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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

40-Gigabit-capable passive optical networks (NG-PON2): General requirements

Recommendation ITU-T G.989.1

ITU-T

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Recommendation ITU-T G.989.1

40-Gigabit-capable passive optical networks (NG-PON2): General requirements

Summary

Recommendation ITU-T G.989 series describes 40-Gigabit-capable passive optical network (NG-PON2) systems in an optical access network for residential, business, mobile backhaul and other applications.

Recommendation ITU-T G.989.1 addresses the general requirements of 40-Gigabit-capable passive optical network (NG-PON2) systems, in order to guide and motivate the physical layer and the transmission convergence layer specifications. This Recommendation includes principal deployment configurations, migration scenarios from legacy PON systems, and system requirements This Recommendation also includes the service and operational requirements to provide a robust and flexible optical access network supporting all access applications.

The physical layer specifications for the NG-PON2 physical media dependent (PMD) layer are described in Recommendation ITU-T G.989.2. The transmission convergence (TC) layer is described in Recommendation ITU-T G.987.3, with unique modifications for NG-PON2 systems captured in Recommendation ITU-T G.989.3. The ONU management and control interface (OMCI) specifications are described in Recommendation ITU-T G.988 for NG-PON2 extensions.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.989.1	2013-03-09	15

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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40-Gigabit-capable passive optical networks (NG-PON2): General requirements

1 Scope

This Recommendation describes the general requirements of NG-PON2 systems supporting a 40-Gbit/s capable aggregate downstream capacity for residential, business, mobile backhaul, and other applications. This Recommendation includes the principal deployment configurations, migration scenarios from legacy PON systems, and system requirements. This Recommendation also includes the service and operational requirements to provide for a robust and flexible optical access network supporting all access applications.

The NG-PON2 system is capable of meeting the needs of a wide range of networks in diverse markets and is deployable in numerous applications in an efficient manner. As much as possible, this Recommendation maintains characteristics from legacy PON systems: [ITU-T G.982], [ITU-T G.983], [ITU-T G.984], and [ITU-T G.987] series of Recommendations. This is to promote backward compatibility with existing optical distribution networks (ODNs) that comply with those Recommendations and re-use established technical capabilities as much as possible. This Recommendation also describes smooth migration scenarios from legacy PON systems to NG-PON2 systems. Furthermore, NG-PON2 systems are is expected to meet bandwidth growth and enable new revenue streams on legacy ODNs as well as supporting greenfield applications over new ODNs.

2 References

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

[ITU-T G.652] Recommendation ITU-T G.652 (2005), *Characteristics of a single-mode optical fibre cable*.

[ITU-T G.902] Recommendation ITU-T G.902 (1995), *Framework Recommendation on functional access networks (AN) – Architecture and functions, access types, management and service node aspects*.

[ITU-T G.982] Recommendation ITU-T G.982 (1996), *Optical access networks to support services up to the ISDN primary rate or equivalent bit rates*.

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

[ITU-T G.983.2] Recommendation ITU-T G.983.2 (2005), *ONT management and control interface specification for B-PON*.

[ITU-T G.983.3] Recommendation ITU-T G.983.3 (2001), *A broadband optical access system with increased service capability by wavelength allocation*.

[ITU-T G.984.1] Recommendation ITU-T G.984.1 (2008), *Gigabit-capable Passive Optical Networks (GPON): General characteristics*.

[ITU-T G.984.2] Recommendation ITU-T G.984.2 (2008), *Gigabit-capable Passive Optical Networks (GPON): Physical Media Dependent (PMD) layer specifications*.

[ITU-T G.984.3] Recommendation ITU-T G.984.3 (2008), *Gigabit-capable Passive Optical Networks (GPON): Transmission convergence layer specification*.

[ITU-T G.984.4] Recommendation ITU-T G.984.4 (2008), *Gigabit-capable Passive Optical Networks (GPON): ONT management and control interface specification*.

[ITU-T G.984.5] Recommendation ITU-T G.984.5 (2007), *Gigabit-capable Passive Optical Networks (GPON): Enhancement band for Gigabit-capable Passive Optical Networks*.

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

[ITU-T G.987.1] Recommendation ITU-T G.987.1 (2010), *10-Gigabit-capable Passive Optical Networks (XG-PON): General requirements*.

