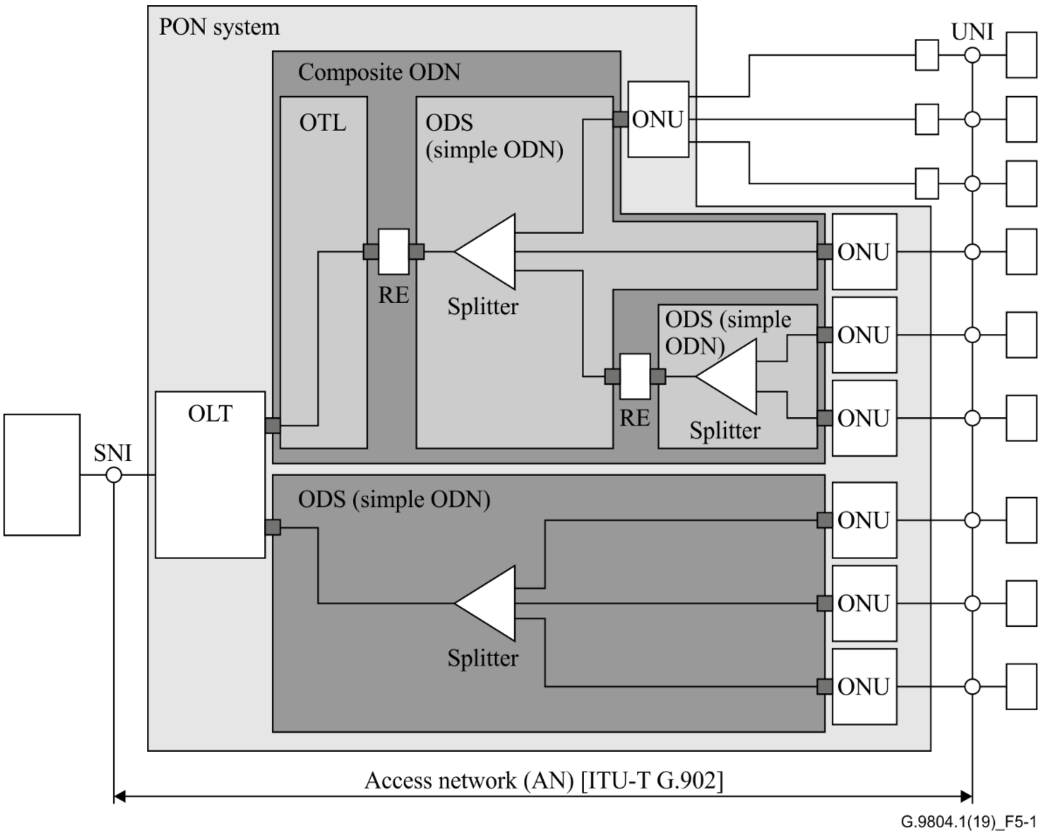

Figure 5-1 – Reference access network architecture

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).

