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Corrigendum 1
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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line
systems for local and access networks

10-Gigabit-capable passive optical networks
(XG-PON): General requirements

Corrigendum 1

Recommendation ITU-T G.987.1 (2016) –
Corrigendum 1

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Recommendation ITU-T G.987.1

10-Gigabit-capable passive optical networks (XG-PON): General requirements

Corrigendum 1

Summary

Recommendation ITU-T G.987.1 addresses the general requirements of 10 Gigabit-capable passive optical network (XG-PON) systems, in order to guide and motivate the physical layer and the transmission convergence layer specifications. The general requirements include examples of services, user network interfaces (UNIs) and service node interfaces (SNIs), as well as the principal deployment configurations that are requested by network operators. This Recommendation also includes the system and operational requirements to meet the needs of supporting various business and residential applications.

Corrigendum 1 aligns Figure 8-1 with the split ratio calculation formula in the very same figure, to fix the typo.

History

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Asymmetric XG-PON (X=10 Gbit/s), general requirements, TDMA.

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Recommendation ITU-T G.987.1

10-Gigabit-capable passive optical networks (XG-PON): General requirements

Corrigendum 1

Editorial note: This is a complete-text publication. Modifications introduced by this corrigendum are shown in revision marks relative to Recommendation ITU-T G.987.1 (2016).

1 Scope

This Recommendation addresses the general requirements of 10-Gigabit-capable passive optical networks (XG-PON) systems, in order to guide and motivate the physical layer and the transmission convergence layer specifications. The general requirements include examples of services, user network interfaces (UNIs) and service node interfaces (SNIs), as well as the principal deployment configurations that are requested by network operators. This Recommendation also includes the system and operational requirements to meet the needs of supporting various business and residential applications.

As much as possible, this Recommendation maintains characteristics from [ITU-T G.982], and the ITU-T G.983.x, and ITU-T G.984.x series of Recommendations. This is to promote backward compatibility with existing optical distribution networks (ODNs) that comply with those Recommendations. Furthermore, this Recommendation provides a mechanism that enables seamless subscriber migration from Gigabit PON (generic term to represent both G-PON and GE-PON) to XG-PON using the wavelength division multiplexing (WDM) defined in the ITU-T G.984.x series of Recommendations.

There are two types of XG-PONs based on the upstream line rate: XG-PON1, featuring a 2.5 Gbit/s upstream path, and XG-PON2, featuring a 10 Gbit/s one, XG-PON2 being symmetrical it can be referred to as XGS-PON. The initial phase of this Recommendation only addresses XG-PON1. XG-PON2 will be addressed at a later phase, when the technology becomes more mature.

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 (2009), <i>Characteristics of a single-mode optical fibre and cable.</i> |
| [ITU-T G.657] | Recommendation ITU-T G.657 (2012), <i>Characteristics of a bending-loss insensitive single-mode optical fibre and cable for the access network.</i> |
| [ITU-T G.703] | Recommendation ITU-T G.703 (2016), <i>Physical/electrical characteristics of hierarchical digital interfaces.</i> |
| [ITU-T G.808.1] | Recommendation ITU-T G.808.1 (2014), <i>Generic protection switching – Linear trail and subnetwork protection.</i> |

[ITU-T G.810]	Recommendation ITU-T G.810 (1996), <i>Definitions and terminology for synchronization networks</i> .
[ITU-T G.813]	Recommendation ITU-T G.813 (2003), <i>Timing characteristics of SDH equipment slave clocks (SEC)</i> .
[ITU-T G.902]	Recommendation ITU-T G.902 (1995), <i>Framework Recommendation on functional access networks (AN) – Architecture and functions, access types, management and service node aspects</i> .
[ITU-T G.982]	Recommendation ITU-T G.982 (1996), <i>Optical access networks to support services up to the ISDN primary rate or equivalent bit rates</i> .
[ITU-T G.983.1]	Recommendation ITU-T G.983.1 (2005), <i>Broadband optical access systems based on Passive Optical Networks (PON)</i> .
[ITU-T G.983.2]	Recommendation ITU-T G.983.2 (2005), <i>ONT management and control interface specification for B-PON</i> .
[ITU-T G.983.3]	Recommendation ITU-T G.983.3 (2001), <i>A broadband optical access system with increased service capability by wavelength allocation</i> .
[ITU-T G.984.1]	Recommendation ITU-T G.984.1 (2008), <i>Gigabit-capable passive optical networks (GPON): General characteristics</i> .
[ITU-T G.984.2]	Recommendation ITU-T G.984.2 (2003), <i>Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification</i> .
[ITU-T G.984.3]	Recommendation ITU-T G.984.3 (2014), <i>Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification</i> .
[ITU-T G.984.4]	Recommendation ITU-T G.984.4 (2008), <i>Gigabit-capable passive optical networks (G-PON): ONT management and control interface specification</i> .
[ITU-T G.984.5]	Recommendation ITU-T G.984.5 (2007), <i>Gigabit-capable Passive Optical Networks (G-PON): Enhancement band</i> .
[ITU-T G.984.5 Amd.1]	Recommendation ITU-T G.984.5 Amd.1 (2009), <i>Gigabit-capable Passive Optical Networks (G-PON): Enhancement band, plus Amendment 1</i> .
[ITU-T G.984.6]	Recommendation ITU-T G.984.6 (2008), <i>Gigabit-capable passive optical networks (GPON): Reach extension</i> .
[ITU-T G.987]	Recommendation ITU-T G.987 (2012), <i>10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations, and acronyms</i> .
[ITU-T G.987.2]	Recommendation ITU-T G.987.2 (2016), <i>10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification</i> .
[ITU-T G.987.3]	Recommendation ITU-T G.987.3 (2014), <i>10-Gigabit-capable passive optical networks (XG-PON): Transmission Convergence (TC) layer specification</i> .
[ITU-T G.988]	Recommendation ITU-T G.988 (2012), <i>ONU management and control interface (OMCI) specification</i> .

[ITU-T G.8261]	Recommendation ITU-T G.8261/Y.1361 (2013), <i>Timing and synchronization aspects in packet networks</i> .
[ITU-T G.8262]	Recommendation ITU-T G.8262/Y.1362 (2015), <i>Timing characteristics of synchronous Ethernet equipment slave clock</i> .
[ITU-T J.185]	Recommendation ITU-T J.185 (2012), <i>Transmission equipment for transferring multi-channel television signals over optical access networks by frequency modulation conversion</i> .
[ITU-T J.186]	Recommendation ITU-T J.186 (2008), <i>Transmission equipment for multi-channel television signals over optical access networks by sub-carrier multiplexing (SCM)</i> .
[ITU-T Y.2001]	Recommendation ITU-T Y.2001 (2004), <i>General overview of NGN</i> .
[ITU-T Y.2201]	Recommendation ITU-T Y.2201 (2009), <i>Requirements and capabilities for ITU-T NGN</i> .
[DSL Forum TR-156]	Broadband Forum TR-156 (2008), <i>Using GPON Access in the context of TR-101</i> .
[IEC 60825-2]	IEC 60825-2 (2007), <i>Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)</i> .
[IEEE 1588]	IEEE 1588-2008, <i>IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems</i> .
[MEF 10.1]	MEF 10.1 (2006), <i>Ethernet Service Attributes Phase 2</i> .

3 Definitions

3.1 Terms defined elsewhere

See clause 3 of [ITU-T G.987].

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

See clause 4 of [ITU-T G.987].

In addition, this Recommendation uses the following abbreviations:

FTTO	Fibre To The Office
MTU	Multi-Tenant Unit
XGS-PON	10Gbit/s Symmetrical Passive Optical Network
XTC	XG-PON Transmission Convergence

5 Architecture of the optical access network

5.1 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 5-1 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), etc. The optical distribution network (ODN) is common to

all the architectures shown in Figure 5-1; hence, the commonality of this system has the potential to generate large worldwide volumes.

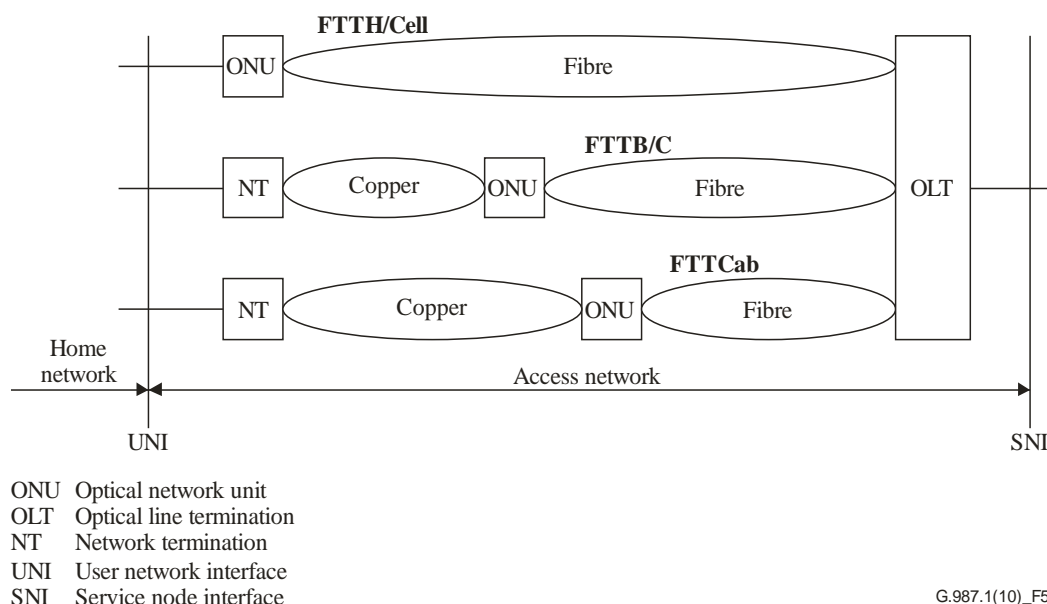


Figure 5-1 – Network architecture

NOTE – An ONU supporting FTTH has been commonly referred to as ONT (see [ITU-T G.987]).

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.

XG-PON should extend the [ITU-T G.984.6] reach extenders capability, inherited from the ITU-T G.984.x series of Recommendations to produce extra optical budget to achieve longer distances and/or additional passive split.

5.1.1 FTTB scenario

The FTTB scenario is divided into two scenarios, one for multi-dwelling units (MDU) and the other for businesses or mixed environments, multi-tenant units (MTUs). Each scenario has the following service categories:

5.1.1.1 FTTB for MDU-served residential users

- Asymmetric broadband services (e.g., 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.).
- 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).

5.1.1.2 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.

5.1.2 FTTCurb and FTTCab scenario

Within this scenario, the following service categories have been considered:

- 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.).
- 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.

5.1.3 FTTH scenario

Within this scenario, the following service categories have been considered:

- Asymmetric broadband services (e.g., IPTV, digital broadcast services, 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).

5.1.4 FTTO scenario

Fibre to the office (FTTO) addresses business ONU dedicated to a small business customer. Within this scenario, 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.

5.1.5 FTTCcell wireless scenario

Within this scenario, the ONU will be called a cell-site backhauling unit (CBU) and 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 cell-site backhaul);
- hot spots.

Figure 5-2 represents exemplary scenarios of XG-PON applications.

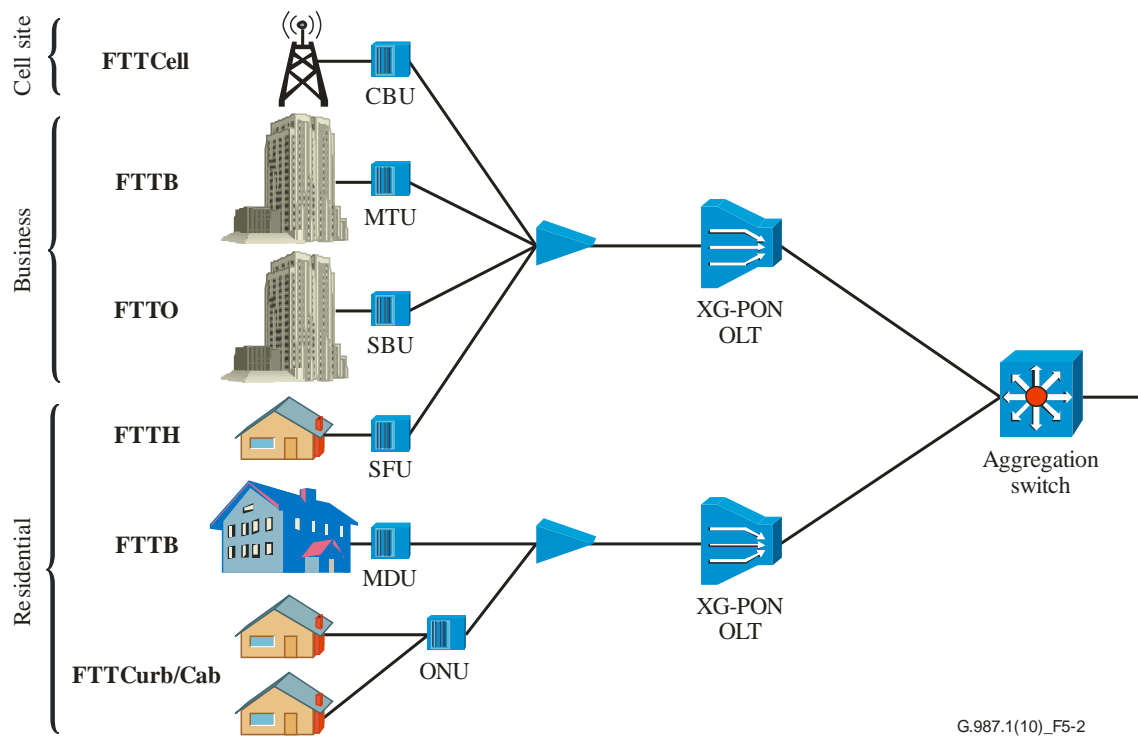


Figure 5-2 – A summary of some XG-PON scenarios

5.1.6 Environment conditions in outdoor scenarios

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.

5.2 Reference configuration

A high level and simple reference configuration of XG-PON is depicted in Figure 5-3, which shows a very similar high level reference configuration as in the ITU-T G.983.x and ITU-T G.984.x series of Recommendations.

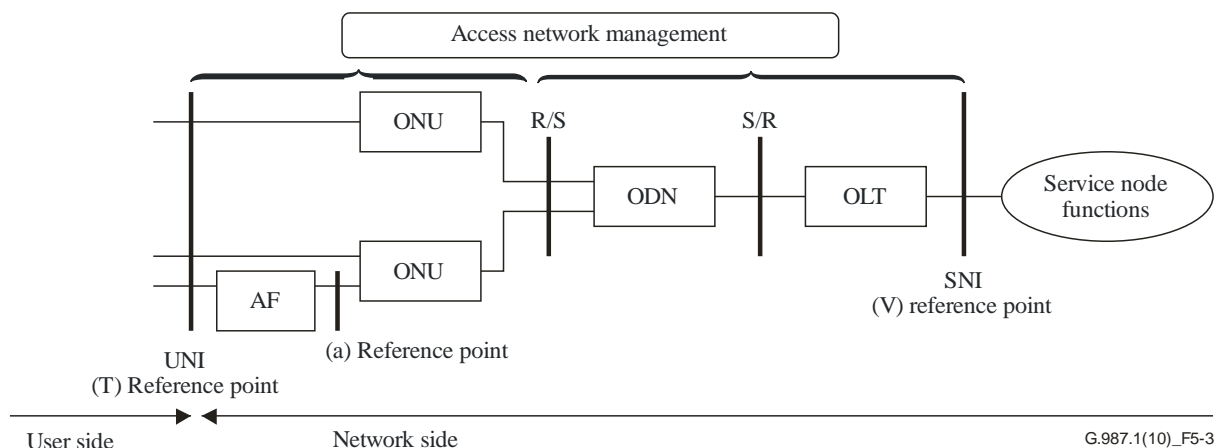


Figure 5-3 – High-level reference configuration of XG-PON

In addition to Figure 5-3, when XG-PON is deployed with an RF video overlay service, the ODN can use a WDM device or an optical coupler/splitter to combine XG-PON and RF video signals. The coupler/splitter can optionally be used to provide a split at the central office (CO). Such architectures are depicted in Figures 5-5 and 5-6.

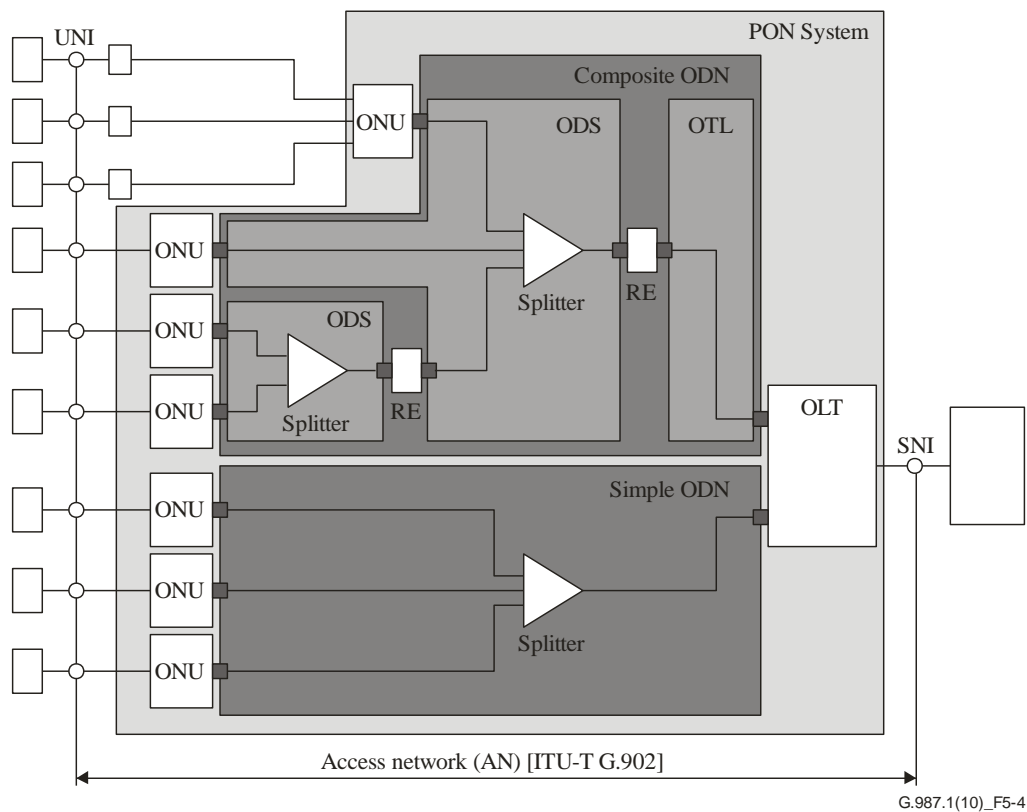


Figure 5-4 – Reference access network architecture

Figure 5-4 depicts the generic optical access network (OAN) reference architecture that applies to the XG-PON. It includes an OLT, ONUs and an optical distribution network between them. As shown in Figure 5-4, an XG-PON ODN can consist of a single passive optical distribution segment (ODS), or a group of passive ODSs interconnected with reach extenders (REs) [ITU-T G.987].