[ITU-T G.987.2] Recommendation ITU-T G.987.2 (2010), *10-Gigabit-capable Passive Optical Networks (XG-PON): Physical Media Dependent (PMD) layer specification*.

[ITU-T G.987.3] Recommendation ITU-T G.987.3 (2010), *10-Gigabit-capable Passive Optical Networks (XG-PON): Transmission convergence (TC) layer specification*.

[ITU-T G.988] Recommendation ITU-T G.988 (2010), *ONU management and control interface specification (OMCI)*.

[ITU-T J.185] Recommendation ITU-T J.185 (2012), *Transmission equipment for transferring multi-channel television signals over optical access networks by frequency modulation conversion*.

[ITU-T J.186] Recommendation ITU-T J.186 (2008), *Transmission equipment for multi-channel television signals over optical access networks by sub-carrier multiplexing (SCM)*.

[IEC 60825-2] IEC International Standard 60825-2 (2004), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS).*

[IEEE 802.3] IEEE 802.3-2012, *IEEE Standard for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements, Part 3: Ethernet*.

3 Definitions

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

3.1 NG-PON2 specific terms

This Recommendation uses the following NG-PON2 specific definitions:

3.1.1 TWDM PON: A time and wavelength division multiplexing passive optical network (TWDM PON) is a multiple wavelength PON solution in which each wavelength is shared between multiple optical network units (ONUs) by employing time division multiplexing and multiple access mechanisms.

3.1.2 PtP WDM: Point-to-point wavelength division multiplexing (PtP WDM) is a multiple wavelength PON solution that provides a dedicated wavelength per ONU in both downstream and upstream directions. The defining characteristic of a PtP WDM is that each ONU is served by one or more dedicated wavelengths.

4 Abbreviations and acronyms

This Recommendation uses the following NG-PON2 specific abbreviations and acronyms:

ANI	Access Node Interface
APC	Angled Physical Contact
BBU	Baseband Unit
CD	Chromatic Dispersion
CE	Coexistence Element
CPRI	Common Public Radio Interface
eNode B	Evolved Node Base station
FTTx	Fibre to the x (B – building, business; H – home; C – cabinet, curb)
G-PON	Gigabit-capable Passive Optical Network, [ITU-T G.984.x]. Unless explicitly stated otherwise, this term also refers generically to [ITU-T G.987] XG-PON.
LTE	Long Term Evolution
MDU/SFU	Multi-Dwelling Unit/Single-Family Unit
ODN	Optical Distribution Network
ODS	Optical Distribution Segment
OLT	Optical Line Terminal
ONU	Optical Network Unit
PON	Passive Optical Network
PtP WDM	Point-to-Point Wavelength Division Multiplexing
QoS	Quality of Service
RE	Reach Extender
RF	Radio Frequency
RRU	Remote Radio Unit
R'/S'	Reach extender interface to optical trunk line [ITU-T G.988]
SMF	Single Mode Fibre
S'/R'	Reach extender interface to optical distribution network [ITU-T G.988]
TC	Transmission Convergence
TWDM	Time and Wavelength Division Multiplexing
UNI	User Node Interface
UPC	Ultra Physical Contact
WDM	Wavelength Division Multiplexing
XG-PON	10-Gigabit Passive Optical Network [ITU-T G.987]

5 Architecture

5.1 System overview

The following provides an overview of NG-PON2 system requirements. Additional requirement details are provided in specific sections within this Recommendation.

NG-PON2 systems requirements include support for:

– Multiple wavelength channel TWDM architecture

– 4-8 TWDM channel pairs (each channel pair comprising one downstream and one upstream wavelength channel), configurable for incremental growth starting from one deployed channel pair (i.e., not all channel pairs need to be active); for example, "pay as you grow" capability of TWDM channels populating in the OLT.