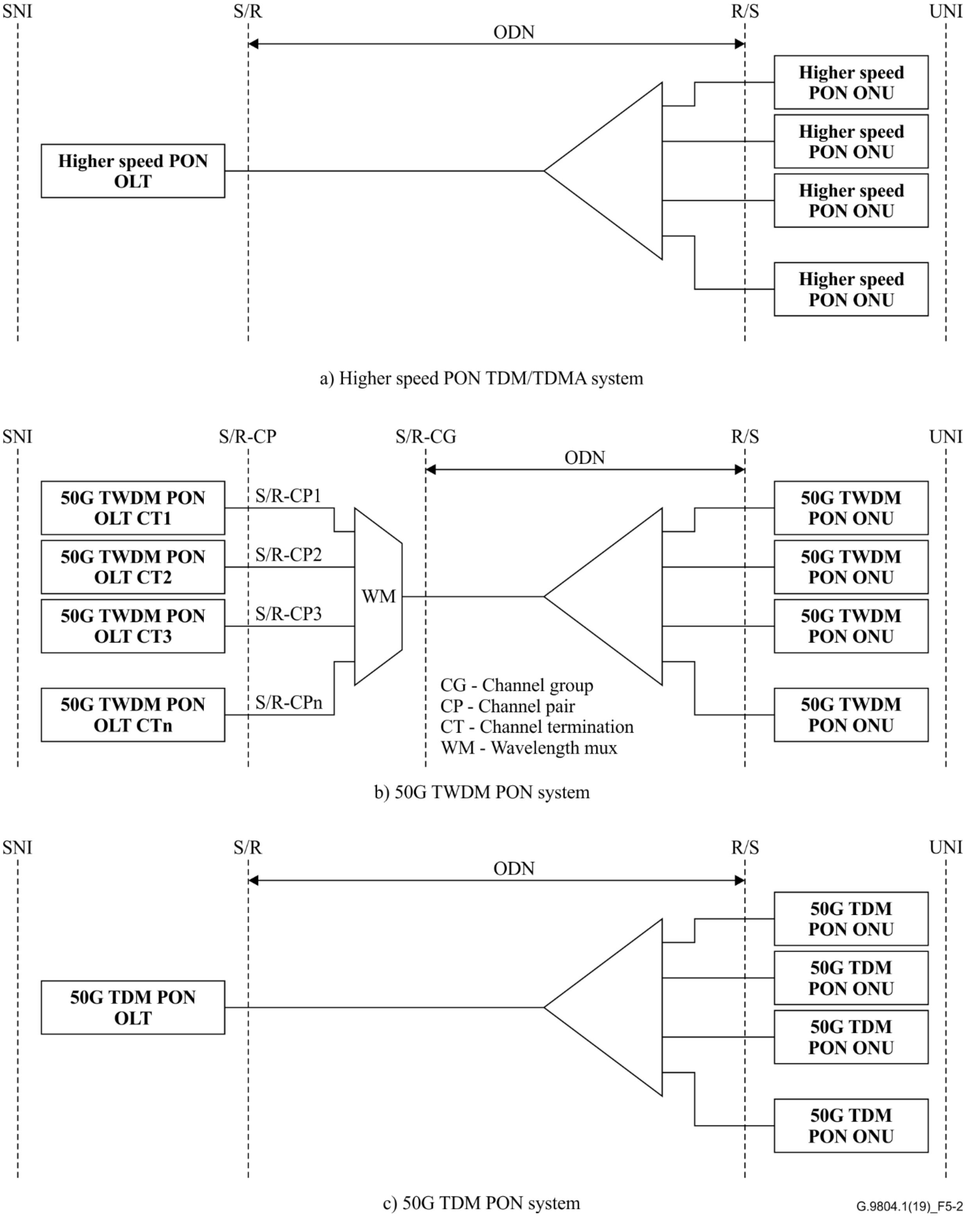

Figure 5-2 – Higher speed PON reference logical architecture

5.3 Optical power and loss parameters

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

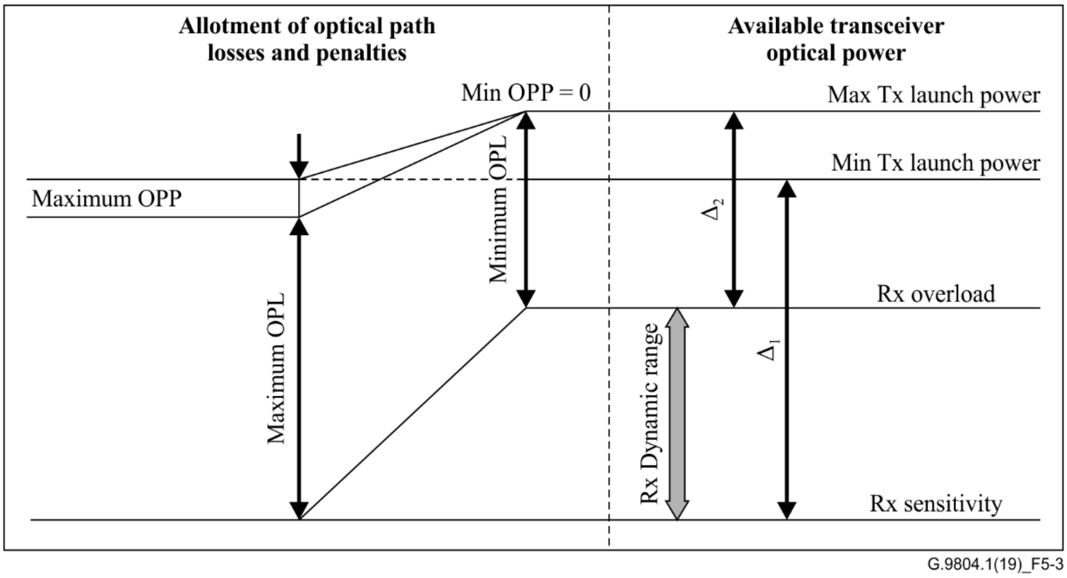

Figure 5-3 – Relationship between optical power and loss parameters

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.

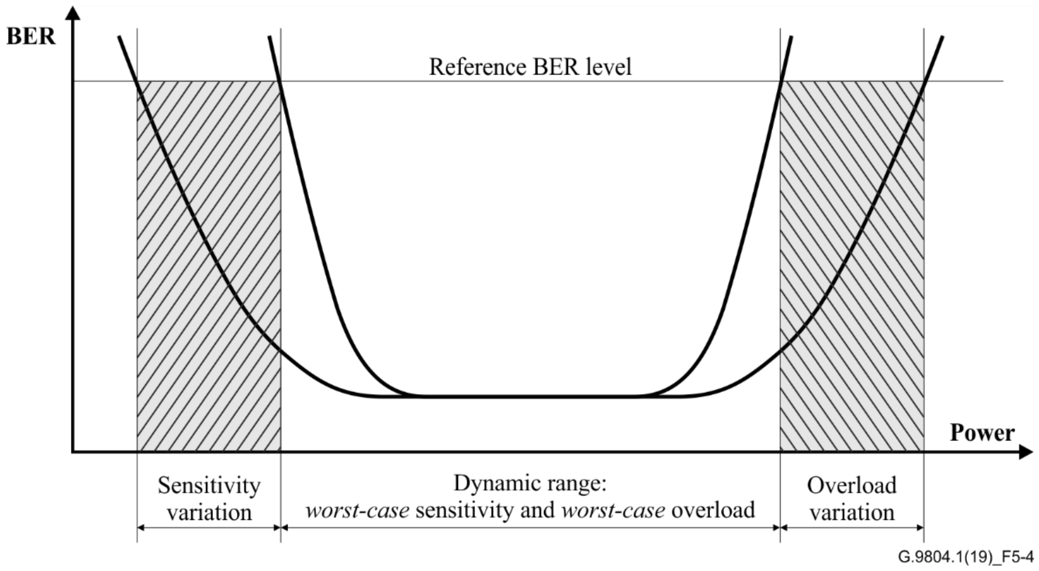

Figure 5-4 – Rx output BER as a function of received optical power, and the definition of dynamic range

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.