5.2.1 ODN architectures

There can be several types of ODN architectures to achieve coexistence between XG-PON1 or XG-PON2 and additional services such as G-PON and video distribution services. Figures 5-5 and 5-6 are reference diagrams of optical access network architectures. The figures assume that wavelength blocking filters (WBFs) are used when XG-PON (1 or 2), G-PON and video are shared within the same ODN.

Note that these diagrams simply provide reference configurations of the ODN and WBF, and are not intended to limit future designs and implementations. In addition, the coexistence of XG-PON1 and XG-PON2 is outside the scope of this clause since this would not affect WDM configuration.

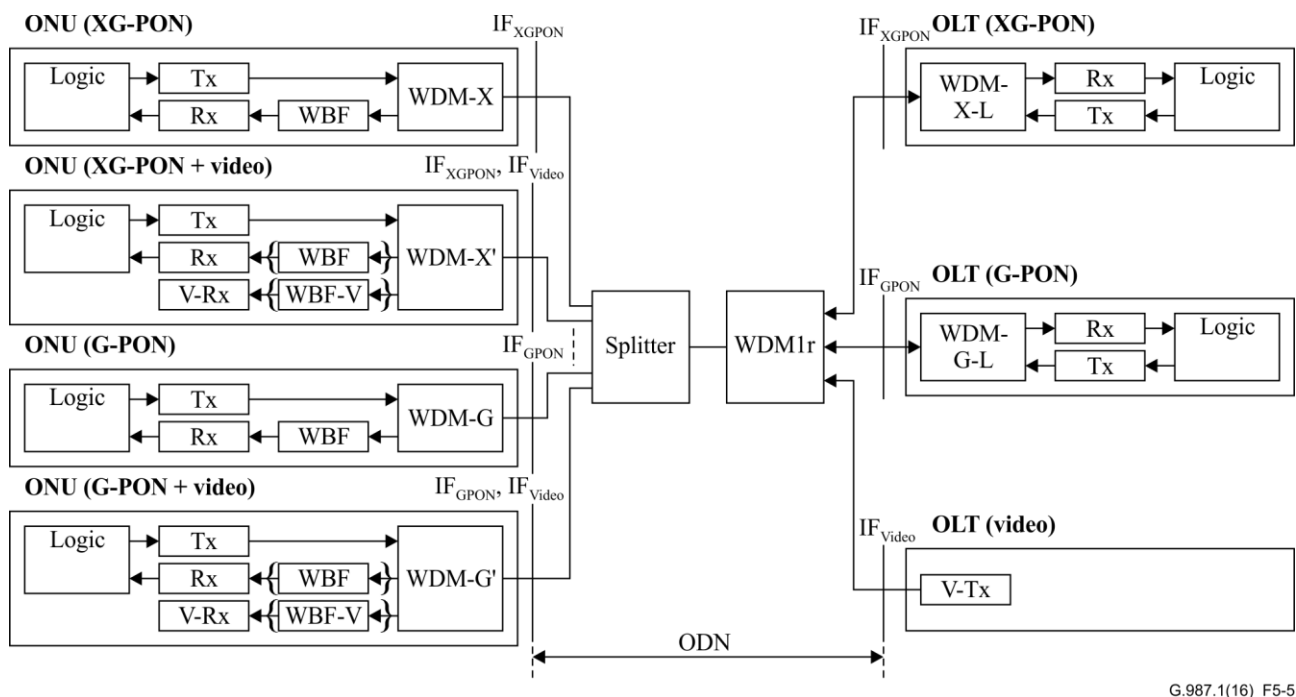


Figure 5-5 – Reference optical configuration for XG-PON coexistence with G-PON through WDM1r

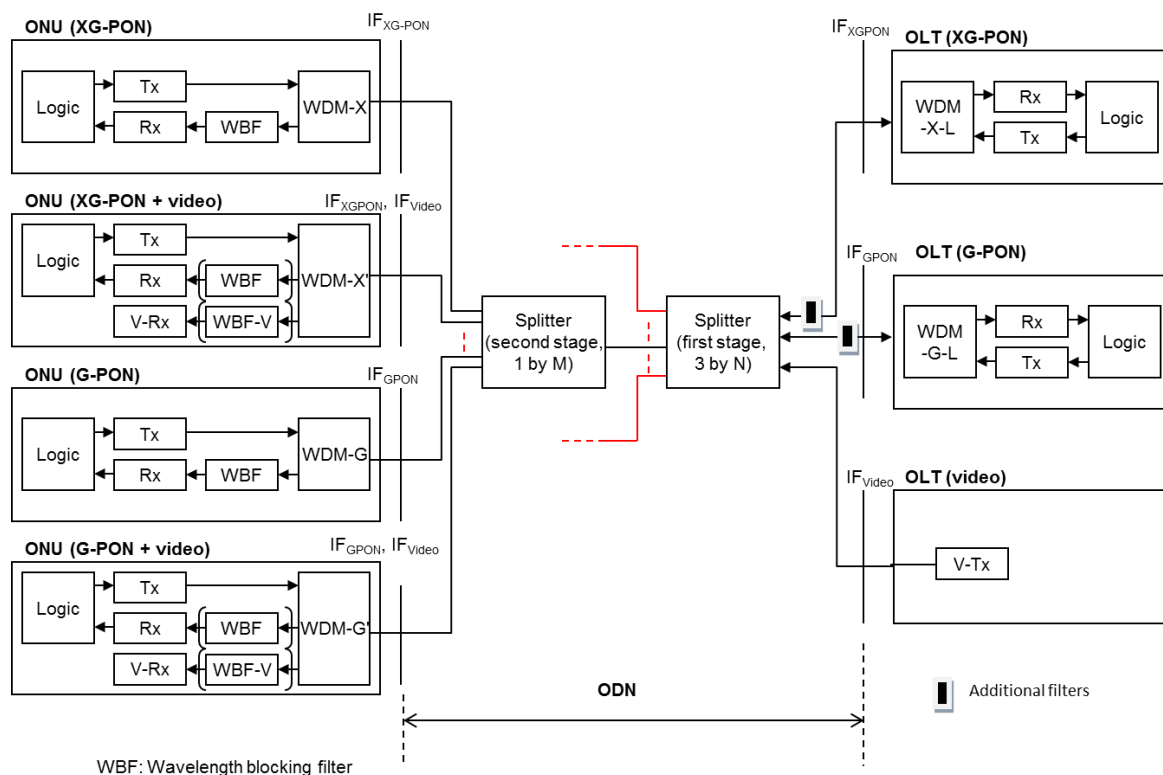


Figure 5-6 – Reference optical configuration for XG-PON coexistence through splitter

NOTE – In case coexistence of XG-PON through a splitter is envisioned, strengthened filtering or additional filtering (as shown in Figure 5-6 revised as above) should be used at OLT for implementation of the WDM-X-L and WDM-G-L to offer the required isolation. Those filters when part of OLT implementation choices are out of the scope of [ITU-T G.987].

Functions of WBFs and WDMs that enable the G-PON and XG-PON coexistence, as shown in Figures 5-5 and 5-6, are listed as follows:

Tx	Optical transmitter
Rx	Optical receiver
V-Tx	Video transmitter
V-Rx	Video receiver
WBF	Wavelength blocking filter for blocking interference signals to Rx.
WBF-V	Wavelength blocking filter for blocking interference signals to V-Rx.
WDM-X	WDM filter in XG-PON ONU to combine/isolate the wavelengths of XG-PON upstream and downstream.
WDM-X'	WDM filter in XG-PON ONU to combine/isolate the wavelengths of XG-PON upstream and downstream and isolate the video signal(s).
WDM-G	WDM filter in G-PON ONU to combine/isolate the wavelengths of G-PON upstream and downstream.
WDM-G'	WDM filter in G-PON ONU to combine/isolate the wavelengths of G-PON upstream and downstream and isolate the video signal(s).
WDM-X-L	WDM filter in XG-PON OLT to combine/isolate the wavelengths of XG-PON upstream and downstream.
WDM-G-L	WDM filter in G-PON OLT to combine/isolate the wavelengths of G-PON upstream and downstream of one or more channels.
WDM1r	WDM filter that may be located in the central office to combine/isolate the wavelengths of XG-PON and G-PON signals and which occasionally combines the video signals.

5.2.2 Operating wavelength for G-PON and XG-PON

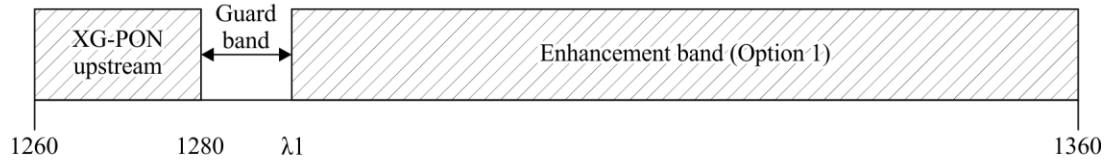
The wavelength range of the XG-PON1 downstream signal on a single-fibre system is from 1575-1580 nm (1575-1581 nm for outdoor application), and the range of upstream signal for XG-PON1 is from 1260-1280 nm. This clause redefines the reserved wavelength range and specifies the tolerance for interference signals of XG-PON1 ONUs to enable the coexistence of XG-PON and additional services such as G-PON and video services.

Figure 5-7 and Table 5-1 define the wavelength allocation plan including the wavelength bands reserved for additional services. The wavelength range of the XG-PON downstream signal is referred to as the "basic band." Reserved bands are referred to as the "enhancement band." Applications for the enhancement band may include G-PON and/or video services. The wavelength range for video services remains the same range as defined in [ITU-T G.983.3].

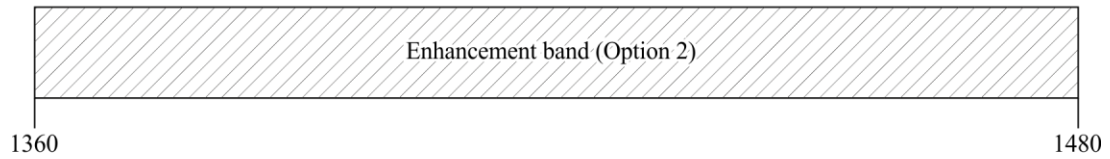
A guard band separates the XG-PON upstream and downstream from the enhancement band. The interference between signals in these two bands causes signal degradation among each other, so it must be reduced to a negligible level. WBFs are used to obtain the required isolation outside the guard band. The wavelength values specified in Table 5-1 take into account guard bands that can be achieved with commercially available low-cost WBFs.

NOTE – Wavelengths in the enhancement band may be used not only for downstream but also for upstream signal transmission in the WDM scheme.

1.3 μm wavelength band



Intermediate wavelength band



1.5 μm wavelength band

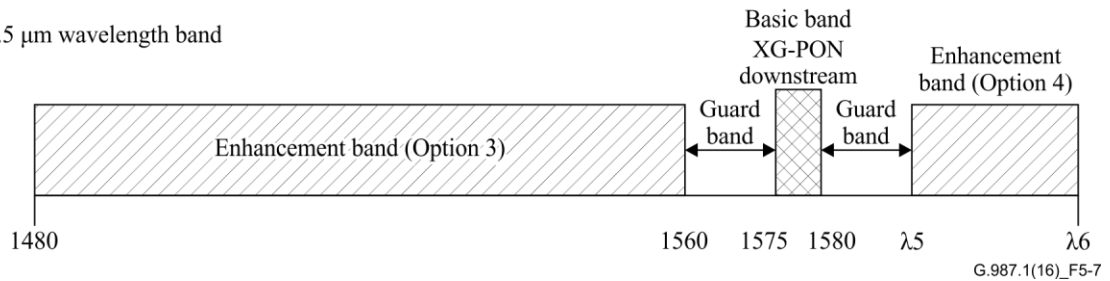


Figure 5-7 – Wavelength allocation

Table 5-1 – Parameters for wavelength allocation in Figure 5-7

Items	Notation	Unit	Nominal value	Application examples
XG-PON1 Upstream				For use in XG-PON1 upstream.
Lower limit	–	nm	1260	
Upper limit	–	nm	1280	
Enhancement band (option 1)				For use in G-PON upstream (Reduced option: 1290-1330 nm).
Lower limit	λ_1	nm	1290	
Upper limit	–	nm	1330	
Enhancement band (option 2)				For future use. NOTE – The values are informative. The loss in this band is not guaranteed in optical branching components for PON (i.e., power splitters) specified in [b-ITU-T G.671] nor in optical fibres specified as [ITU-T G.652] A&B (non-low-water-peak fibres).
Lower limit	–	nm	1360 (<i>Informative</i>)	
Upper limit	–	nm	1480 (<i>Informative</i>)	
Enhancement band (option 3)				For use in G-PON downstream (1480-1500 nm) and/or video distribution service (1550-1560 nm).
Lower limit	–	nm	1480	
Upper limit	–	nm	1560	
XG-PON downstream (Basic band)				For use in XG-PON1 downstream (Note 2)
Lower limit	–	nm	1575	
Upper limit	–	nm	1580	

Table 5-1 – Parameters for wavelength allocation in Figure 5-7

Items	Notation	Unit	Nominal value	Application examples
Enhancement band (Option 4)				For future use.
Lower limit	λ_5	nm	TBD	NOTE – The upper-limit value is determined as an operator choice from TBD (to be determined) to 1625 nm, considering the following factors: bending loss of optical fibre that increases at longer wavelengths; loss of a filter that separates/combines a monitoring signal and user signal(s) (if an optical monitoring system is used)
Upper limit	λ_6	nm	TBD to 1625	
NOTE 1 – Proper guard bands should be considered in the case of multiple wavelengths in the same Enhancement band.				
NOTE 2 – Enhanced wavelength band of 1575-1581 nm is allowed in the case of outdoor OLT operations.				

5.2.3 User network interface (UNI) and service node interface (SNI)

As depicted in Figure 5-3, ONU provides the UNI towards end users, while the OLT provides the SNI interface towards the core network. The types of UNI/SNI interfaces depend on the services that the service provider offers. See [ITU-T G.902].

- Examples of UNI are described in clause I.1.2.
- Examples of SNI are described in clause I.1.3.

5.2.4 Interface at reference points S/R and R/S

The interface at reference points S/R and R/S at OLT and ONU optical port is defined as IF_{XG-PON}. This is a PON-specific interface that supports all the protocol elements necessary to allow transmission between OLT and ONUs.

5.2.5 Layered structure of XG-PON optical network

The protocol reference model is divided into physical medium, transmission convergence (TC), and path layers (see [ITU-T G.902] and the ITU-T G.984.x series of Recommendations). An example applied to XG-PON is shown in Table 5-2. In an XG-PON network, the path layer corresponds to the X-GEM encapsulation layer.

Table 5-2 – Layered structure of XG-PON network

Path layer			
Transmission medium layer (Note)	XTC layer	Adaptation	X-GEM encapsulation
		PON transmission	DBA
			X-GEM port bandwidth allocation
	QoS handling & T-CONT management		
			Privacy and security
			Frame alignment
			Ranging
			Burst synchronization
			Bit/byte synchronization
	Physical medium layer		E/O adaptation
			Wavelength division multiplexing
			Fibre connection
NOTE – The transmission medium layer must provide the related OAM functions.			

The XTC layer is divided into PON transmission and adaptation sublayers, which correspond to the transmission convergence sublayer of the X-GEM conveying various data types. The PON transmission sublayer terminates the required transmission function on the ODN. The PON-specific functions are terminated by the PON transmission sublayer, and it is not seen from the adaptation sublayer.

The two layers considered are the physical medium dependent layer and the TC layer.

6 Migration scenarios

Gigabit PONs such as G-PON (ITU-T G.984.x series of Recommendations) and 1G-EPON ([b-IEEE 802.3]) have been standardized and are now being deployed worldwide. With the ever increasing bandwidth demand from consumer and business applications, the most general requirement for a next-generation PON (NG-PON) is to provide higher bandwidth than Gigabit PON. In addition, given the major investments spent on time and money on deploying Gigabit PON mainly in the fibre infrastructure, NG-PON must be able to protect the investment of the legacy Gigabit PONs by ensuring seamless and smooth migration capability for subscribers from Gigabit PON to NG-PON. Coexistence between XG-PON and G-PON, which is addressed by this Recommendation, is enabled through the wavelength band plan enhancements specified in [ITU-T G.984.5 Amd.1], which also provides optional overlay capability of broadcast TV on a separate wavelength. Coexistence with other legacy PON systems is for further study and will not be covered in this version of this Recommendation.

There are several migration scenarios to meet different service providers' needs. These reflect recognition that differing service introduction strategies might affect requirements for the NG-PON specifications. This clause describes two likely migration scenarios:

PON brown field migration scenario

PON brown field 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 XG-PON. Some subscribers on an existing Gigabit PON system might require an upgrade to such higher speed tier service and the network operator may therefore choose to move over these subscribers to the XG-PON system, while other subscribers remain on the Gigabit PONs. At a certain point, some network operators may eventually perform a 'forced migration' from Gigabit PON to XG-PON when the number of Gigabit PON subscribers becomes low. It is likely that both Gigabit PONs and XG-PONs will continue to

coexist for a relative long time in this scenario. In a similar, but slightly different migration scenario, a network operator might want to replace an existing Gigabit PON with an XG-PON completely. In this case, it would still make sense to run both Gigabit PON and XG-PON at the same time and update customers one at a time. But, the upgrade window is rather much shorter.

General requirements for this scenario are as follows:

- coexistence between Gigabit PON and XG-PON on the same fibre must be supported for the case that the fibre resource is not necessarily abundant;
- service interruption for the non-upgrade subscribers should be minimized;
- XG-PON must support/emulate all G-PON legacy services in the case of full migration.