– Downstream and upstream nominal line rates per channel:

  • 10 Gbit/s downstream and 10 Gbit/s upstream

  • 10 Gbit/s downstream and 2.5 Gbit/s upstream

  • 2.5 Gbit/s downstream and 2.5 Gbit/s upstream

– Passive fibre reach of at least 40 km and maximum differential fibre distance of up to 40 km with configurable maximum differential fibre distance as 20 km and optionally 40 km,

– Capability to reach 60 km, preferably with passive outside plant

– Support for a split ratio of at least 1:256

NG-PON2 systems require flexibility to balance trade-offs in speed, distance, and split ratios for various applications. The set of parameter combinations that are supported by the system must include:

– 40 Gbit/s downstream capacity and 20 km reach with at least 1:64 split

– 10 Gbit/s upstream capacity and 20 km reach with at least 1:64 split

– Access to peak rates of 10/2.5 Gbit/s downstream/upstream

– Longer distances with lower split ratios are also possible

NG-PON2 systems may also support:

– 40 Gbit/s upstream capacity with 10 Gbit/s per upstream channel and 20 km reach with at least 1:64 split

– 2.5 Gbit/s per downstream channel and 2.5 Gbit/s per upstream channel with 40 km reach and 1:32 split

– 10 Gbit/s per downstream channel and 10 Gbit/s per upstream channel with 40 km reach and 1:32 split

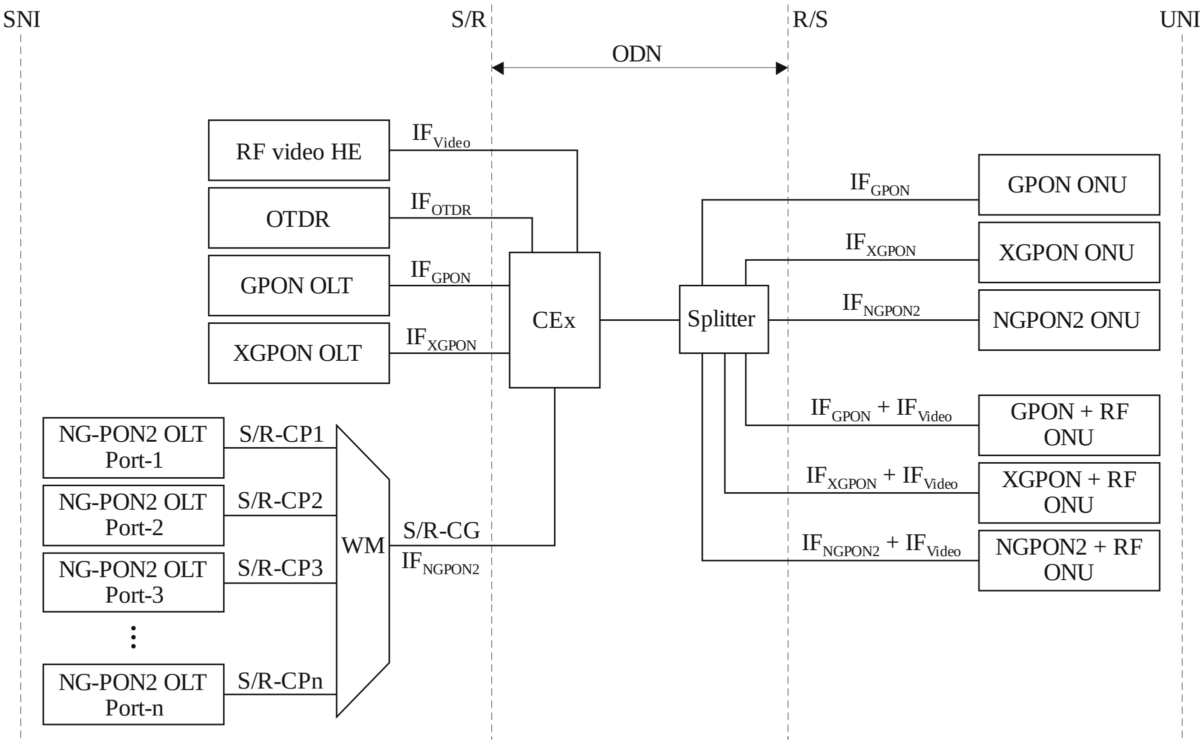
– Access to peak rates of 10/10 Gbit/s downstream/upstream

– Tunable point-to-point WDM with the capability to co-exist with other PON systems

5.2 Network reference architecture

Figure 5-1 depicts the functional optical access network architecture and reference points that apply to NG-PON2 systems with legacy systems coexistence. The ODN consists of the splitter and the coexistence element (WDM) and, optionally, reach extenders may also be used in the ODN.