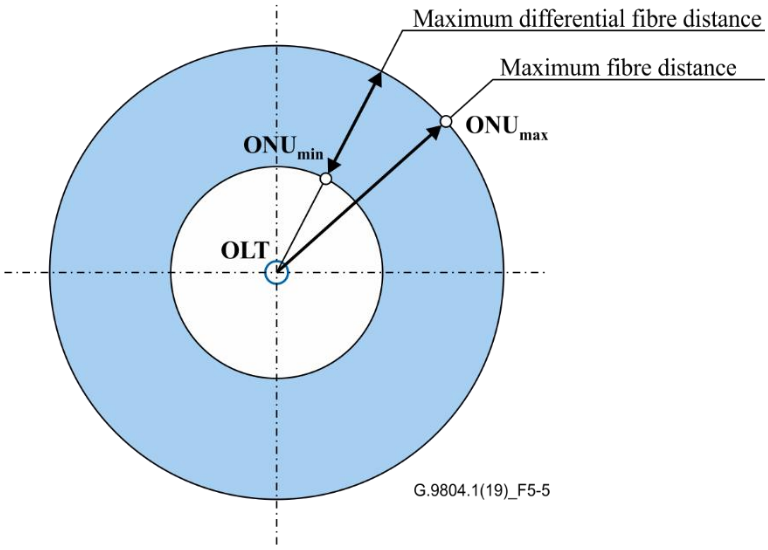

Figure 5-5 – Fibre distance concepts

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.

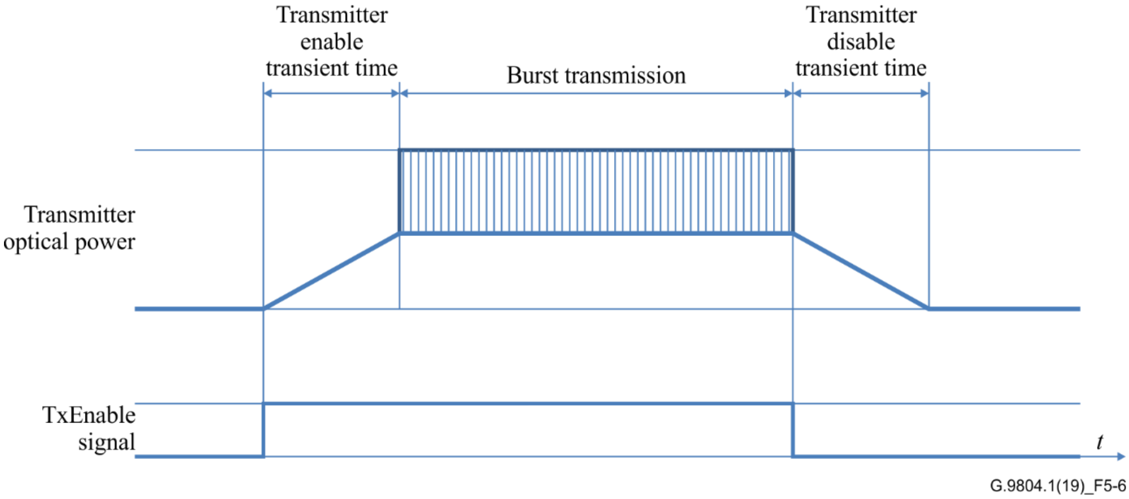

Figure 5-6 – The TxEnable signal and the associated transient times of a burst- mode transmitter

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.

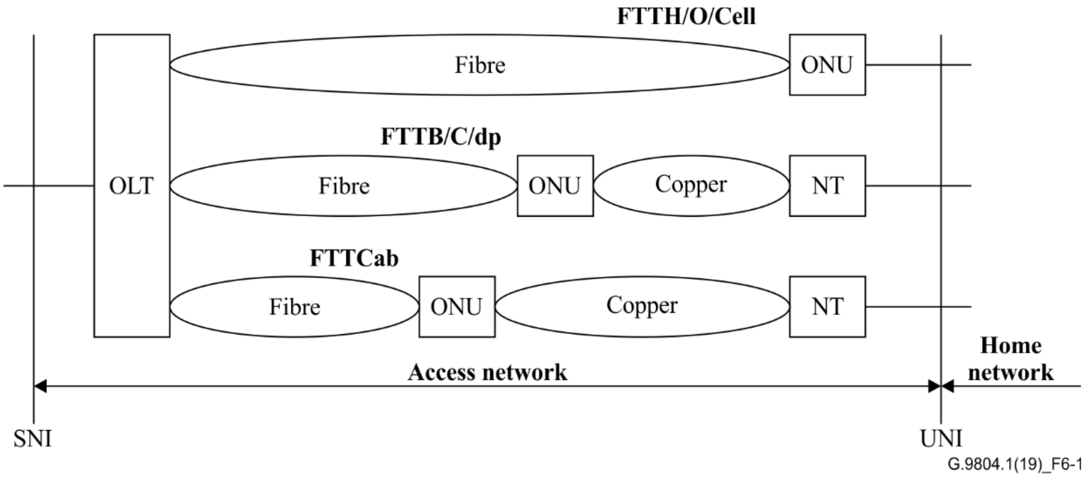

Figure 6-1 – Network architecture

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.