PON green field migration scenario

Renovating the access network to FTTx infrastructure is the biggest investment of service providers and may take a long time. When XG-PON technology becomes mature, service providers might be interested in using XG-PON to replace copper-based infrastructure or to deploy in a brand new development area for the benefit of higher bandwidth and/or higher splitting ratio. An area where Gigabit PON had not been deployed before is referred to as "PON green field". This scenario may help service providers achieve better economics while supporting the same or better bandwidth offer per user as Gigabit PON. In this scenario, the requirement of coexistence with Gigabit PONs is not necessary.

6.1 Migration from legacy PON to XG-PON

To assure this smooth migration capability, overlay through WDM technology in compliancy to optical wavelength allocation described in [ITU-T G.984.5 Amd.1] must be implemented in all ONUs. It will, of course, remain the choice of the operator whether to use this capability or rather run a full PON active devices replacement from day 1 of an upgrade process.

In the transition period, to get simultaneous G-PON and XG-PON working, a WDM1r combiner/splitter is installed in the network, as illustrated in Figure 6-1.

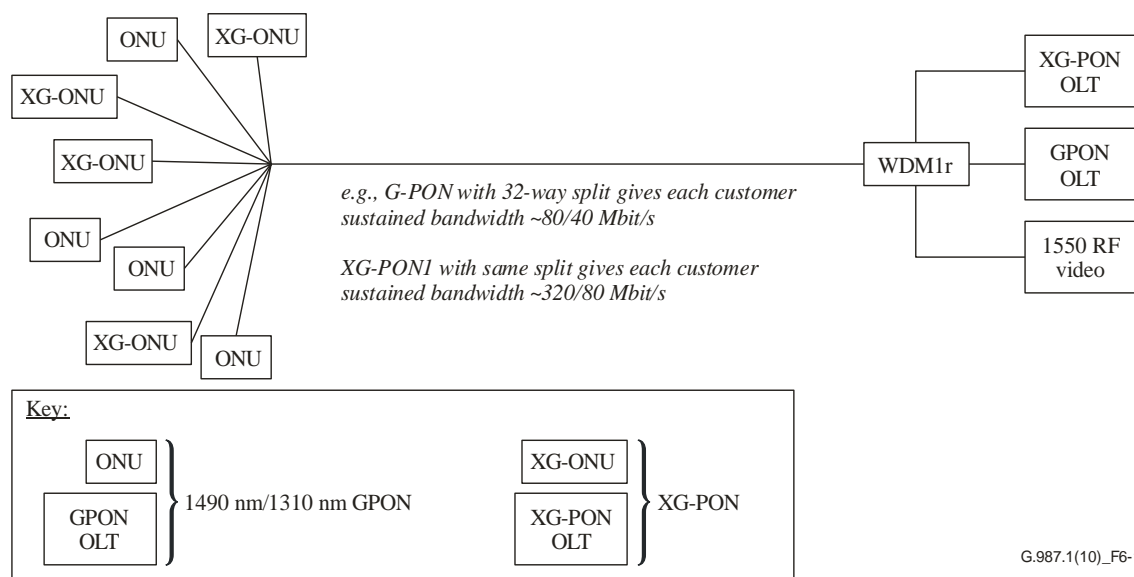


Figure 6-1 – Example of coexistence of G-PON and XG-PON with video overlay option

Any coexistence combination of XG-PON may be used. Specifically, XG-PON can coexist with RF video overlay only; the required WDM1r characteristics and performances can be found in [ITU-T G.984.5 Amd.1].

6.2 Migration from XG-PON1 to XG-PON2

The need of coexistence between XG-PON1 and XG-PON2 still requires further study and therefore will not be addressed in this version, but rather in a future revision. Regardless of the need of the coexistence requirement, it is desirable to support a common TC layer for XG-PON1 and XG-PON2 derived from G-PON's TC with the necessary enhancements.

6.3 Overlay of XG-PON or hybrid XG-PON

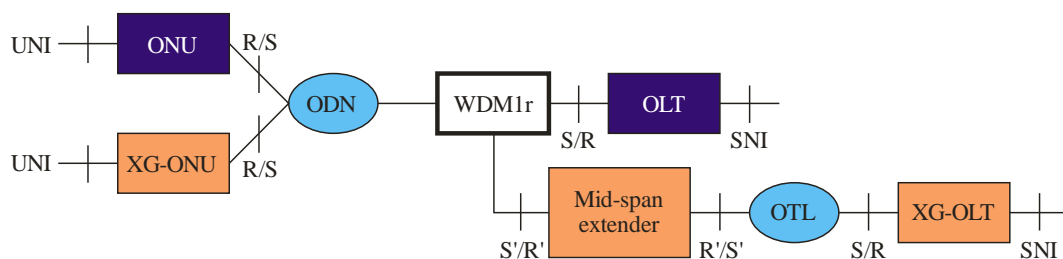
It is possible to overlay multiple XG-PONs on the same ODN to create even higher capacity using WDM. In such extensions, spectrum allocation is critical to make this overlay approach work. The requirement for overlaying XG-PON or hybrid XG-PON is for further study in a future revision.

6.4 RE architecture options

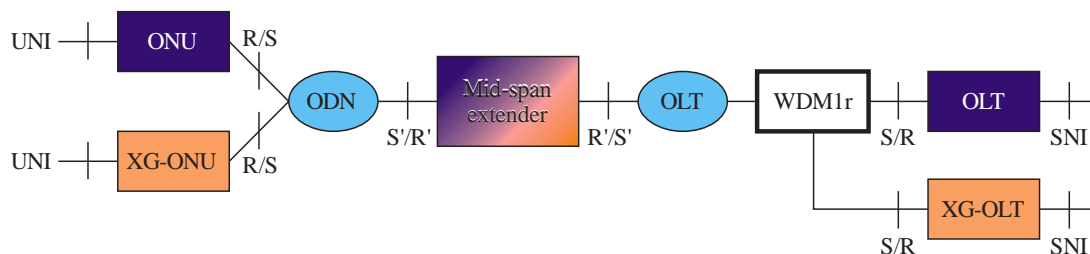
This clause focuses on mid-span architectures, since single-end solutions such as those described in [ITU-T G.984.6] will be part of each dedicated technology options and, as such, will be treated as OLT implementation options.

In the XG-PON world, two main architectures involving reach extenders are required, as described in Figure 6-2:

- one for deployments in which network consolidation will take place when migrating from G-PON to XG-PON;
- the other for deployments in which REs have already been deployed for the G-PON systems, in which case two situations will occur depending on the early RE technology deployed:
 - either the RE had from the start the capability to cover G-PON and XG-PON requirements; or
 - the early RE has to be replaced by what will onwards be called a "combo" RE.



Use case 1: G-PON / XG-PON Overlay with mid span XG-PON only extender



Use case 2: G-PON / XG-PON Overlay with a mid span extender

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Figure 6-2 – RE migration scenarios

The goal of using a mid-span RE is to provide additional optical budget with normal OLT and ONU performances, in order to enable, without it being at its maximum, the use of simultaneous full capability of the technology for both distance and split. The use of such REs must not require any change in the OLT and ONU requirements in order to avoid any interoperability issue. Many further options that are under development for [ITU-T G.984] will also be considered in the XG-PON environment, addressing the capability to save fibres in the OTL section. These are for further study.

7 Service requirements

7.1 Services

Telecommunication networks are evolving from traditional circuit-based networks to the packet-based (i.e., IP/Ethernet-oriented) next-generation networks (NGNs), which can effectively provide various services with a common platform (see [ITU-T Y.2201] and [ITU-T Y.2001]). In addition to emerging packet-based services, NGN also provides legacy services such as TDM and POTS using either emulation (complete replication of a legacy service) or simulation (providing a service that is almost the same as the legacy service).

NG-PON is required to fully support various services for residential subscribers, business customers, and mobile backhauling application through its high quality of service and high bit-rate capability. NG-PON should support legacy services, such as POTS and T1/E1 using emulation and/or simulation, as shown in Table 7-1, to harmonize with the concept of NGN.

- The emulation option delivers packet-formatted traffic through the PON network, i.e., from ONU to OLT, 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 CPE terminal adaptation device or ONU, to the NG-PON access and the NGN packet network.

Table 7-1 summarizes examples of NG-PON services.

Table 7-1 – Examples of NG-PON services

No.	Service		Remark
1	Telephony	VoIP	
2		POTS	Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. If echo cancellation is used in the network, the mean signal transfer delay time between T-V (or (a)-V) on the PON-based system may be longer, provided end-to-end transfer delay requirements are met. 8 kHz reference has to be provided. (see Note) Signal on the T reference point and V reference point must be continuous. Emulation and/or simulation, as defined in [ITU-T Y.2201], is assumed. e.g., packetized voice at ONU
3	TV (real-time)	IPTV	To be transported using IP multicast/unicast
		Digital TV broadcasting	Transported using RF-video overlay (see [ITU-T G.983.3], [ITU-T J.185] and [ITU-T J.186])

Table 7-1 – Examples of NG-PON services

No.	Service		Remark
4	Leased line	T1	Bearer rate is 1.544 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. Emulation is assumed primarily.
5		E1	Bearer rate is 2.048 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. Emulation is assumed primarily.
6	High speed Internet access		UNI is typically Gigabit Ethernet
7	Mobile backhaul		Accurate frequency/phase/time synchronization should be supported.
8	L2 VPN Services		such as Ethernet services, etc.
9	IP Services		such as L3 VPN, and VoIP, etc.
NOTE – See [ITU-T G.810], [ITU-T G.813], [ITU-T G.8261], [ITU-T G.703], and [ITU-T G.8262].			

For business applications, XG-PON should provide access to Ethernet services such as point-to-point, multipoint-to-multipoint and rooted-multipoint Ethernet virtual connection (EVC) services (also called E-Line, E-LAN and E-Tree, respectively). XG-PON shall also support accurate frequency/phase/time synchronization for the mobile backhaul application.

As a general requirement, XG-PON needs to support IPv6.

7.2 Maximum/mean signal transfer delay tolerance

XG-PON must accommodate services that require a maximum mean signal transfer delay of 1.5 ms.

Specifically, XG-PON systems must have a maximum mean signal transfer delay time of less than 1.5 ms between T-V (or (a)-V, depending on the operator's preference). See clause 12 in [ITU-T G.982]. Delays introduced by the adaptation functions such as circuit emulation are not included in this value.

Although a section of the delay measurement is T-V for FTTH system or (a)-V for the other application in [ITU-T G.982], in a XG-PON system, the reference points are not restricted by the system configuration.

7.3 Maximum Ethernet packet size

XG-PON technology shall support Ethernet frames having a maximum length of 2000 bytes. Jumbo frames with lengths beyond 2000 bytes and up to 9000 bytes (generally recognized as the upper limit for jumbo frames) should be optionally supported. If jumbo frames beyond 2000 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.

7.4 Synchronization features and quality

Network operators are motivated to leverage the XG-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 wireless.

XG-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, XG-PON shall provide a function to transfer the accurate phase/time information between OLT and ONUs taking into account 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. Table II.1 contains a summary of the synchronization requirements for different wireless technologies; see clause IV.2.2 of [ITU-T G.8261].

The mechanisms, for instance as specified in [ITU-T G.8261] and [ITU-T G.8262], for distributing accurate timing to the 3G/4G 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 ESMC messages transport over PON with IEEE 1588v2, are developed respectively in Appendices IV, V and VI.

7.5 Leased line T1/E1 emulation

T1/E1 emulation services require that the timing of the signal be similar at both ends of the packet network. There are four methods identified in clause 8 of [ITU-T G.8261], and they are:

- Network synchronous operation – this method relies on a PRC-traceable clock to be available at both ends of the packet network. This method does not preserve the service clock.
- Differential methods – this method encodes the difference between the service clock and the common reference clock and transmits it across the packet network. The service clock is recovered at the far end of the packet network by using a common reference clock available at both ends of the network.
- Adaptive methods – this method relies simply on packet arrival times (or inter-arrival times). Other forms of adaptive methods are available and are based on the use of time stamps and non-linear filtering to achieve better performance.
- Reference clock available at the TDM end systems – this method is a trivial case where both ends of the packet network has access to a timing reference.

Clause 9.1 of [ITU-T G.8261] specifies the maximum wander network limits for circuit emulation.

7.6 QoS and traffic management

XG-PON must be capable of supporting multiple existing and emerging services across multiple market segments, such as consumer, business, and mobile backhaul. Like G-PON, XG-PON must provide simultaneous access to packet-based services, such as high speed Internet access, IPTV, and VoIP, as well as legacy services, such as POTS voice and T1/E1. In addition, an XG-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) for business customers. These varieties of services present a broad range of QoS characteristics; therefore, they require systems to provide appropriate traffic management mechanisms.

For the POTS telephone services, XG-PON must support POTS voice quality with guaranteed fixed bandwidth to meet the low-delay and low-jitter requirements. Similarly, XG-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, XG-PON must provide at least four classes of services to map UNI flows. It is desirable for XG-PON to provide at least six classes of services to map UNI flows. XG-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 [DSLTF TR-156], XG-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 XG-PON to provide full MAC address learning for the whole Metro-Ethernet network. The XG-PON will utilize the Metro Ethernet network capability to provide full Ethernet services.

XG-PON must support any mix of residential, business, and mobile backhaul traffic within the same PON as illustrated in Figure 5-2. It must also support a mix of consumer and business users within a multiple subscriber ONU. XG-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.

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

8 Physical layer requirements

The XG-PON architecture is based on single fibre transmission.

8.1 Fibre characteristics

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

8.2 Optical wavelengths of XG-PON

To achieve a low cost implementation of such a compatibility feature, the retained wavelengths are:

- for the upstream, the "O- Band", ranging from 1260 to 1280 nm;
- for the downstream, "1577 nm", ranging from 1575 to 1580 nm (extension for outdoor is 1575 to 1581 nm).

8.3 Bit rates

XG-PON identifies two transmission speed sets named as follows:

- XG-PON1: nominally 10 Gbit/s down, 2.5 Gbit/s up;
- XG-PON2: nominally 10 Gbit/s down, 10 Gbit/s up.

The initial phase of this Recommendation only focuses on the XG-PON1 bit rate.

Due to the current technology challenges that need to be overcome to obtain low cost 10 Gbit/s upstream burst mode building blocks, XG-PON2 will be specified in a later phase.

8.4 Optical power budget

Coexistence of Gigabit PON and XG-PON on an ODN featuring a class B+ optical budget is the nominal requirement. With the additional loss introduced by the WDM1r device, two "Nominal" power budget classes between the two IF_{XG-PON} reference points in Figure 5-5 have been selected, i.e., Nominal1 (29 dB) and Nominal2 (31 dB) at BER of $1E-12$. In addition, coexistence of Gigabit PON and XG-PON on an ODN featuring C+ optical budget drives the extended power budget requirement, allowing for an additional split in the ODN with appropriate margins, or alternatively an increase in the supported system reach.

The detailed specifications for nominal classes and the extended class will be addressed in [ITU-T G.987.2].

Reach extender based optical budget extensions are discussed in the reach extender section.

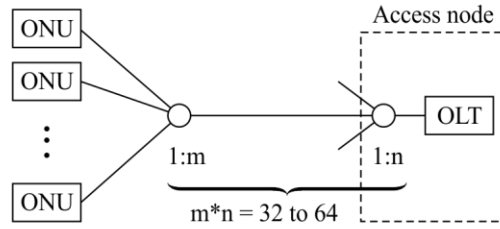
8.5 Split ratio

As many network operators have constructed their ODN infrastructure with 1:32 to 1:64 split for Gigabit PONs, 1:64 split (subject to the overall loss budget) shall be the minimum requirement for XG-PON to allow the coexistence described in clause 6. A generic splitter deployment of Gigabit PONs is shown in Figure 8-1 (a).

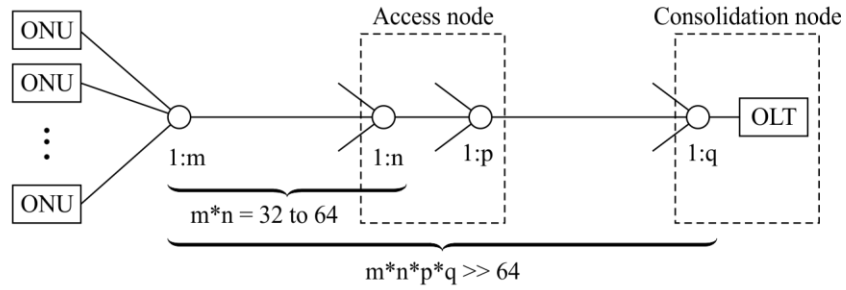
In this model, a single-split architecture is a special case, where $m = 64$ and $n = 1$ and no splitter is needed at the access node. Some network operators expressed their interest in extending the split beyond 1:64 (e.g., 1:128 to 1:256) to improve XG-PON overall economics compared to G-PON.

This high split ratio is very attractive especially for the 'service-independent introduction scenario'. The higher splitter ratio allows to extend PON in the backhaul section as shown in Figure 8-1 (b) and/or to extend PON towards the end users as shown in Figure 8-1 (c) to provide flexible splitter configurations and efficiently support a variety of deployment scenarios. Considering these options, the XG-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 Figure 8-1 (b) and Figure 8-1 (c), in addition to extending the system nominal reach.