The optical technologies specified for NG-PON2 systems shall be compatible with legacy power splitting ODNs (that is an ODN that may contain power splitters and a coexistence element). Optical technologies that specifically require wavelength filtering in the ODN are precluded from this Recommendation. NG-PON2 systems also support new (greenfield) ODNs that may consist of wavelength filters only, or a combination of both wavelength and power splitters.



Key:
CG = Channel group
CP = Channel pair
CEx = Instance of co-existence element
HE = Head end
WN = Wavelength multiplexer

Figure 5-1 – Functional reference architecture and points for NG-PON2 system coexistence with legacy systems

6 Migration

PON systems such as G-PON [ITU-T G.984] series, XG-PON [ITU-T G.987] series and 1G-EPON [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 an NG-PON2 system is to provide higher bandwidth than these legacy PON systems. In addition, given the major investments made to deploy these legacy PON systems (including the fibre infrastructure), NG-PON2 systems must be able to protect these investments by ensuring seamless and smooth migration capability for subscribers to NG-PON2 systems. Coexistence is enabled through the wavelength band plan which also provides the optional overlay capability of broadcast TV on a separate wavelength.

There are several migration scenarios to meet different network needs. These scenarios reflect recognition that differing service introduction strategies might affect requirements for the NG-PON2 system specifications. This clause describes two likely migration scenarios:

PON brownfield migration scenario

PON brownfield scenario in this Recommendation refers to the deployment scenario where a PON system has already been deployed and this existing fibre infrastructure is leveraged to offer higher bandwidth carrier services or other features, using NG-PON2 systems. Some subscribers to an existing PON system might require an upgrade to such a higher speed tier service and it might be beneficial to move these subscribers over to the NG-PON2 system, while other subscribers remain on the legacy PON. It is likely that two or three PON generations will continue to coexist for a relatively long time.

In a slightly different migration scenario, it may be desirable to replace an existing PON with NG-PON2 completely. In this case, it would still be useful to operate both legacy PON and NG-PON2 systems at the same time on the ODN and update customers one at a time. The timeframe for this type of upgrade is generally much shorter.

General requirements for this scenario are as follows:

– Coexistence between legacy PON and NG-PON2 systems on the same fibre must be supported for the situation where the fibre resource is not necessarily abundant.
– Service interruption for the non-upgrade subscribers should be minimal (if at all).
– NG-PON2 systems must support/emulate all legacy PON services in the case of full migration.
– Legacy PON systems include GPON, XG-PON1, GEPON and 10G-EPON.

PON greenfield migration scenario

Upgrading the access network to FTTx infrastructure is a significant investment for service providers and takes a long time to fully realize. When NG-PON2 technology becomes mature, it may be desirable to use NG-PON2 systems to replace copper-based infrastructure or to deploy in a brand new development area for the benefit of higher bandwidth, higher splitting ratios, and other capabilities. An area where PON had not been previously deployed is referred to as "PON greenfield". This scenario may help service providers achieve better economics while supporting the same or better bandwidth offer per user as previous PON systems. In this scenario, the requirement of coexistence with legacy PONs is not necessary.

6.1 Co-existence, stacking and overlay

Several concepts have been used in the GPON and XG-PON Recommendations that may generate uncertainty in increasingly complex environments. Table 6-1 captures the meaning assumed in this document.

Table 6-1 – Definitions of legacy compatibility terminology

	Definitions	Options	Impact on WL plan
ODN re-use	Ability to re-use existing ODN/ODS plant as is ("legacy" optical budget to be supported)	* Existing RE * Existing OTL * co-existence	–
Stacking	Ability for a generation of independent PON systems based on the same TC to share part or all of the ODN/ODS through WDM. PMD for each stacked system only differs through wavelength allocations	* WL selected devices	Definition of a "stacking dedicated" WL plan