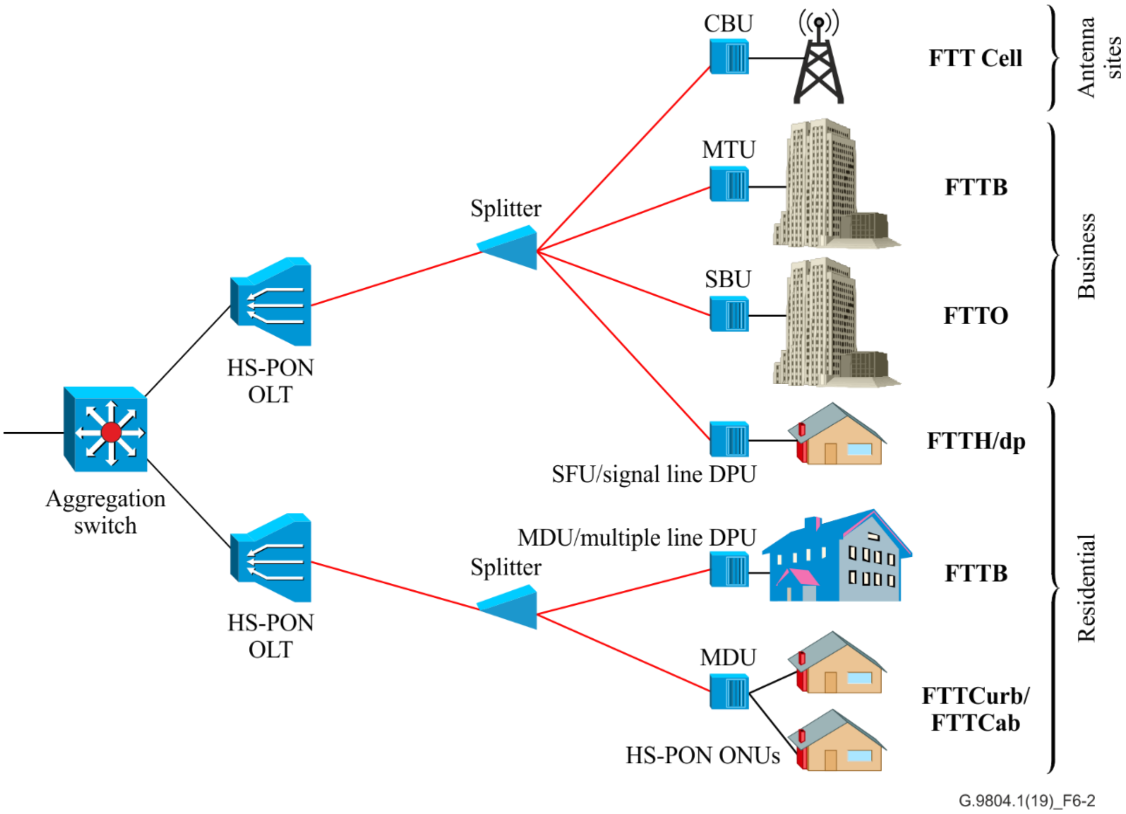

Figure 6-2 – Deployment scenarios of higher speed PON

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:
    - approximately 50 Gbit/s in the downstream and 25 Gbit/s in the upstream,
    - 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.

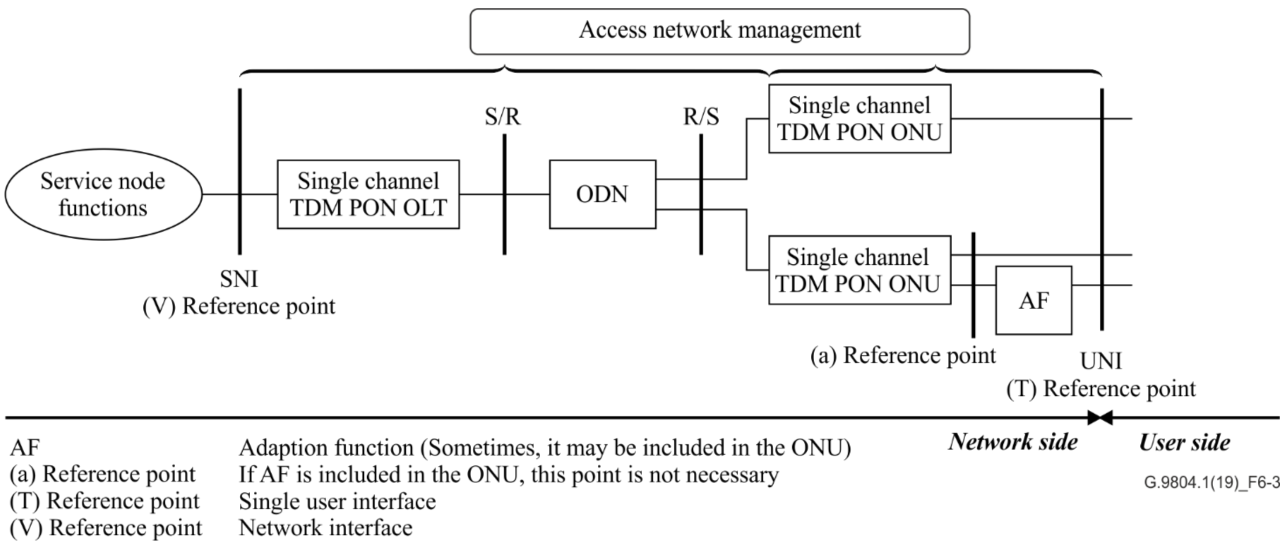

Figure 6-3 – High-level reference configuration of single channel TDM PON

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.