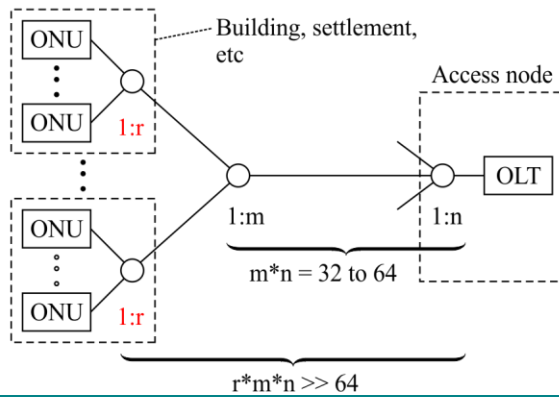
(a) Generic configuration



(b) Support of extra split in higher access network level



(c) Support of extra split in lower access network level



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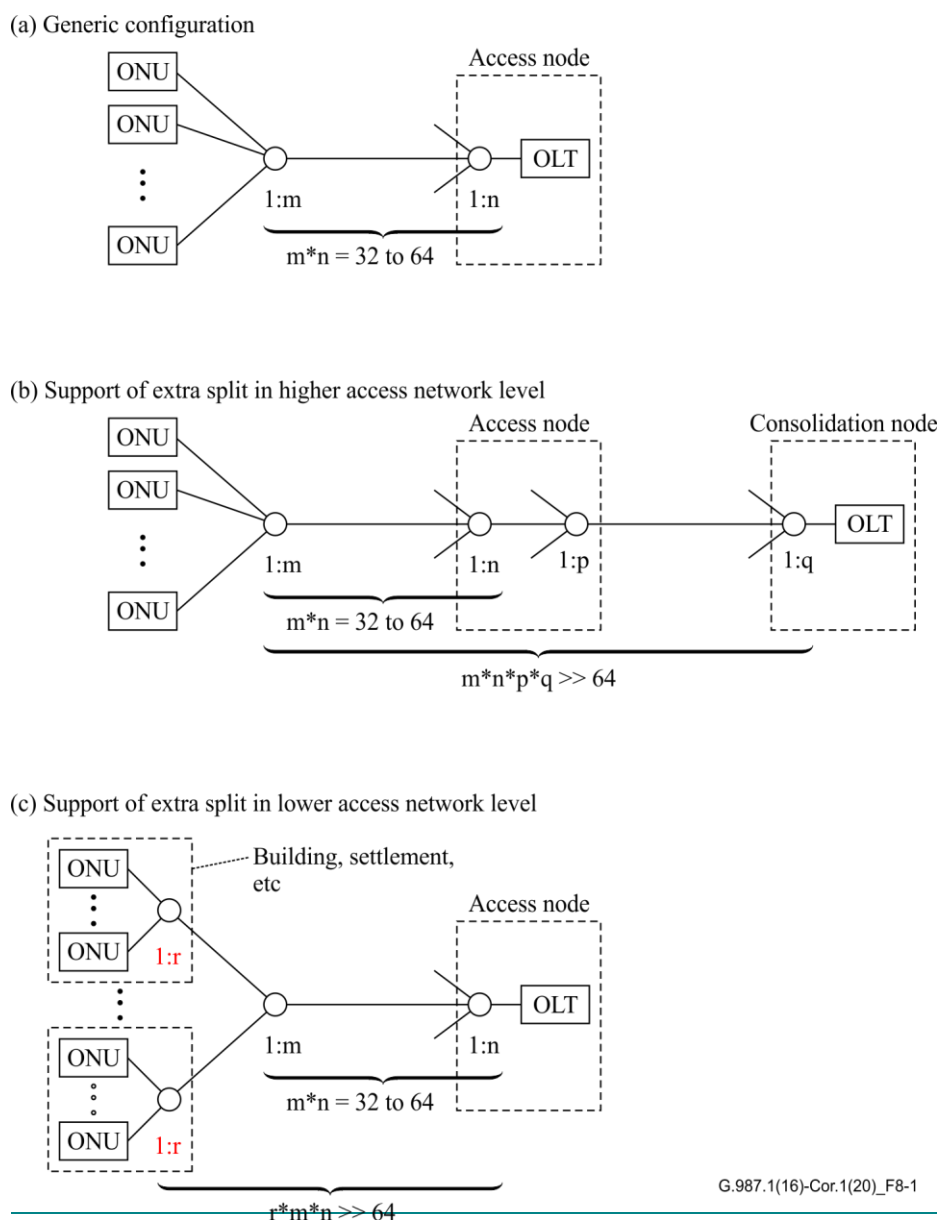


Figure 8-1 – XG-PON splitter architecture options

8.6 Fibre distance

[ITU-T G.987] introduces the concept of fibre distance and max differential fibre distance.

XG-PON1 must support the maximum fibre distance of at least 20 km.

In addition, XG-PON1 TC layer needs to support the maximum fibre distance of 60 km. XG-PON1 TC layer also needs to support the maximum differential fibre distance of up to 40 km. XG-PON1 TC layer also needs to be able to configure the maximum differential fibre distance with a 20 km step.

9 System level requirements

9.1 Power saving and energy efficiency

Power saving in telecommunication network systems has become an increasingly important concern in the interest of reducing operators' OPEX and reducing the network contribution to greenhouse emission gasses. The primary objective of the power saving function in access networks is to keep providing the lifeline service(s) such as a voice service as long as possible through the use of a backup

battery when electricity service goes out. For example, some operators require a minimum sustainability for a lifeline interface to operate for 4 to 8 hours after mains outage. Therefore, the XG-PON TC layer shall support better energy efficiency than the [ITU-T G.984] G-PON TC layer whenever compatible with the service requirements, based on the mechanisms derived from [b-ITU-T G-Sup.45]. The secondary goal is to reduce power consumption at all times. It is also an important requirement that we should not sacrifice service quality and user experience.

Full service mode, dozing mode, and sleep mode 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 XG-PON, [b-ITU-T G-Sup.45] compares the efficiency of each power saving technique as well as the level of service impact.

9.2 Authentication/identification/encryption

Like G-PON, XG-PON 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 and identification mechanisms must be standardized. Use of these mechanisms is optional and will be determined by the operators. They shall include, but will not be limited to:

- identification of ONU serial number and/or a registration ID used for the ONU registration process;
- authentication of CPE, based on [b-IEEE 802.1X];
- a strong authentication mechanism is required.

A simple but secure identification 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., AES. Therefore, XG-PON shall also provide a reliable key exchange mechanism that is necessary to start an encrypted communication. In the upstream direction the encryption function shall be optional, and implemented upon each operator's requirement.

9.3 Dynamic bandwidth assignment (DBA)

The XG-PON 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 two 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.

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.

The OLT may support any of the dynamic activity indication methods or a combination thereof. It is outside the scope of the requirement specification to define which specific methods have to be supported, or how the OLT utilizes the obtained dynamic activity indication information, or how the OLT upstream scheduler is implemented.

DBA spreading across several upstream wavelengths in case of overlay XG-PONs or redundancy through dual homing is out of the scope of this Recommendation.

9.4 Eye safety

Given the higher launched optical power that can be injected on the fibre in the XG-PON era, both at the OLT and the RE level, all necessary mechanisms must be provided to insure that no eye damage can be caused to the end users unaware of the risks, especially if fibre is terminated inside the home. The XG-PON 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 Operational requirements

10.1 ONU management

10.1.1 OMCI managed ONU

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

10.1.2 Dual managed ONU

XG-PON shall optionally support collaborative ONU management partition between XG-PON OMCI and remote configuration mechanisms.

10.2 PON supervision

While it is most important to minimize capital expenditure in the initial stage of FTTH deployment, it is getting 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 XG-PON.

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. Several key points for the supervision of XG-PON can be summarized as follows:

ODN monitoring/checking: Monitoring and on demand checking the condition of ODN independently from a PON system is important to differentiate ODN failures from system failures. It is desirable that such monitoring and checking be available regardless of whether the ONU is in

service or even connected. An optical time domain reflectometer (OTDR) is a powerful tool for diagnosing such faults in the ODN, and a power meter and light source can be used to aid in the process. Several demarcation devices are under research for further improving the ODN monitoring and checking.

XG-PON systems would benefit from an ability to automatically and autonomously detect and locate ODN faults. This is especially critical for the feeder section between the serving CO and the first-stage splitter, the length of which can be up to 60 km if an 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 monitoring and 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 on how to use PON status reports.

Coexistence of G-PON with XG-PON via WDM1r: It is desirable to immediately localize any problems in the case of Gigabit PON and XG-PON coexistence. Interworking of the supervision function between Gigabit PON and XG-PON is one possibility here, but further studies are necessary.

11 Resilience and protection on ODN

Service resilience over previous generations of PONs has not been a strong requirement from operators. XG-PON is required to support a diverse range of high value services (e.g., IPTV) for residential and also business applications with increasing levels of system integration at the head-ends. Failures in the shared portions of the PON will impact multiple customers and services. Consequently, the capability to offer improved service availability figures in XG-PON systems will become increasingly important.

Individual operators need to determine the best resilience architecture for their specific market and geography. As such, XG-PON should include a range of cost-effective resilience options with both duplex and dual-parented duplex system configurations, as defined in clause 14 of [ITU-T G.984.1], as well as the extensions described in Appendices II and III of that same Recommendation. These resilience schemes should be options available on XG-PON 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 XG-PON 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., LTE (Mobile's 4G standard also known as long term evolution), for backup for better economics. Further information on protection switching can be found in [ITU-T G.808.1].

Appendix I

Examples of practical XG-PON system architecture

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

This appendix provides various examples of practical XG-PON system aspects. First, a review of the typical external interfaces (e.g., UNIs and SNIs) a XG-PON system supports is given. Second, a selection of system architectures is illustrated. Third, the common protocol stack traces are laid out for all these services and systems.

It should be noted that since XG-PON can address multiple market segments, e.g., consumer, business, and mobile backhaul and the overall scope of all the variants is very large, any single implementation of an ONU will not implement all of the possible features. The objective of this appendix is only to give a comprehensive overview of the options that might be encountered.

I.1 Services, UNIs and SNIs

I.1.1 Examples of services

The examples of services that XG-PON can offer are described in clause 7.1.

I.1.2 Examples of UNI

In this appendix, UNI is defined as the interface that includes the following conditions:

- 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.

Examples of UNIs, physical interfaces and services that they provide are shown in Table I.1.

Table I.1 – Examples of UNI and services

UNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
1000/100/10BASE-T [b-IEEE 802.3]	–	Ethernet
[b-ITU-T Q.552]	–	POTS
[ITU-T G.703]	PDH	DS3, E1, E3
[b-ATIS 0900102] and [b-ATIS 0600107]	PDH	T1, DS3
NOTE 1 – There are many other services accommodated in XG-PON, 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.		

I.1.3 Examples of SNI

In this appendix, SNI is defined as the interface that includes the following conditions:

- described by a well-known standard;
- includes a physical layer aspect.

Examples of SNIs, physical interfaces and services that they provide are shown in Table I.2.

Table I.2 – Examples of SNI and services

SNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
1000BASE- [b-IEEE 802.3]	—	Ethernet
10 GigE [b-IEEE 802.3]	—	Ethernet
40 GigE [b-IEEE 802.3]	—	Ethernet
100 GigE [b-IEEE 802.3]	—	Ethernet
[b-ITU-T G.965]	V5.2	POTS,
[ITU-T G.703]	PDH, STM-1e	DS3, E1, E3, STM-1, DS1
[b-ITU-T G.957]	STM-1,4,16	E1, E3, DS1, DS3, GFP, E4, STM-n
[b-ATIS 0600107]	PDH	DS1, DS3
<p>NOTE 1 – There are many other services accommodated in XG-PON, but those services do not have specified SNIs.</p> <p>NOTE 2 – Each item in the "Physical interface" column is illustrated by the corresponding entry in the "SNI" column.</p> <p>NOTE 3 – The column labelled "Service" shows which services can be supported by the physical interface.</p>		

I.2 Typical system architectures

Figure I.1 shows a generic XG-PON system. This system will be developed more specifically in the next six figures. Note, these figures are illustrative examples, not requirements.

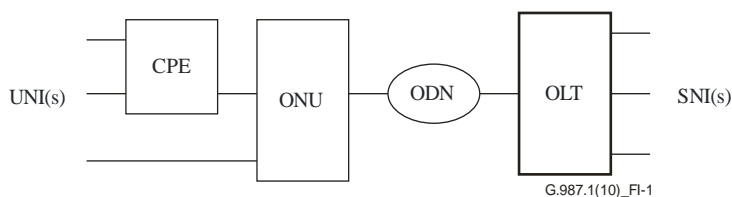


Figure I.1 – Generic XG-PON system

I.2.1 OLT variants

Figure I.2 shows a pure Ethernet OLT option. In this case, the OLT equipment contains only the XG-PON adaptation function, and typically (but not necessarily) some level of Ethernet aggregation function. It is the simplest form of OLT, and avoids as much specific service linkages as possible.

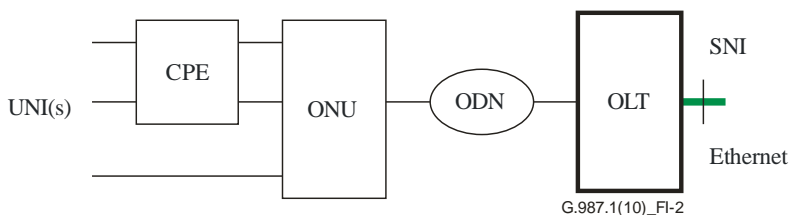


Figure I.2 – Pure OLT scenario

Figure I.3 shows a grooming OLT scenario. In this case, the OLT takes on additional service grooming functions, typically including voice gateway and TDM circuit emulation functions. Note that these services can be provided using a 'pure OLT' and a separate voice gateway.

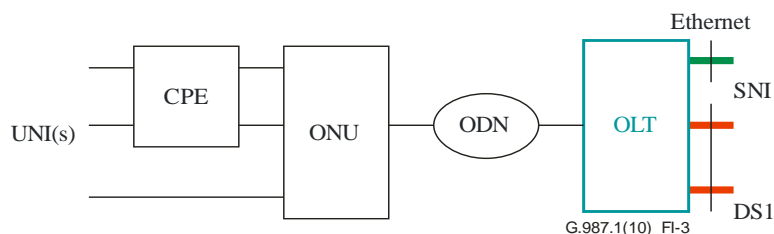


Figure I.3 – Grooming OLT scenario

I.2.2 ONU variants

Figure I.4 shows the 'VDSL/POTS ONU' variant. The distinguishing feature of this variation is that the ONU is used to create copper-based interfaces just like a digital loop carrier/digital subscriber line access multiplexer (DLC/DSLAM) would do. There are two sub-types of this scheme. The first is where the ONU provides both POTS and VDSL interfaces to the customer, trying to centralize functions and reduce the need for CPE. The second is where the ONU provides VDSL-only interfaces, trying to minimize the ONU's size and power, albeit at the cost of requiring POTS derivation at the CPE. This alternative is useful mostly in FTTB and FTTC applications.

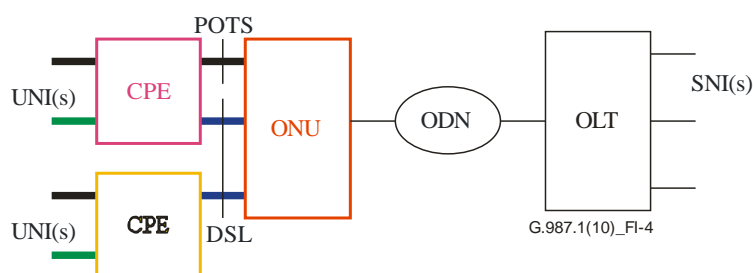


Figure I.4 – VDSL/POTS ONU scenario

Figure I.5 shows the 'XG-PON Modem' variant, where the ONU is made as small and simple as possible. In this case, it resembles a modem that provides layer 1 and 2 interworking between the XG-PON optical interface and the data link technology. The data link then carries all service flows to the CPE, which does the bulk of the service interworking function. The popular data link technologies in use today are Cat5-based Ethernet, HPNA-over-Coax, and MoCA. This system is mostly used in FTTH applications.

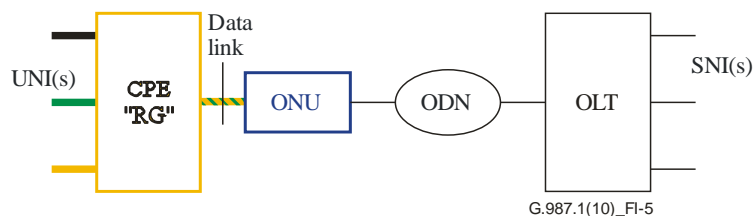


Figure I.5 – XG-PON modem scenario

Figure I.6 shows the 'integrated ONU' situation. This can be thought of as the merger of the XG-PON modem and the service-deriving CPE in the previous diagram. However, this merging of functions has critical implications on what system is responsible for the management of the services. It should also be noted that even though significant functions have been incorporated into the ONU, a CPE is typically still placed in the home. This scenario is also popular for FTTH.

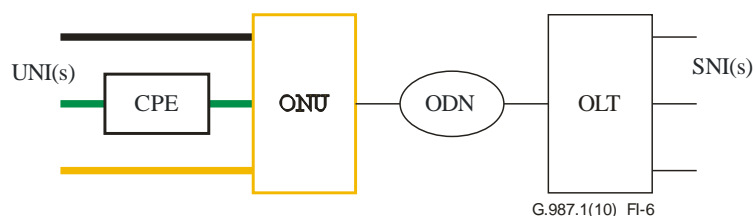


Figure I.6 – Integrated ONU scenario

Figure I.7 shows the 'Residential gateway ONU' situation. This can be thought of as the merger of the integrated ONU and the service-deriving CPE in the previous diagram. This draws layer 3 functionalities into the ONU, including such items as routing, NAT, and firewall functionality. This scenario is also popular for FTTH.

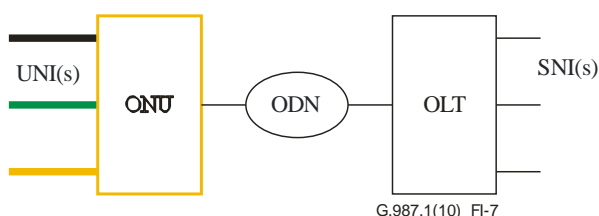


Figure I.7 – Residential gateway ONU scenario

I.3 Service protocol stacks

This clause describes a list of protocol stacks for the important service traces in XG-PON systems. By service, we mean the basic layer 2-3 interfaces that have major impact on XG-PON equipment. Many high-layer services can ride on top of these interfaces; however, they tend not to have such a concrete impact on the XG-PON equipment, or at least, not an impact any different than any other access system.

I.3.1 Common functions

The common XG-PON layers are shown in Figure I.8. [ITU-T G.987.2] specifies the XG-PON physical medium and the physical media dependent layer (optics). [ITU-T G.987.3] defines the transmission convergence layer, which deals primarily with the construction of the transmission frame, and the encapsulation of payload datagrams inside XG-PON encapsulation method (XGEM) fragments. There is a wealth of other auxiliary features described in [ITU-T G.987.3], including the PLOAM channel, dynamic bandwidth allocation, and the PON-level QoS frameworks that are possible.

It should be noted that the DBA algorithm is not specified in any standard, but this is not an interoperability issue, and the non-specification has been intentional.