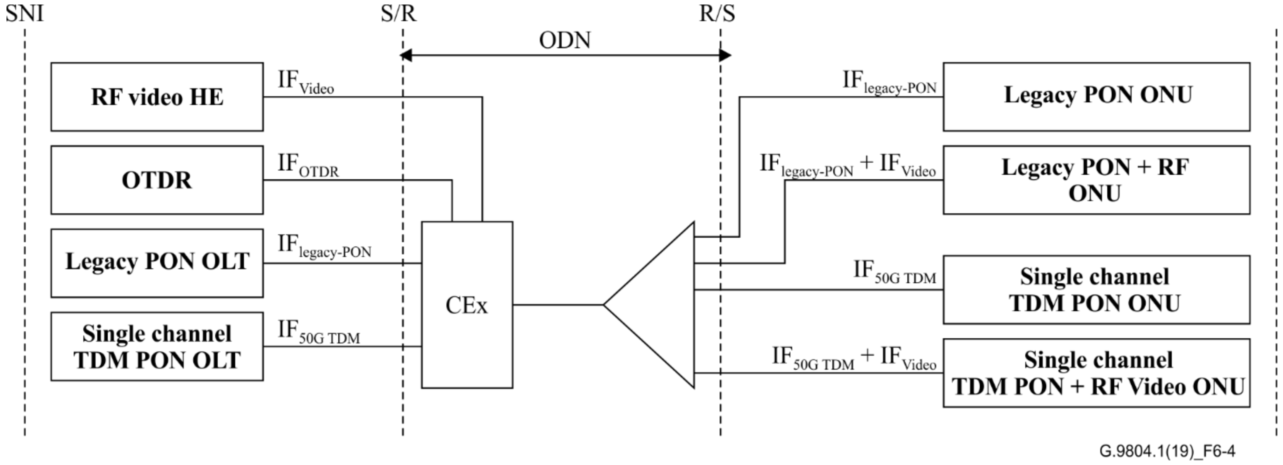

Figure 6-4 – Functional reference architecture and points for single channel TDM PON system coexistence with legacy systems

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.

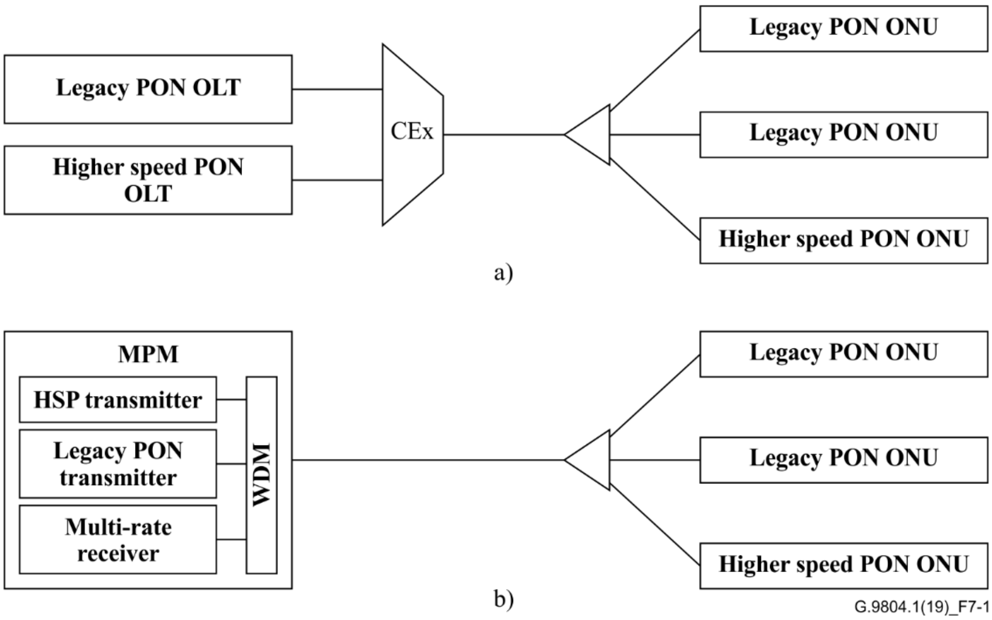

Figure 7-1 – ODN co-existence scenario (a) with CEx device, (b) higher speed TDMA system with multi-PON module

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.