The QoS system in the XG-PON defines a scheme where each ONU may contain one or more transmission containers (T-CONTs). Each T-CONT may contain one or more XGEM Ports, which are the smallest connection entity that XG-PON systems handle. Similar to [ITU-T G.984.3], [ITU-T G.987.3] may leave the arrangement of T-CONT and GEM Ports open for the flexibility. It is expected that a similar arrangement as the current mainstream arrangement of the four service-bearing T-CONTs per ONT per service category, with each T-CONT representing a different class of service will be followed.

[ITU-T G.988] defines the ONU management and configuration interface (OMCI). It defines both a management information base (MIB) for all the functions controlled in the ONU, as well as the ONU management communication channel (OMCC) that provides all the mechanisms required for the OLT to provide FCAPS functionality for the ONU.

The OLT management is a somewhat more complex object. It contains by proxy all the MIBs of all the ONUs supported by that OLT, as well as all the other MIBs that describe the other functions in the OLT. This MIB is defined by several standards groups, including the Internet Engineering Task Force (IETF) and the Tele-management forum (TMF). Typically, these MIBs are accessed using standard IETF defined protocols (SNMP over TCP/IP). Most OLTs provide a dedicated interface for this management traffic.

All of the functions mentioned above are common functions involved in all of the service traces that follow. They will be more compactly represented in the later diagrams for the sake of brevity.

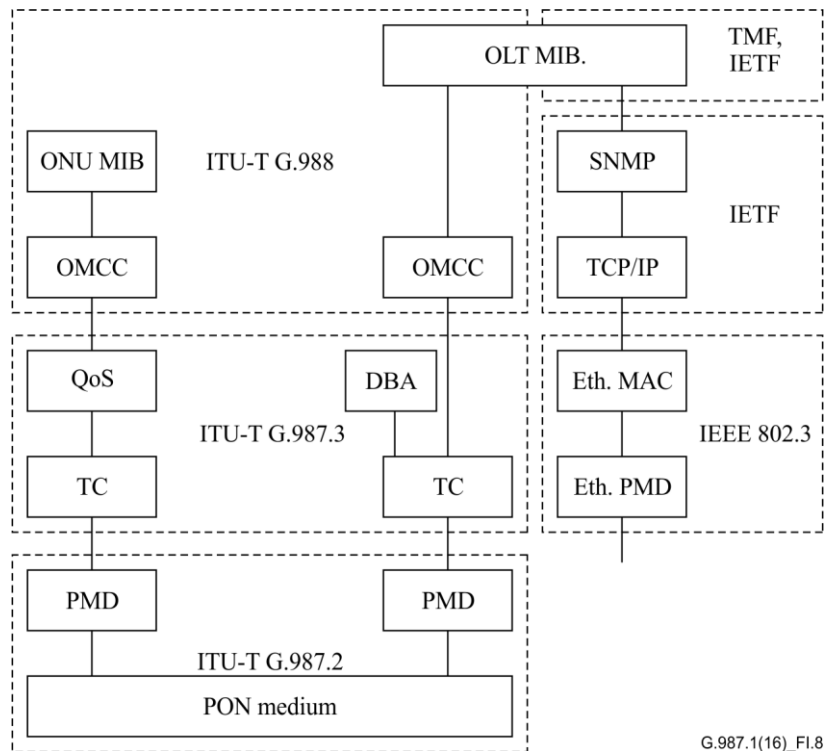


Figure I.8 – XG-PON common functions

The XG-PON real-time management clock service is shown in Figure I.9. The OLT receives real-time clock data (typically using NTP, over an Ethernet interface via UDP over IP). The OLT thereby maintains its own internal RTC, which it uses to time-stamp all manner of event data. Other methods of establishing the OLT RTC are possible, see Figure I.11.

The ONU does not extend this RTC for the purposes of management. Rather, its performance monitoring and event collection processes are synchronized with those of the OLT via the OMCI. The OLT routinely collects all of this data every 15 minutes, and logs it with the OLT RTC.

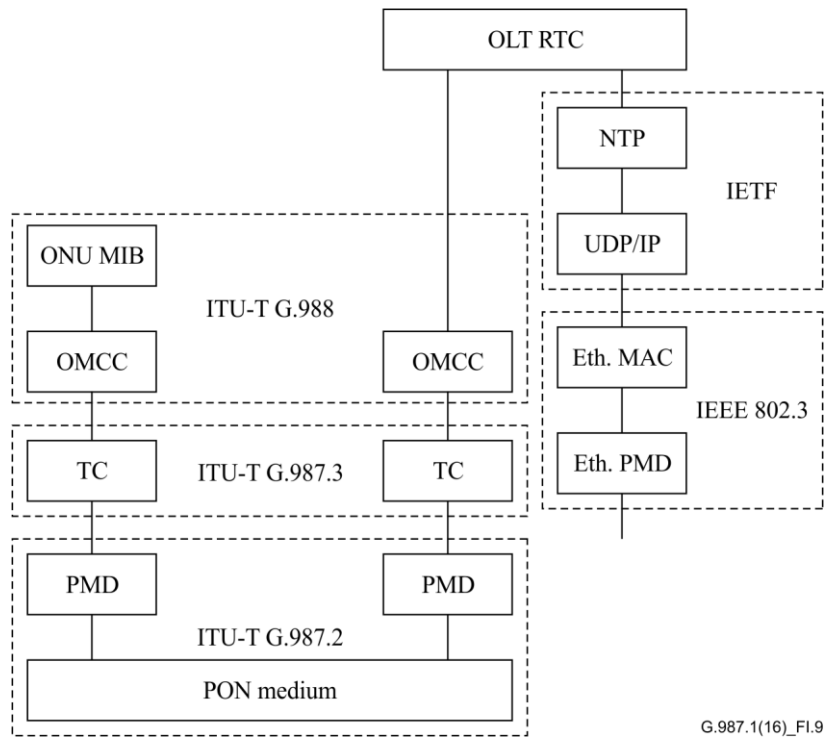
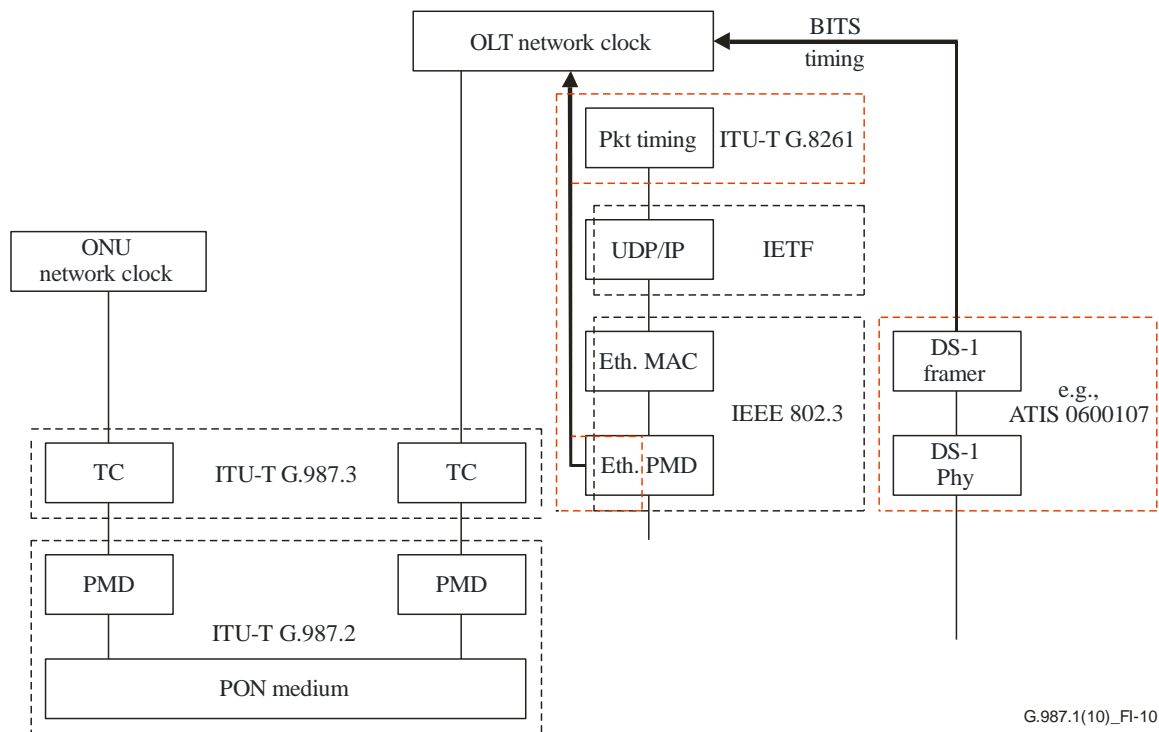


Figure I.9 – Real-time management clock service

The XG-PON network clock scheme for passing frequency synchronization to ONU is shown in Figure I.10. The OLT needs to obtain a high quality traceable timing clock, which serves as the master for all XG-PON interface timing. The normal source for the OLT's clock is a BITS timing input. However, in cases where a BITS source is not available, then an alternative method is needed. The alternative could be synchronous line timing from an SNI that is traceable to the network clock, or a packet-based timing.

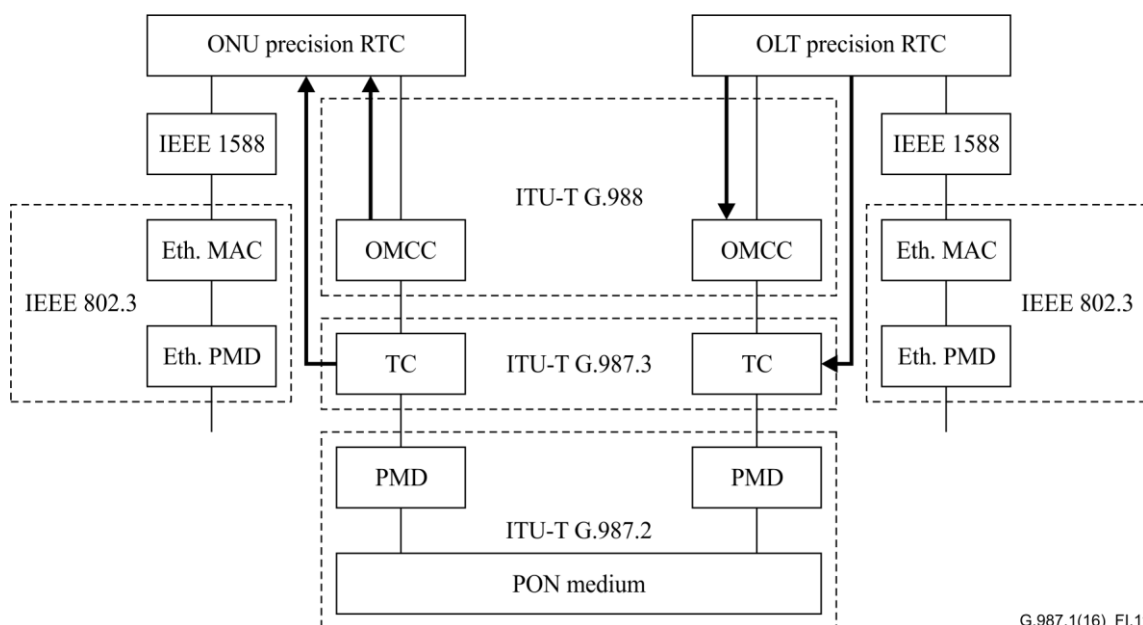
Once the OLT network clock is established, it is used to source timing to the XG-PON interfaces, which in turn distribute timing to the counterpart ONU XG-PON interfaces. The ONU equipment then obtains its network clock from the XG-PON interface. This timing signal is ideal for TDM service interworking functions that are integrated into the ONU. Typically, this timing signal is not available at UNI. However, if the timing signal is provided to the terminal adapters, then among many synchronization methods, the synchronous Ethernet method provides more precise synchronization.



G.987.1(10)_FI-10

Figure I.10 – Example of network clock service

For applications where the ONU requires a very accurate real-time clock with phase errors in the nanoseconds range, the following precision real-time clock is defined. The OLT obtains a precise real-time clock, typically using [IEEE 1588], optionally with some additional assistance of the previously mentioned network clock service. The OLT then passes this clocking information to the ONUs using a combination of the TC layer and the OMCI layer. The ONU can then calculate the precise time, and establish its precision RTC. If the ONU must pass the precision RTC on to client equipment, it can support the [IEEE 1588] protocol towards the UNI side.



G.987.1(16)_FI.11

Figure I.11 – Precision real-time clock service

I.3.2 Data functions

The layer shown for Ethernet service is shown in Figure I.12. In the ONU, Ethernet frames as defined in [b-IEEE 802.3] are extracted from the TC layer. In some ONUs, the Ethernet layer is quite abbreviated, and little processing is done on the frames from their reception on the XG-PON interface to their transmission on the UNI. In other ONUs, true bridging is performed, with MAC address processing, and potentially more. In some cases, PPPoE (not shown) is supported; however, this scheme seems to be waning.

OLT and ONU share the responsibility of access node VLAN requirement defined in Broadband Forum document [b-DSL TR-101]. To enhance the interoperability of G-PON, [DSL TR-156] further provides the guideline on specific VLAN operations at G-PON OLT and at ONU for 1:1, N:1, and VBES services defined in [b-DSL TR-101]. In general, this guideline should be applied to XG-PON as well.

For N:1 service, ONU adds an S-tag to upstream un-tagged frame, or translate the customer Q-tag to an S-tag, then OLT will pass through the S-tagged frame to the upstream.

For 1:1 service, ONU always adds a tag to untagged frames or translates an incoming Q-tag in the upstream direction. In the case of single tagged VLAN at the V interface, OLT will pass through the S-tag added by ONU to the upstream. In the case of double tagged VLAN at the V interface, the OLT adds an S-tag on the top of the C-tag that the ONU provided.

For the VBES service, the U interface can be untagged, single tagged, or double tagged. For the untagged or single tagged frame, the ONU adds the S-tag, and the OLT passes through the tag just like in the N:1 model. For the case in which customer frames are double tagged, the frames with valid S-tags are accepted and may be translated to a new S-tag at ONU, and then passed through the OLT.

The traffic leaves the OLT going into the network over some type of Ethernet interface, for connection to an edge routing device or other Ethernet aggregation devices.

It should be noted that there are several different interfaces that can take the place of an Ethernet Physical interface. These include xDSL (e.g., see below), MoCA, HPNA, HPNA-over-Coax, 802.11 Wi-Fi, and perhaps others yet to be devised. However, due to Ethernet's pervasive nature, all of these alternative PHYs are defined so that they operate nearly the same as Ethernet, and so their impact on the XG-PON system is rather small.

All of these ONU features are controlled via the OMCI, as defined in [ITU-T G.988].

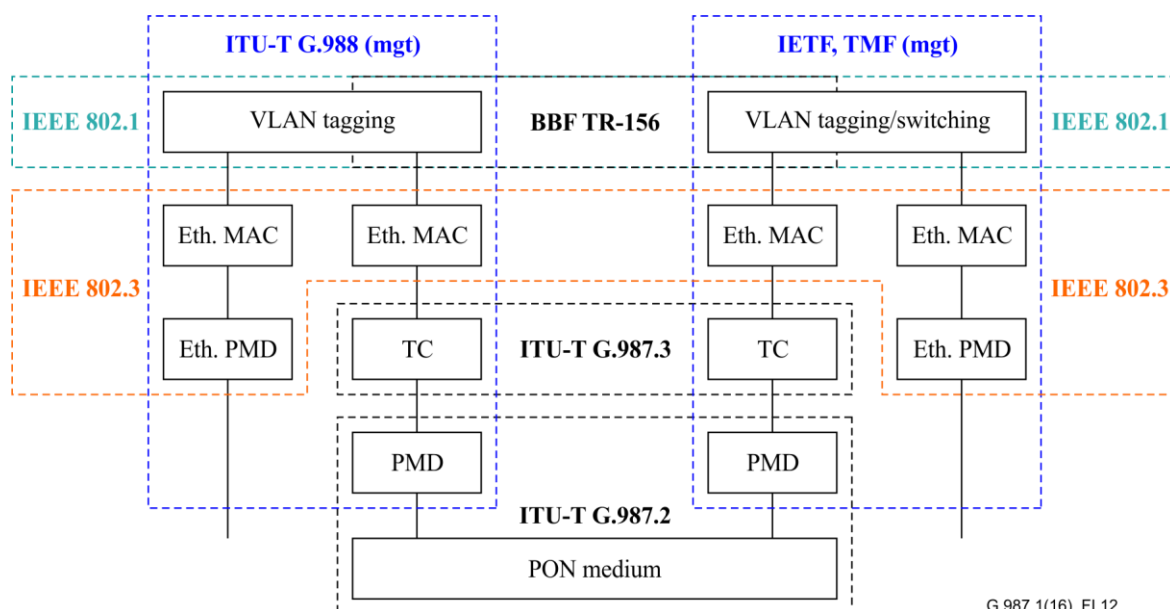


Figure I.12 – Ethernet data service

The VDSL2 service is shown in Figure I.13. The first thing to be said is that the DSL type that is most relevant for XG-PON is VDSL2 (defined in the [b-ITU-T G.993.x] series of Recommendations), using packet transport mode. It is possible that ADSL2+ or VDSL1 might be implemented for compatibility reasons; however, it will not be the main thrust of most XG-PON development. With this said, the VDSL2 VTU-O function in the ONU operates as an Ethernet PHY, and most of the layer diagram is similar to that of an Ethernet service. There are important differences, the biggest of which is the presence of multiple bearer channels in the same port. Each of these bearers would be treated as a 'virtual PHY', and the overall system is still unchanged.

The management of the VTU-O located in the ONU is described in [ITU-T G.988].