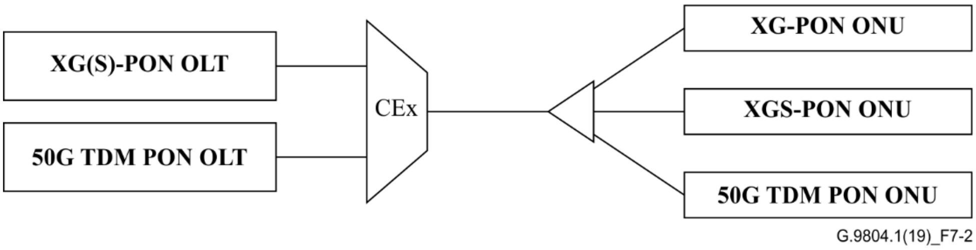

Figure 7-2 – Coexistence of XG(S)-PON and 50G TDM PON by independent CEx device

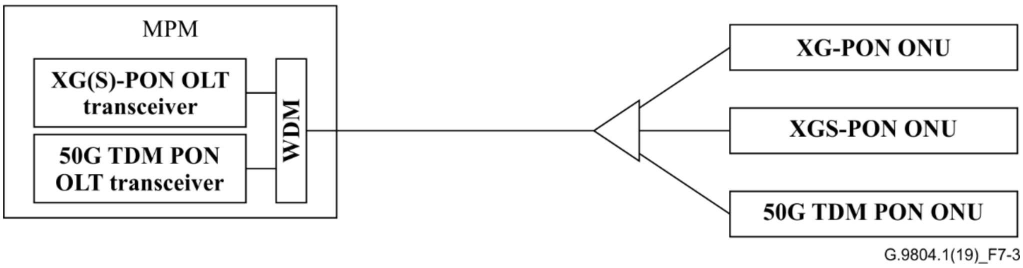

Figure 7-3 – Coexistence of XG(S)-PON and 50G TDM PON by MPM method

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.

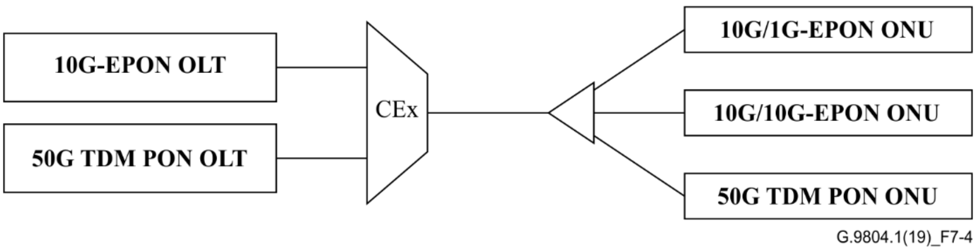

Figure 7-4 – Coexistence of 10G-EPON and 50G TDM PON by independent CEx device

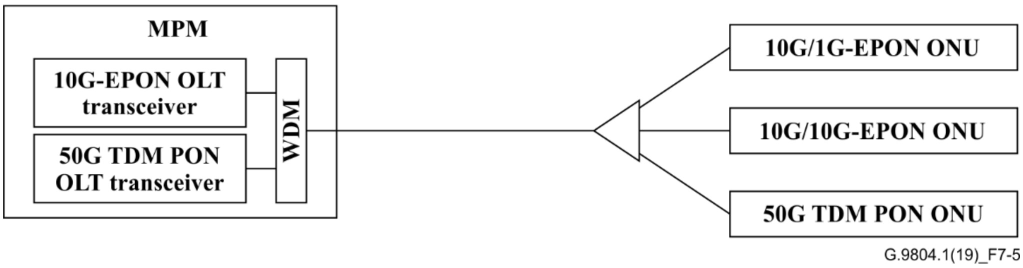

Figure 7-5 – Coexistence of 10G-EPON and 50G TDM PON by MPM module

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.

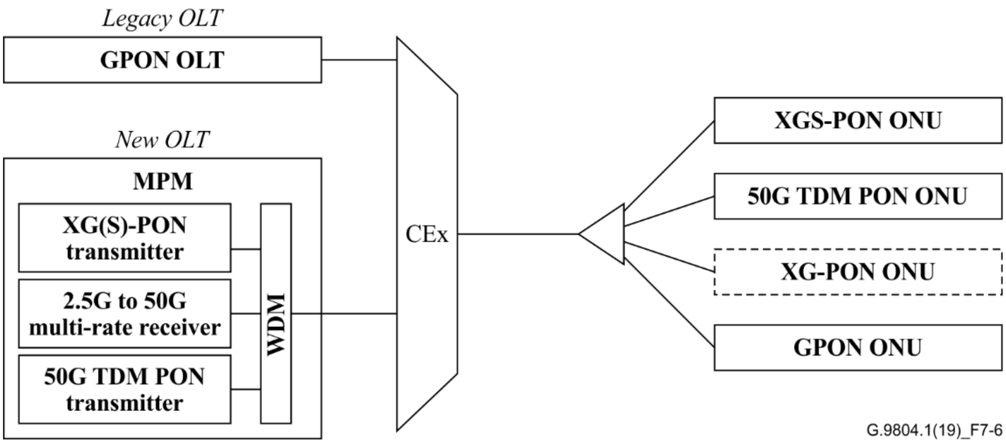

Figure 7-6 – Co-existence scenario of three generation PON systems by mixing WDM and multi-rate receiver

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.

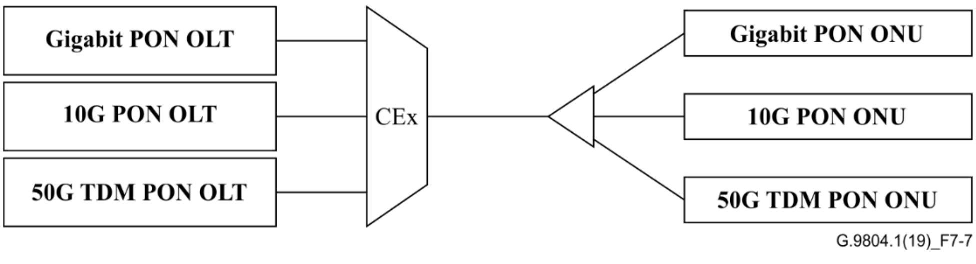

Figure 7-7 – Coexistence scenario of three generation PON systems by pure WDM

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.

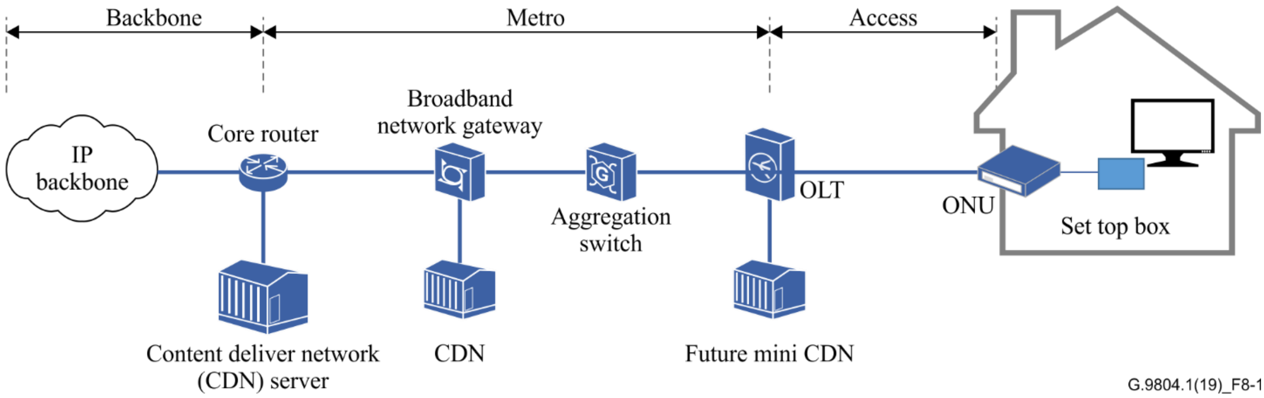

Figure 8-1 – Architecture of video services over PON

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.