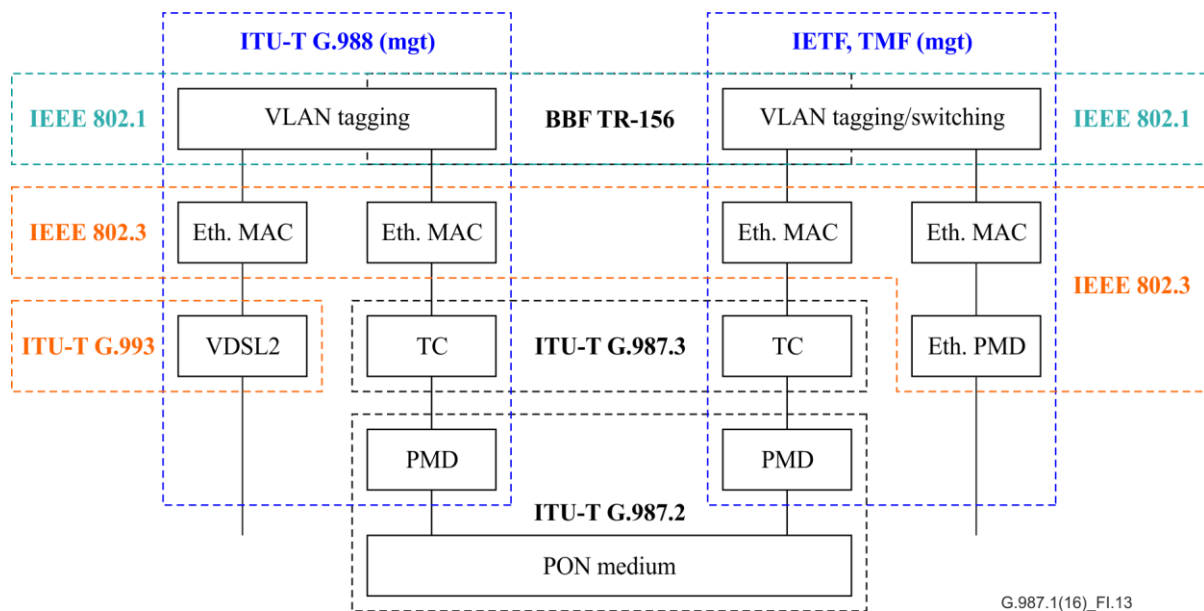


Figure I.13 – VDSL2 service

Figure I.14 describes the multicast service. This is really a logical service, usually provided in conjunction with an Ethernet UNI (or similar). However, it has impact on the XG-PON system, so it is included here. The multicasting interactive signalling is provided by the [IETF IGMP], versions 2 or 3 for IPv4, and MLDPv2 for IPv6. This IP-layer multicasting topology is typically translated into Ethernet-layer multicasting via the trivial mapping defined in the IEEE 802.1 standards. The management of multicasting, including the eligibility of UNIs to receive multicast traffic, the XG-PON ports that contain the multicast traffic and their interconnection are defined in [ITU-T G.988].

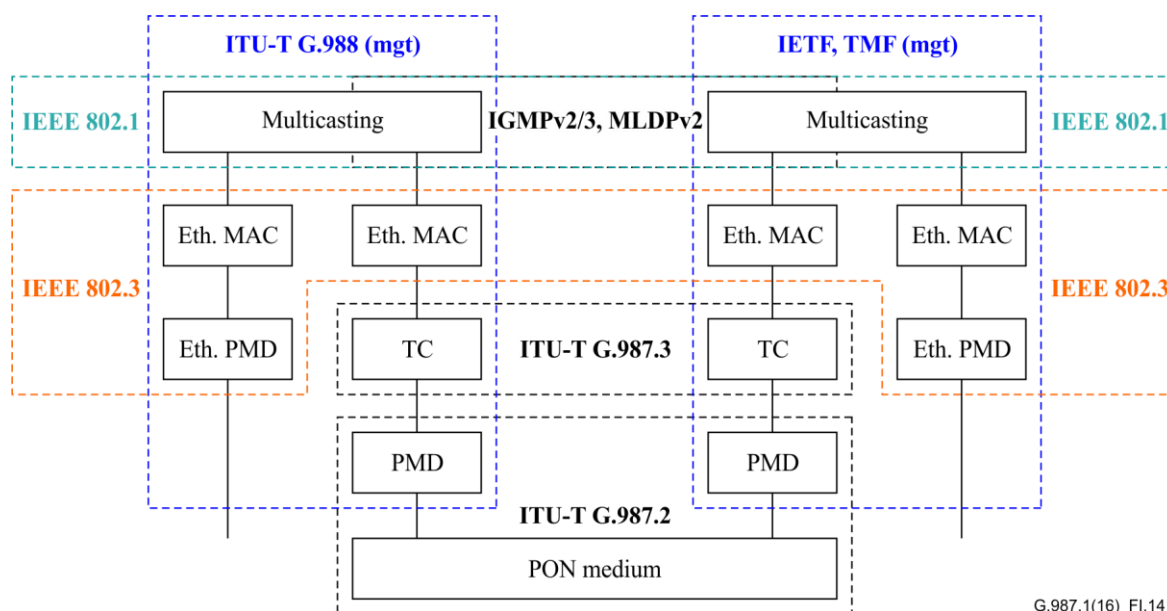


Figure I.14 – Multicast service

I.3.3 Voice functions

The packet-based voice service flow is pictured in Figure I.15. By packet voice service, it is understood a voice service that does not terminate on a class 5 TDM switch but instead is transported via an IP network to its destination. The mainstream protocol system used in this scenario is SIP, running over RTP/UDP/IP, all defined in the IETF documents. This is easy to say, but because SIP-based VoIP aims to replace the class 5 switching system, it must therefore implement the sizable set of voice service features. A great deal of interoperability engineering must be done in any combination of VoIP-ONU and Softswitch.

The voice CODECs are defined in the [b-ITU-T G.711.x], [b-ITU-T G.729.x], [b-ITU-T G.726.x], and [b-ITU-T G.723.x] series of Recommendations. It should be noted that while the majority of VoIP systems are actively exploring advanced CODECs for compression reasons, XG-PON is not concerned with this, since bandwidth is plentiful. In contrast, the codec selection here is mainly driven by interoperability with the far end of the SIP VoIP session.

The POTS UNI is defined for the large part by national standards (e.g., European operators use [b-ETSI ETS 300 001]). However, it must be noted that POTS remains a very intricate service, and many operators have special requirements on the POTS interface, particularly on the lowest-level mechanical and electrical specifications of the metallic interface.

From the SIP agent in the ONU, the service flow traverses a path very similar to the standard Ethernet service. The user traffic, both bearer and signalling, leaves the OLT via an Ethernet interface, usually shared with other services.

The management of the packet voice service may be varied. [ITU-T G.988] provides a full FCAPS support of SIP VoIP. However, there are several other in-band systems that are in-play, such as [b-DSL-F TR-069], IETF sipping, and various proprietary configuration servers. These in-band systems are good in that they can manage VoIP terminal adapters, especially for the in-home unit, anywhere on a network, so they have a wide reach. However, most suffer from poor practical standardization, and a lack of interactive features (such as the support of alarms and performance management). To help address this last point, even when an in-band system is used for configuration of VoIP, the OMCI can still be used to gather alarms and PM information. This is basically a mixed management system.

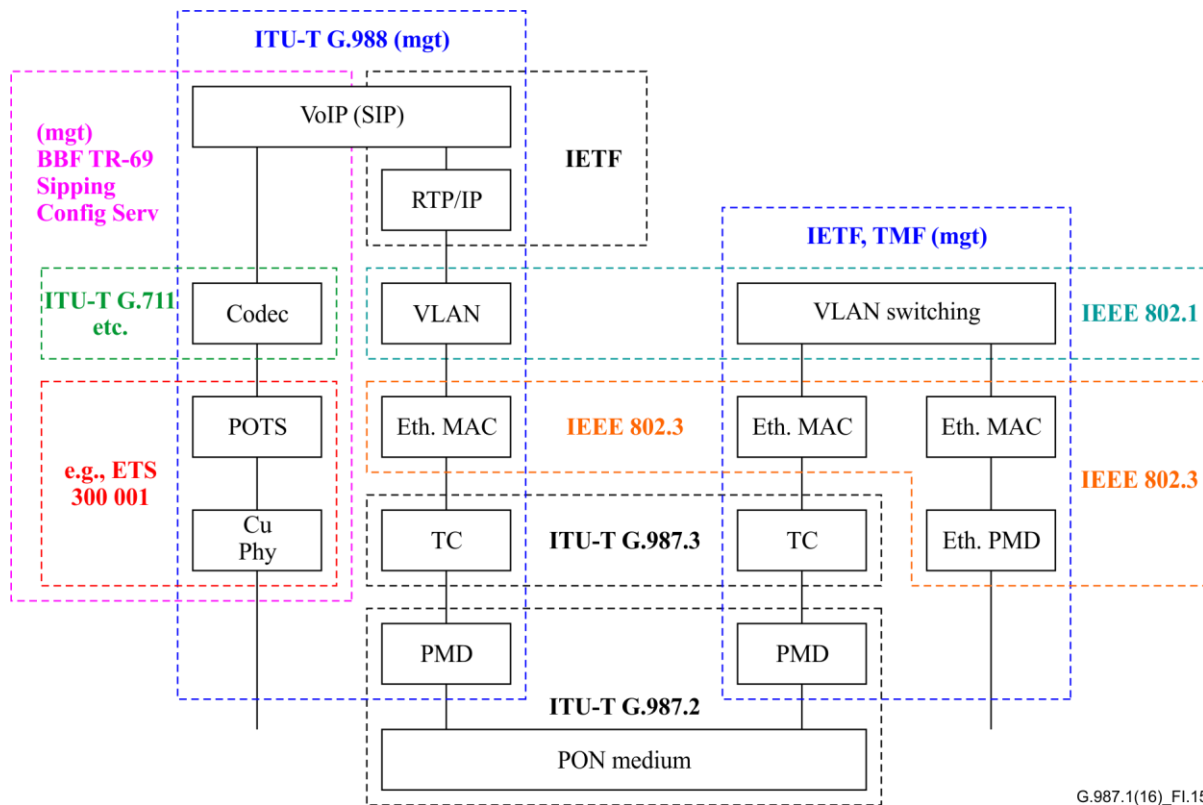


Figure I.15 – Packet voice service

The protocol stack diagram for the circuit-switched voice service is shown in Figure I.16. In this scenario, VoIP is being used to transport the voice signals from the ONU to the class 5 TDM switch in the central office, and no further. The protocol used in this case is usually ITU-T H.248, since this system is suited to voice gateway interfaces, of which the ONU and OLT or possibly an aggregated uplink node each has one.

At the ONU, from the codec and below, the arrangement is exactly the same as in the packet voice case.

At the OLT or possibly an aggregated uplink node, the ITU-T H.248 flow is terminated, usually in a special purpose voice gateway module. This module's function is to regenerate the customer's voice interface, and format the data representing that interface in the way that a conventional DLC system would, as defined by the appropriate regional standard (e.g., V5.2). This interface, most commonly carried physically by DS1 or E1 interfaces, can then be tied directly into a class 5 switch with integrated DLC interfaces. The whole intent is to minimize the impact of the XG-PON deployment on the normal operation of voice services in the central office.

The management of this kind of VoIP also has the potential for standard overlap, since all the options are available for ITU-T H.248 ONUs. However, the OMCI method is used quite often in this case, since the advantages of the in-band system all but disappear for this scenario. The OMCI is a self-contained solution for the management of voice services on XG-PON, and seems an easy choice in this scenario.

There are additional combinations of transport protocols, functional architectures, and management protocols possible. The intent of the two illustrations here is to highlight the most active combinations.

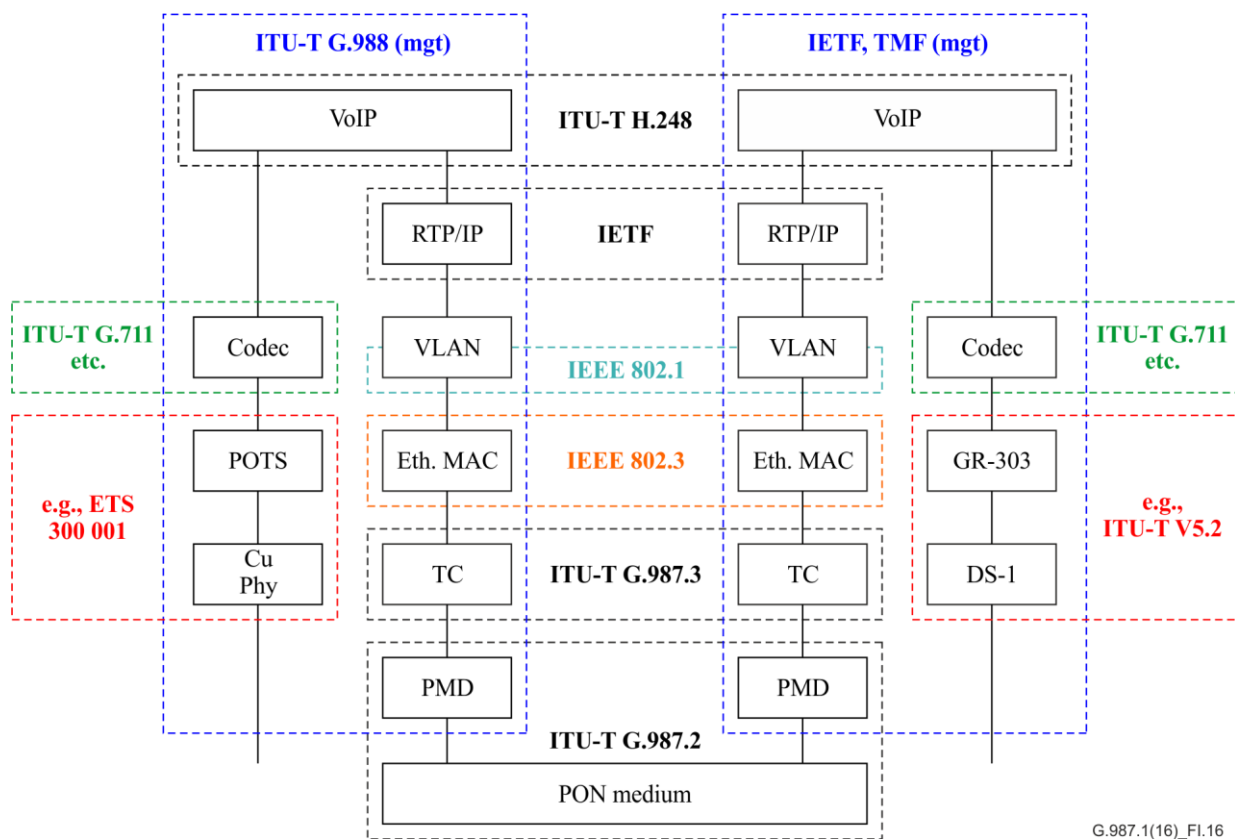


Figure I.16 – Circuit-switched voice service

I.3.4 Circuit emulation functions

TDM interfaces can also be supported over packet transport on XG-PON, as shown in Figure I.17 and Figure I.18 (note the DS-1/E1 framer would not be required for a transparent T1/E1 service). There are several options that can be exercised here. The first involves the transport of the actual TDM payload, using either a variant of the [IETF PWE3] system of protocols, or the Metro Ethernet forum's MEF-8 protocol. The second involves the use of a local OLT TDM interface, or the use of a packet interface on the OLT leading to a gateway somewhere else in the network. This would seem to present quite a large set of alternatives, but in practice it has turned out not to be a big issue because most hardware supports nearly all of the options. So, interoperability is mostly a matter of negotiating the transport protocol. Circuit emulation may also require a network clock to be delivered to the PWE3 interworking functions. Differential timing mode supports better jitter/wander performance than adaptive mode.

The XG-PON core, up to and including the VLAN layer is similar to the typical Ethernet service.

The actual TDM interfaces are defined in, for example, [ITU-T G.703] for DS1 and E1 interfaces, or the appropriate regional standard (e.g., [b-ATIS 0600107] for DS1 interfaces, and [b-ETSI ETS 300 166] for E1 interfaces).

The management of either PWE3 or MEF-8 interworking is described in [ITU-T G.988].

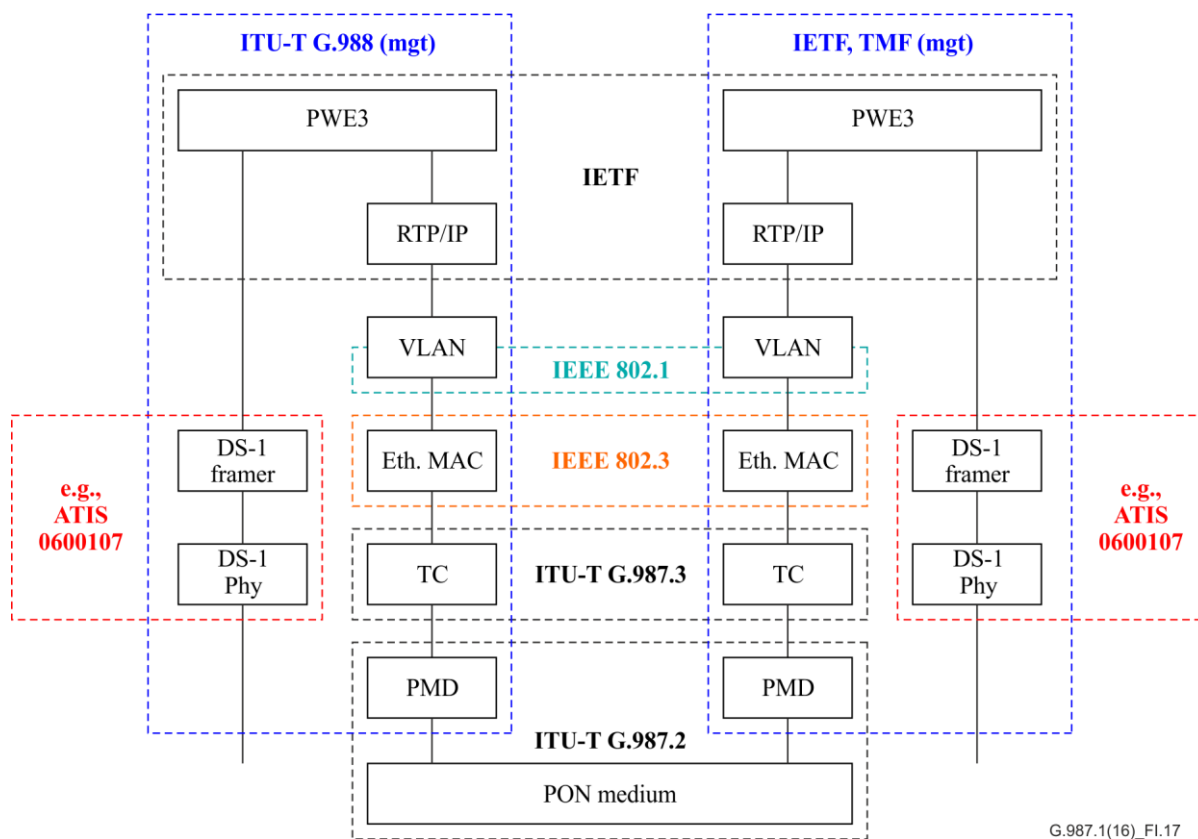


Figure I.17 – Packet TDM service using PWE3 and grooming OLT

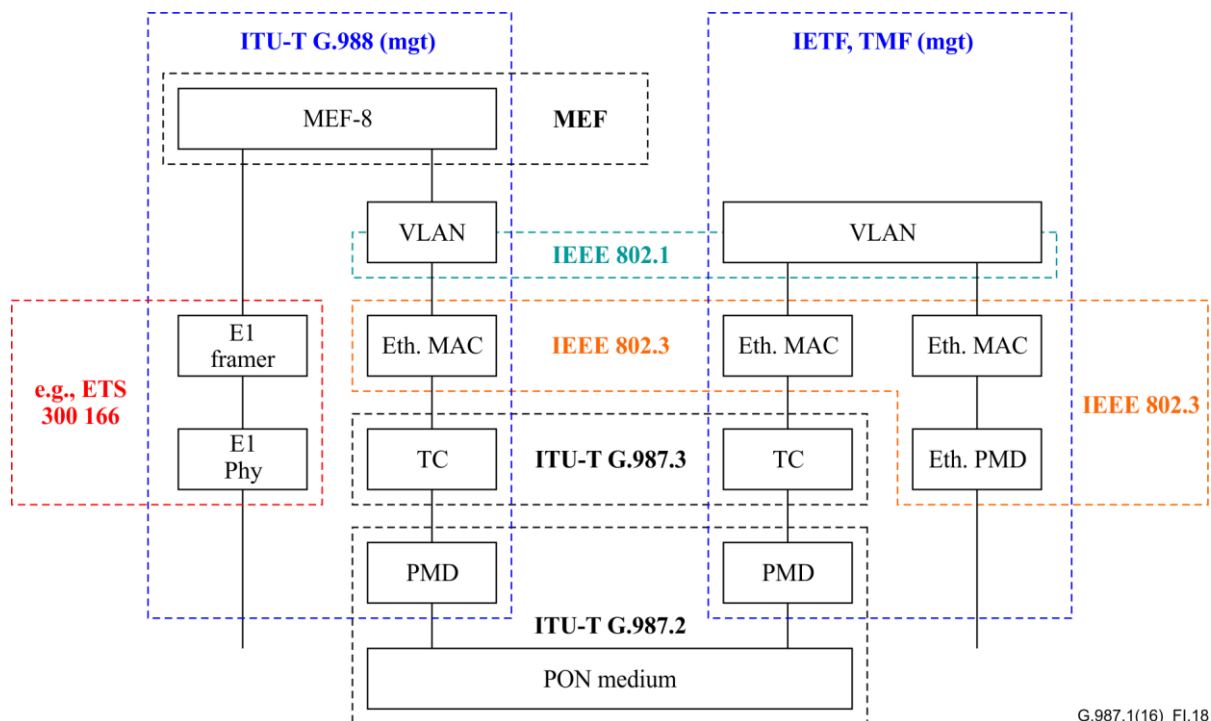


Figure I.18 – Packet TDM service using MEF-8 and pure OLT

I.3.5 Video overlay functions

Figure I.19 shows the video overlay service. This is carried on the PON using a third wavelength, and is practically distinct from the other services. The signal format delivered to the customer is defined by SCTE standards, and the management of the ONU interface is given by [ITU-T G.988]. The optical interfaces throughout the rest of the service path are generally defined by [ITU-T J.186]. In practice, the details of the video OLT and subtending optical amplifiers are left to network operator engineering, especially the signal levels at each point in the network. This is due to the large variations in network physical topology and channel plans.

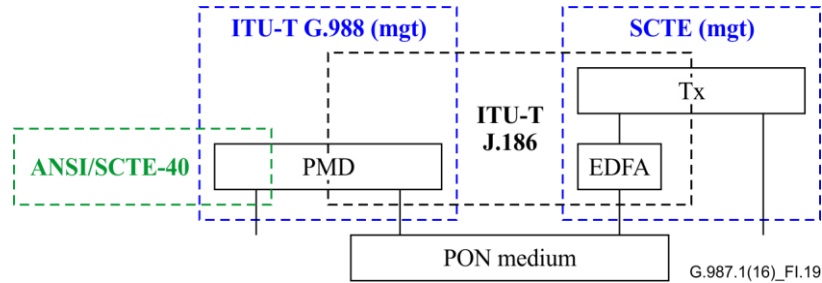


Figure I.19 – Video overlay service

Appendix II

Synchronizing requirements for wireless in CBU scenario

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

Table II.1 – Synchronization requirements for wireless

Application	Synchronization requirements
UMTS-FDD	<ul style="list-style-type: none">• Frequency accuracy for the radio interface of the base stations is ± 50 ppb• For Pico base stations, the accuracy can be relaxed to ± 100 ppb
UMTS-TDD	<ul style="list-style-type: none">• Frequency accuracy for the radio interface of the base stations is ± 50 ppb• For Pico base stations, the accuracy can be relaxed to ± 100 ppb• The phase alignment of neighbouring base stations must be within $2.5 \mu\text{s}$
CDMA2000	<ul style="list-style-type: none">• Frequency accuracy for the radio interface of the base stations is ± 50 ppb• For Pico base stations, the accuracy can be relaxed to ± 100 ppb• The pilot time alignment error should be less than $3 \mu\text{s}$ and must be less than $10 \mu\text{s}$
TD-SCDMA	<ul style="list-style-type: none">• Frequency accuracy for the radio interface of the base stations is ± 50 ppb• For Pico base stations, the accuracy can be relaxed to ± 100 ppb• The phase alignment of neighbouring base stations must be within $3 \mu\text{s}$

Appendix III

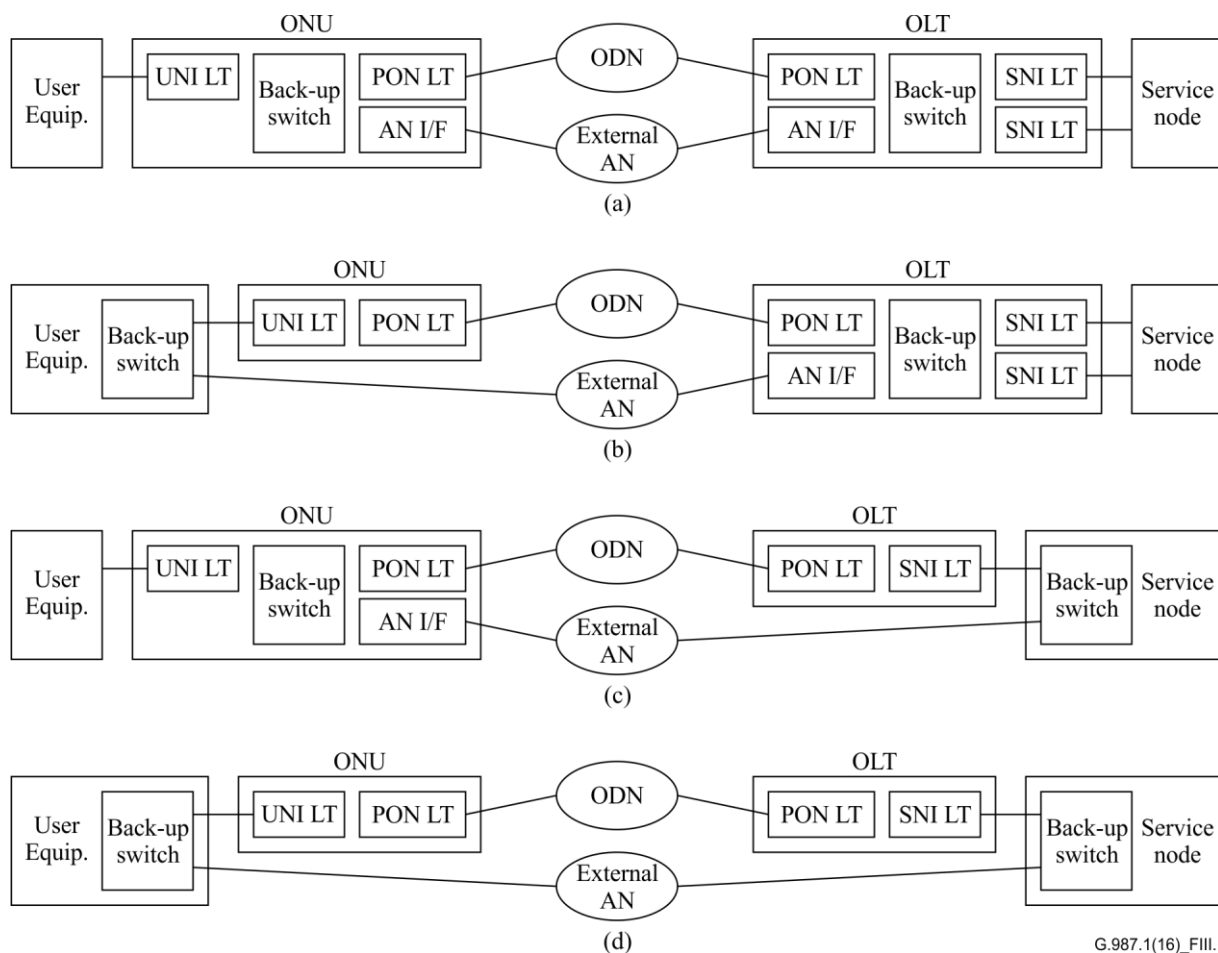
External access network back-up

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

In many applications, some resilience to faults in the optical access network is desired, but the cost of full protection is not supportable. In these cases, a cost-effective alternative is to provide a lower capacity back-up to the service via an external access network. Examples of the external access networks include fixed wireless, mobile wireless, hybrid fibre coax networks, etc.

Because of the wide range of back-up access networks, the interface from the PON equipment to the back-up network has to be at the data frame networking layer, described in the IEEE 802.1 standards. By abstracting the interface to this layer, the PON equipment need not worry about the details of the back-up network (nor does the back-up network need to worry about the PON).

The key aspect of such external back-up is the location and control of the back-up switching logic. Because of the widely disparate capacities of the primary PON and the back-up network, it does not make sense to send two copies of traffic at all times. Also, due to the packet-nature of the traffic, it is difficult for the receiver to resolve multiple copies of the same packets. It is assumed that the receiver will simply accept all packets arriving from either access network; therefore, it is important to only send one copy of any packet. The source side must direct the traffic to the appropriate access network, and it must have the information required to make the correct choice. In addition, the source side switching equipment must also have the ability to prioritize traffic, and selectively discard traffic that exceeds the capacity of the back-up network when back-up is in force. In the upstream, the back-up switch can be located in the ONU, or beyond the UNI. In the downstream direction, the back-up switch can be located in the OLT, or beyond the SNI. These arrangements are illustrated in Figure III.1.



**Figure III.1 – Four switching arrangements
for external access network back-up**

In option a, the switches are both located in the PON equipment. It is assumed that the PON equipment has knowledge of the PON link's operational state, and therefore it can direct traffic to the PON interface if it is working correctly and to the back-up network interface if it is not. Therefore, no additional signalling is required. The configuration of the ONU's dual ANIs must be supported in the OMCI.

In option b, the upstream switch is located beyond the ONT's UNI. A typical situation would be for this function to be located in an Ethernet switch or IP router. Therefore, that switch must be capable of learning the status of the ONU's PON link via some form of signalling. This could be as crude as the ONU deactivating the UNI when the PON link has failed, to more sophisticated Ethernet alarm indication signal (AIS) such as the one described in [b-ITU-T Y.1731]. The downstream switch is internally controlled within the OLT.

In option c, the downstream switch is located beyond the OLT's SNI. A typical function would be for this function to be located in an Ethernet aggregation network, or in a service edge router. Just as in option b, this switching logic must be given the information on the status of the PON link to the ONT in question. Unlike the previous case, however, a sophisticated per-ONT AIS scheme must be employed, since the SNI is shared over many ONUs, some of which may not have a PON transmission problem. This could be the AIS as described in [b-ITU-T Y.1731], but applied on a per-VLAN basis. The upstream switch is internally controlled within the ONU, with the configuration of the ONU's dual ANIs being supported in the OMCI.

In option d, both of the switches are located beyond the PON equipment. This scheme is most distantly removed from the access networks, since all the back-up switching/routing is happening in other equipment. This raises the possibility of allowing the back-up to occur using the more autonomous schemes such as Ethernet spanning-tree or IP routing. In either case, the back-up link would need to be configured as the 'expensive link', so that it would not be used if the PON link was available. These layer 2 or 3 schemes tend to take longer than more direct schemes mentioned in the previous options a-c. Their performance could be improved by implementing the direct AIS schemes to provide a faster feedback into their control algorithms.

Appendix IV

Operation with IEEE 1588: Principles

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

[IEEE 1588] describes a protocol for transferring time and/or frequency through a packet network. A good explanation of this can be found in section 7 of [b-ISPCS-2008].

XG-PON distributes the [IEEE 1588] master and slave functionality between the OLT and the ONU. The OLT will perform the slave port function (or in the case of a shelf, the OLT will receive the frequency and time from the function in the shelf which performs the slave port function). The OLT synchronizes the PON line rate to the network clock frequency, and transfers the time of day information to the ONU using the method in [ITU-T G.987.3] clause 13.2. The ONU uses the methods specified in [ITU-T G.987.2] to recover frequency and [ITU-T G.987.3] to recover time. The ONU will then either function as a master port to subsequent nodes or output the time and frequency through another interface.

Appendix V

Operation with IEEE 1588: Use cases for frequency and time of day synchronization

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

There are many applications where precise time and/or frequency must be transferred through a packet network from a source to a destination. In this appendix several use cases are described, in terms of the methods used to deliver frequency and/or time. Since most of the use cases mentioned are related to mobile backhauling applications, examples will use the RNC and Node B network elements, though these use cases are not intended to be exhaustive.

Frequency and/or time of day synchronization is provided to the OLT via either:

- 1) Physical timing interface (e.g., synchronous Ethernet) (frequency only)
- 2) [IEEE 1588] + synchronous Ethernet
- 3) [IEEE 1588] + non- synchronous Ethernet
- 4) Physical time of day(ToD) interface + SyncE

Frequency and/or time of day synchronization is supplied from the ONU via either:

- 1) Physical timing interface (e.g., synchronous Ethernet) (frequency only)
- 2) [IEEE 1588] + synchronous Ethernet
- 3) [IEEE 1588] + non-synchronous Ethernet
- 4) Physical ToD interface + SyncE

The use cases are described in terms of various combinations of these synchronization inputs and outputs as shown in Table V.1.

Table V.1 – XG-PON synchronization use cases

Use case	Network synchronization to OLT	UNI synchronization from ONU
1	SyncE (frequency only)	SyncE (frequency only)
2	[IEEE 1588] and SyncE	[IEEE 1588] and SyncE
3	[IEEE 1588]	[IEEE 1588]
4	[IEEE 1588]	[IEEE 1588] and SyncE
5	[IEEE 1588] and SyncE	ToD interface and SyncE
6	[IEEE 1588]	ToD interface and SyncE
7	ToD interface and SyncE	ToD interface and SyncE

Figure V.1 depicts use case 1 where frequency only is transferred through the XG-PON network. The clock interface at the OLT input and the ONU output is a physical timing interface such as synchronous Ethernet (SyncE), defined in [ITU-T G.8262]. The OLT synchronizes the PON line rate to this physical interface. The ONU outputs a physical timing interface such as synchronous Ethernet which is synchronous to the PON line rate.

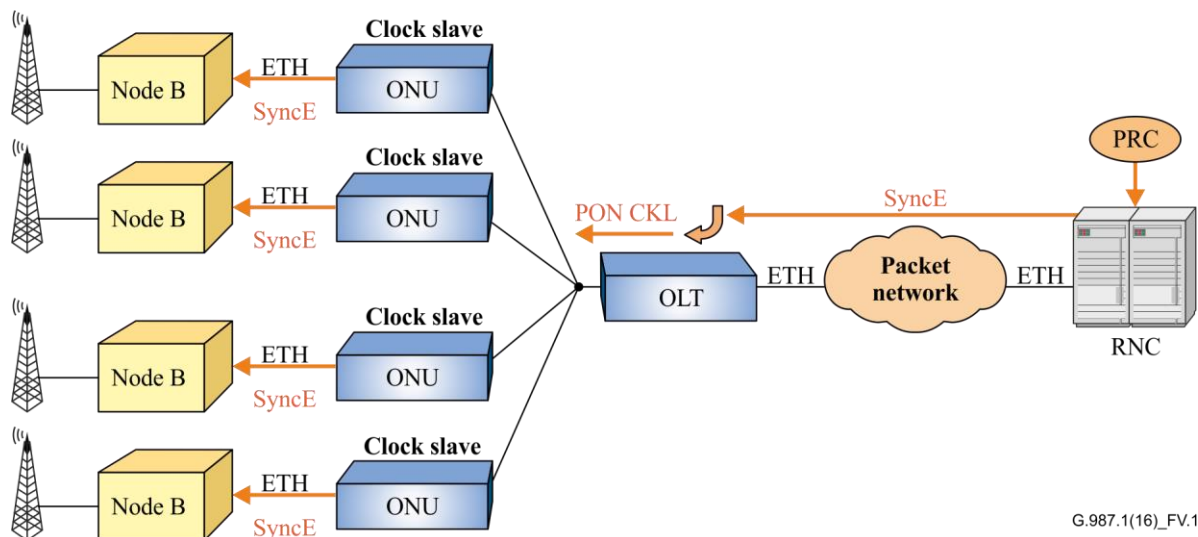


Figure V.1 – Using synchronous Ethernet in XG-PON (use case 1)

There are several use cases of interest which use [IEEE 1588] (use cases 2 through 6), with the following assumptions. The PRC provides a frequency reference. The OLT network interface is Ethernet, with the Ethernet line rate either synchronous to a network frequency reference (synchronous Ethernet) or not synchronous to a network frequency reference. The OLT obtains time of day using [IEEE 1588], usually through intervening nodes between the OLT and the PRC. The OLT synchronizes to the network frequency reference either using synchronous Ethernet, [IEEE 1588], or some other physical layer synchronous interface. The OLT transfers the time of day to the ONU using the method specified in clause 13 of [ITU-T G.987.3]. The OLT transfers the network frequency reference to the ONU via its downstream line rate, which is synchronous to the network frequency reference. The ONU user interface is Ethernet, with the Ethernet line rate either synchronous to a network frequency reference (synchronous Ethernet) or not synchronous to a network frequency reference. The ONU may also have a physical time interface (e.g., 1 pps).