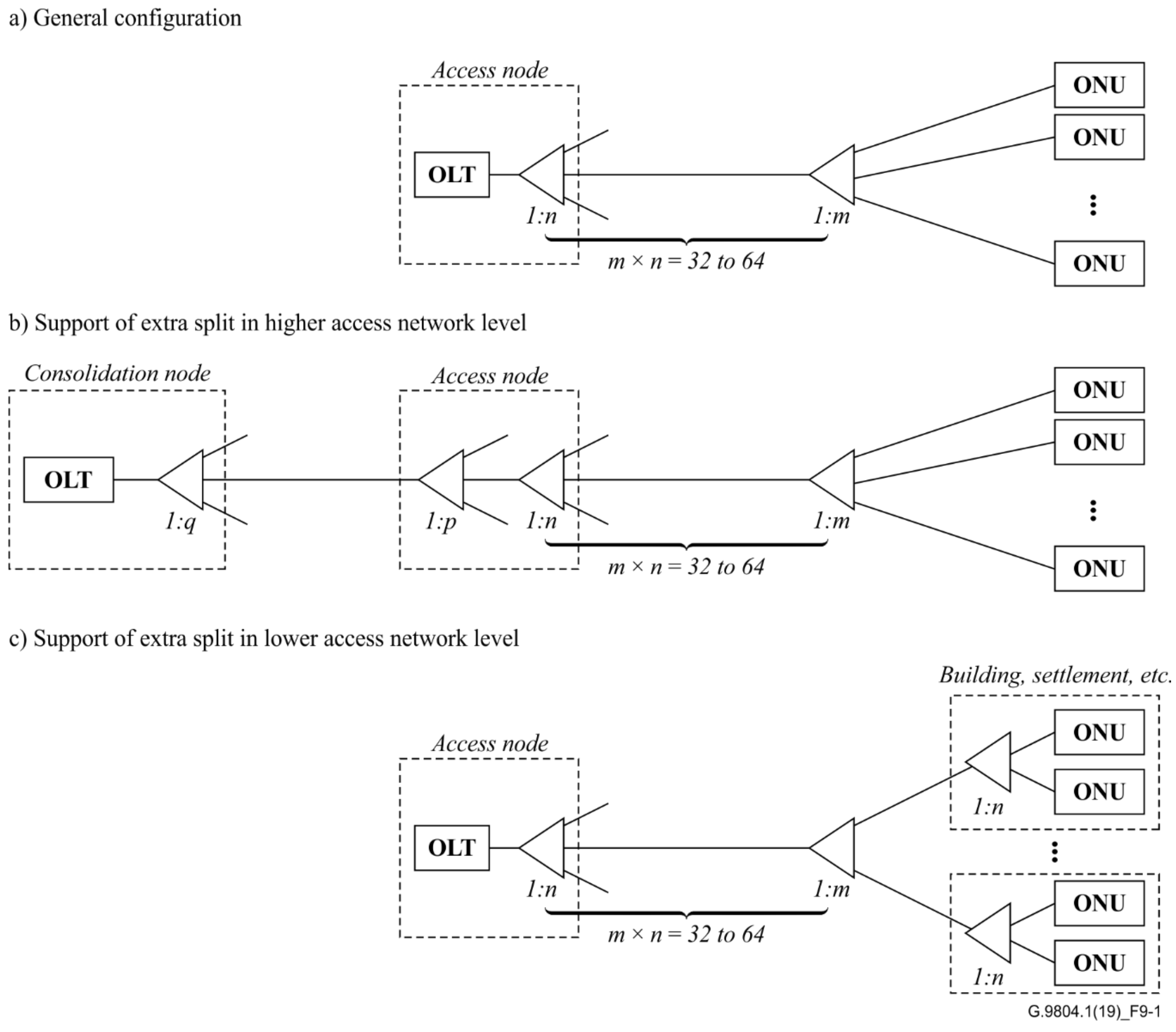

Figure 9-1 – 50G TDM PON splitter architecture options

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.

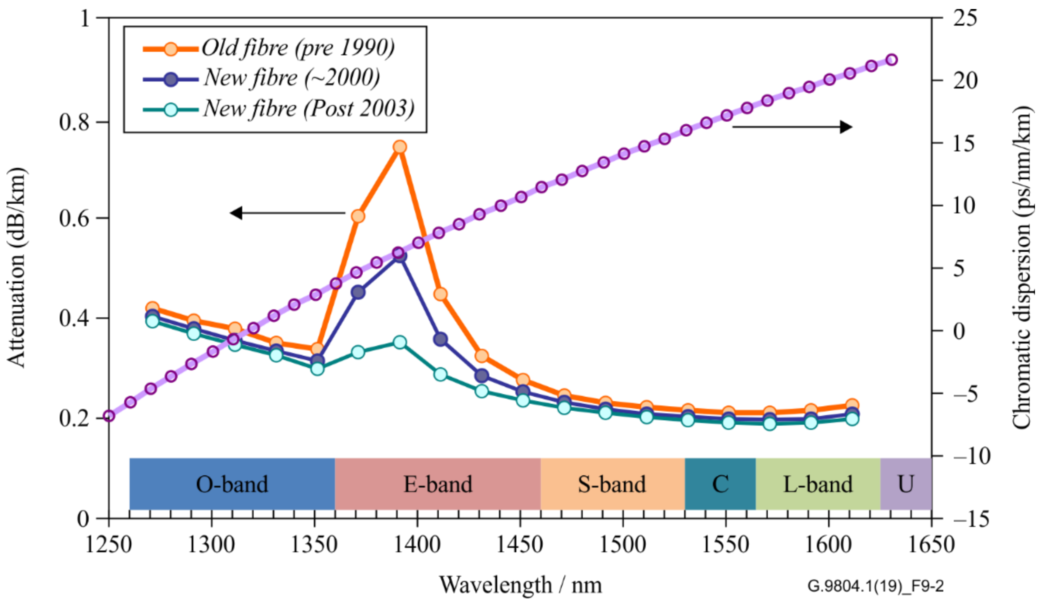

Figure 9-2 – Single mode fibre attenuation and chromatic dispersion

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.

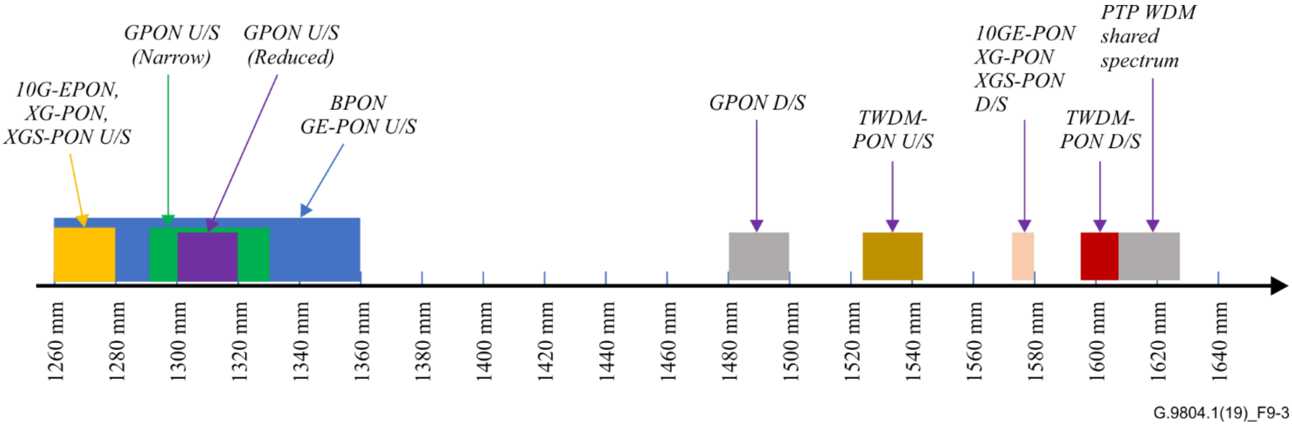

Figure 9-3 – Wavelength plans of legacy PON systems

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