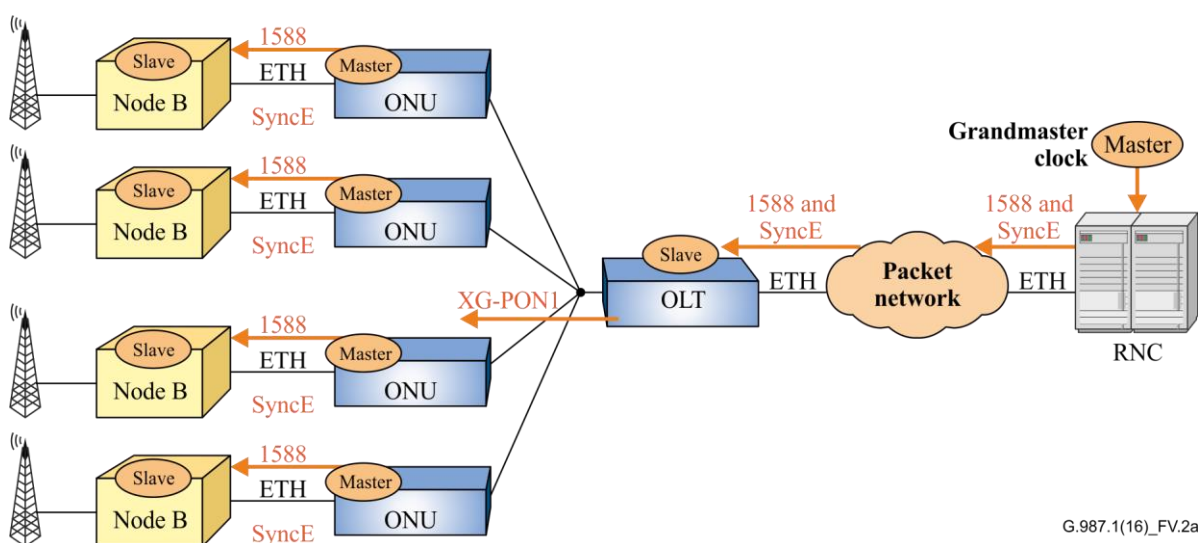


Figure V.2a – PTP use cases 2: ONU as IEEE 1588 master, OLT as IEEE 1588 slave with SyncE at both SNI and UNI

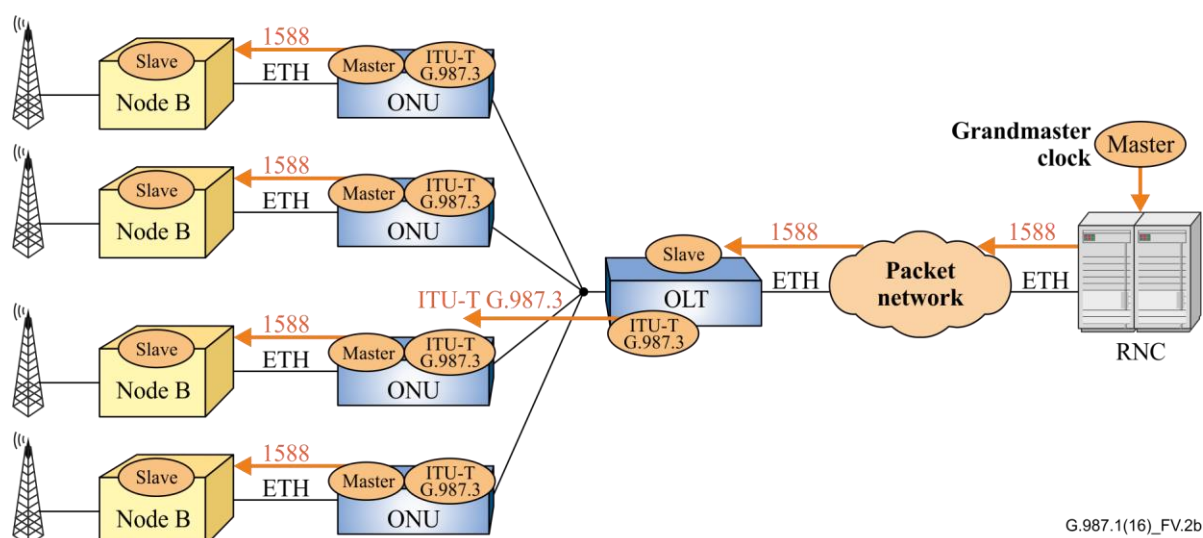


Figure V.2b – PTP use cases 3: ONU as IEEE 1588 master, OLT as IEEE 1588 slave without SyncE

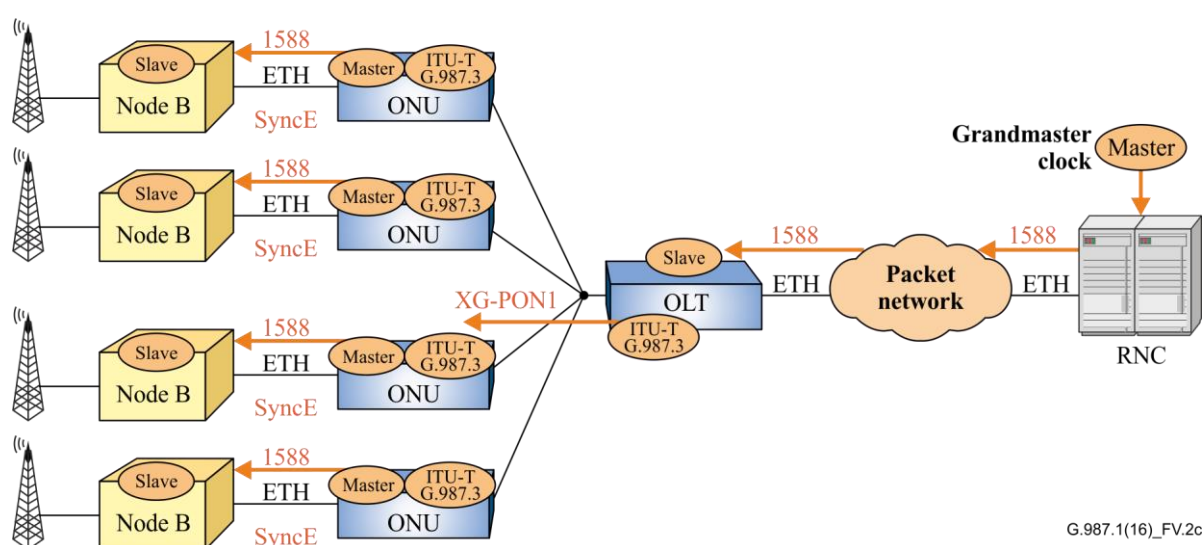


Figure V.2c – PTP use case 4: ONU as IEEE 1588 master, OLT as IEEE 1588 slave, with SyncE at UNI

Figures V.2 (a and b) show use cases 2 and 3 for wireless backhaul. The OLT has an [IEEE 1588] slave port at the SNI, which obtains the time of day from the network. This time of day is passed to the ONU as described above, and the ONU passes the time of day from an [IEEE 1588] master port to the Node B. If the OLT network feed is synchronous Ethernet (use case 2), then the OLT will synchronize its downstream PON line rate to the synchronous Ethernet line rate; otherwise the OLT will synchronize its downstream PON line rate to the [IEEE 1588] time of day (use cases 3). If the link between the ONU and the Node B is synchronous Ethernet (use cases 2), then the synchronous Ethernet line rate will be synchronized to the downstream PON line rate. Synchronous Ethernet ESMC messages would be used in conjunction with the synchronous Ethernet to indicate clock quality.

Figure V.3a shows use case 5, while Figure V.3b illustrates use case 6 for wireless backhaul. The only difference between Figure V.2 and Figure V.3 is that the ONU has a physical interface for transferring time to the Node B, such as a ToD interface. If the OLT network feed is synchronous Ethernet (use case 5), then the OLT will synchronize its downstream PON line rate to the synchronous

Ethernet line rate; otherwise the OLT will synchronize its downstream PON line rate to the [IEEE 1588] time of day (use cases 6).

Figure V.2c illustrates use case 4 where the OLT does not receive synchronous Ethernet and derives the downstream PON line rate from 1588. In this case the ESMC messages would correspond to the 1588 clock quality and not a clock quality received via ESMC at the OLT.

Figure V.4 shows use case 7, where a physical ToD interface is provided as an input to the OLT. The OLT processes the ToD information and sends timing information to the ONU according to the description provided in clause 13.2 of [ITU-T G.987.3]. The ONU processes the received timing information and outputs the timing information using a physical ToD interface.

NOTE – The details of the physical ToD interface are FFS.

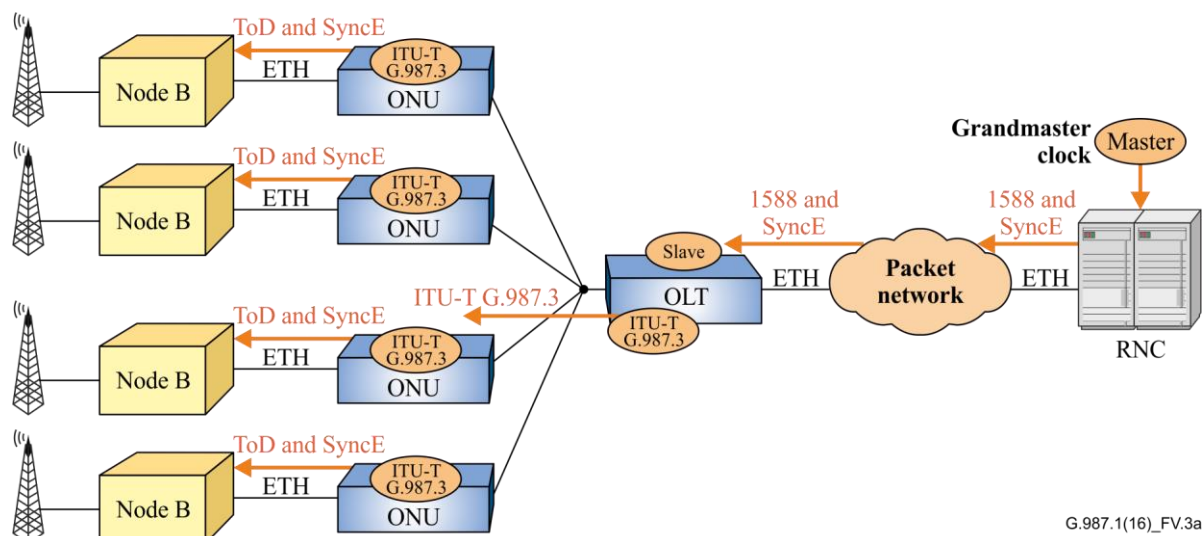


Figure V.3a – PTP use case 5: ONU with physical time interface, OLT as IEEE 1588 slave with SyncE at both SNI and UNI

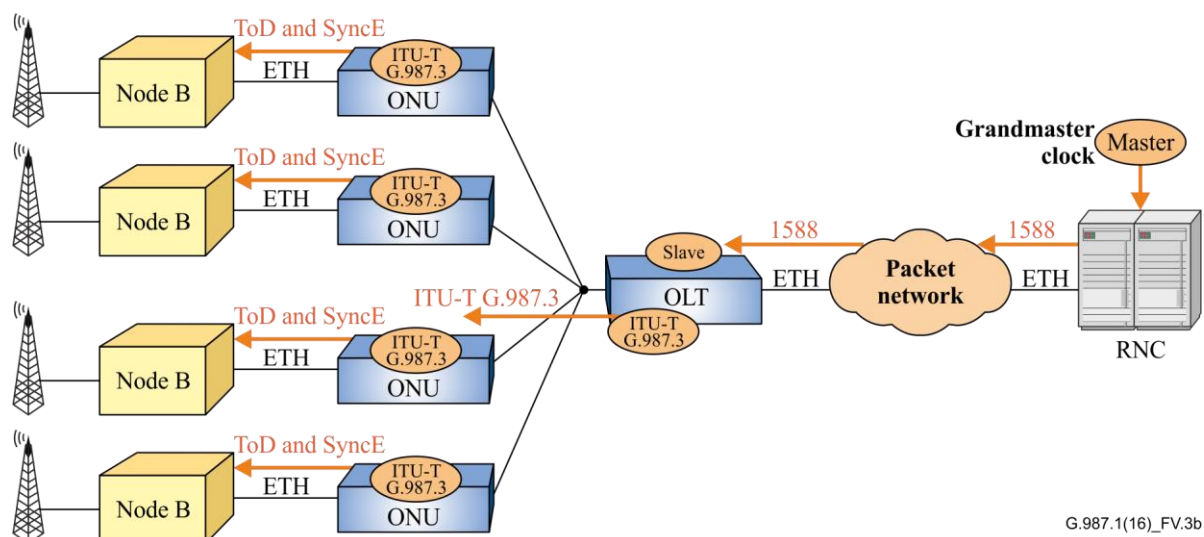


Figure V.3b – PTP use case 6: ONU with physical time interface, OLT as IEEE 1588 slave with SyncE at UNI only

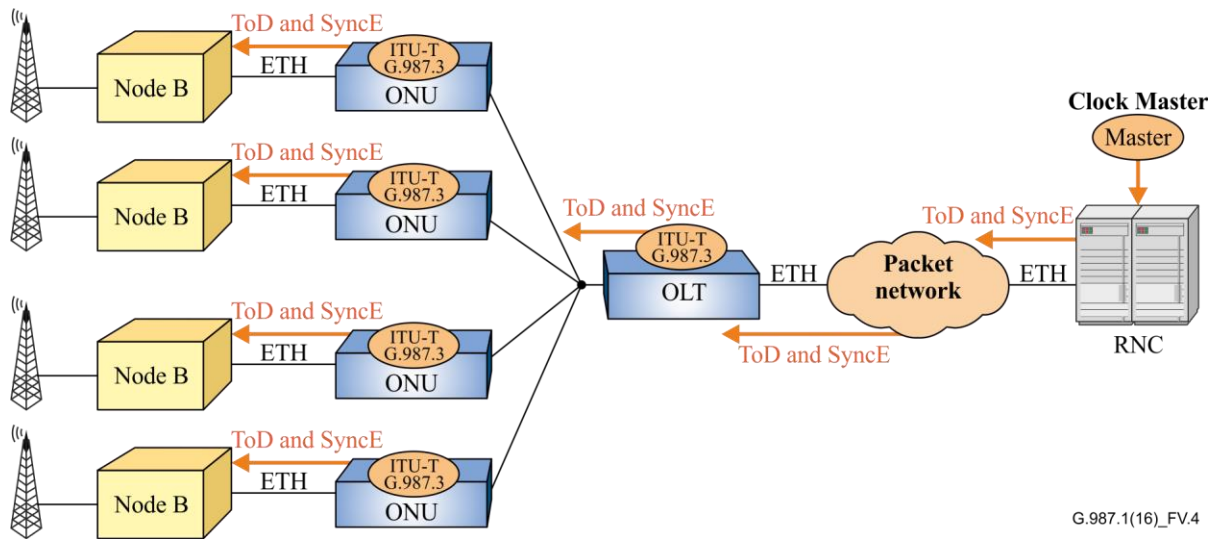


Figure V.4 – Use case 7, ONU and OLT with physical time interface

Appendix VI

Operation with IEEE 1588

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

Transport of ESMC messages over PON

In Appendix V, the use case of synchronous Ethernet over the PON was described and the Ethernet synchronization messaging channel (ESMC) was introduced. This appendix addresses frequency synchronization over XG-PON but focuses on a recommended method to transfer the SSM carried in the ESMC (as defined in [b-ITU-T G.8264]) that are used to send the synchronous Ethernet clock quality in a one-way fashion from the clock master to a base station or other end device. Refer to Figure V.1, "Using synchronous Ethernet in XG-PON" in Appendix V.

Within the physical layer, synchronous Ethernet is transferred over the OLT/ODN/ONU in the following way. A synchronous Ethernet-capable OLT will lock the XG-PON clock to the received Ethernet clock at the OLT SNI, and a synchronous Ethernet-capable ONU will in turn lock the Ethernet clock of one or more provisioned Ethernet port UNIs ([ITU-T G.8262] defines the types of UNIs capable of Synchronous Ethernet) to the XG-PON clock.

Characteristics of the ESMC

- Simple, stateless unidirectional protocol for communicating the current reference clock quality between nodes.
- Uses the [IEEE 802.3] organization specific slow protocol (OSSP).
- Destination address is the IEEE defined slow protocol multicast address.
- One message type, the synchronization status message.
- Sent at approximately one message per second containing the clock quality level (QL).

ESMC messages over XG-PON

ESMC messaging must be handled by the OLT/ONU as a system.

The main difference in how a PON must handle ESMC messages versus an Ethernet switch is that the OLT to ONU link is not a point-to-point Ethernet link but rather uses the XG-PON point to multipoint protocol, with the ESMC messages sent via GEM encapsulation. While different in this respect, in all *functional* aspects the OLT and the ONU may handle ESMC messages largely as defined in [b-ITU-T G.8264].

Method for sending Synchronization Status Messages over XG-PON

An OLT that is Synchronous Ethernet-capable should provisionally process and act upon ESMC messages that are received on Synchronous Ethernet provisioned SNI ports.

If there are multiple provisioned Synchronous Ethernet-capable ports then the OLT should synchronize to and obtain the clock quality (QL value) from the best port using the synchronization selection methods defined in [b-ITU-T G.8264] and [b-ITU-T G.781].

The OLT should then send OSSP ESMC messages of equal clock quality minimizing additional impact on PON traffic. The OLT should not send ESMC messages unless it has been provisioned to do so.

ONUs may be provisioned to recognize ESMC through the normal process of configuring an incidental broadcast GEM port, the appropriate VLAN, and a bridge to the desired Ethernet UNIs. After intercept, the ONU will have obtained the clock quality which will equal to that of the ESMC received at the OLT. The ONU should then send ESMC messages that are compliant to [b-ITU-T G.8264], only from UNIs that are members of the ESMC VLAN bridge.

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