Table 6-1 – Definitions of legacy compatibility terminology

	Definitions	Options	Impact on WL plan
Co-existence	Ability for two PON system generations to operate simultaneously on at least one section of the fibre plant. Requires the definition of specific filter isolation values when different transmission standards are used simultaneously.	* WDM domain as for legacy PONs * TDM domain as for XG-PON1/ XG-PON2 * on ODN/ODS * on RE * on OTL	Compliancy to a co-existence WL plan (e.g., Amd.1 of [ITU-T G.984.5]) or a multi-rate TC layer
Overlay	Different services are multiplexed by WDM to PONs, e.g., RF-Video.	–	–

Smooth migration from one PON technology to another on the same ODN provides for an enhanced end customer experience by minimizing the disruption of the existing optical plant. Co-existence facilitates a smooth migration from legacy PON to NG-PON2 systems. Without this co-existence capability, customers may have to wait longer to move their service and all customers on an ODN may experience unacceptable service disruption if parts of the passive infrastructure must be exchanged/reconfigured. The coexistence of two PON generations could enable a flexible migration and/or on-demand deployment of new PON connections without service interruption. For maximum flexibility, NG-PON2 systems must allow co-existence with both GPON and XG-PON1 on the same ODN.

To facilitate co-existence, an NG-PON2 system must be capable of reusing existing legacy PON optical power splitters and must also operate in usable spectrum not occupied by legacy PONs in a particular deployment. However, an NG-PON2 system could re-use the spectrum allocated to legacy PON systems if not co-existing with those PONs. NG-PON2 systems must allow co-existence over the whole, end-to-end ODN including co-existence over the feeder fibre (see Figure 6-1). The end-to-end ODN of NG-PON2 is delimited by R'/S' to S'/R' reference points as shown in Figure 5-1 which are analogous to R'/S' to S'/R' as defined in [ITU-T G.984.1] and [ITU-T G.987.1]. NG-PON2 systems support power-based splitting ODNs; however, other types of ODNs may apply in greenfield applications. Appropriate filtering must be installed in ONUs to eliminate interference between the co-existing generations of PON. Furthermore, any interference due to fibre non-linearity should also be taken into account.

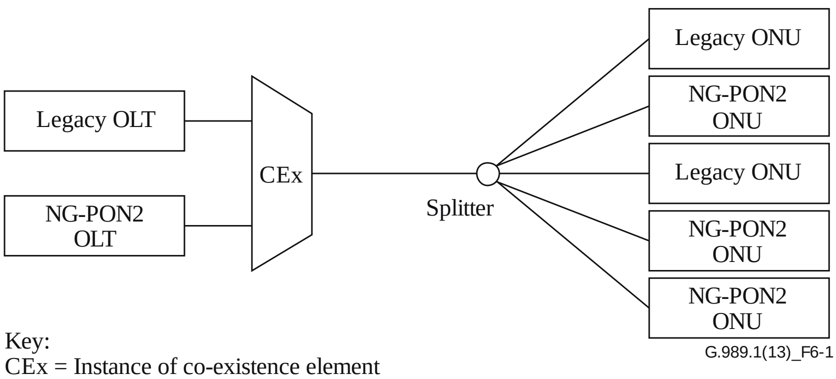


Figure 6-1 – ODN co-existence scenario

The co-existence of NG-PON2 systems with legacy RF-video overlay must be supported. RF-video overlay defined in [ITU-T J.185] or [ITU-T J.186] will continue to be used into the foreseeable future to support video delivery. Many legacy PON deployments use RF-video overlay for video delivery; therefore, co-existence will enable easy migration to NG-PON2 systems. This requirement should not increase system complexity when RF-video overlay is not required.

6.2 Migration path options

NG-PON2 systems must allow a technology migration on existing infrastructure without any prolonged service interruption. It must be capable of upgrading single customers on demand and it must support a migration path from GPON to NG-PON2 and a migration path from XG-PON1 to NG-PON2.

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

Straight migration

This covers a straight migration path in line with the PON generation order from GPON over XG-PON1 to NG-PON2. This requires a finalized migration from GPON to XG-PON1 before starting with the NG-PON2 upgrade. This migration option could be realized by removing the GPON from the ODN and re-using the GPON wavelength windows to enable an NG-PON2 technology coexisting with XG-PON.

Flexible migration

Flexible migration covers a direct migration path from GPON to NG-PON2. Flexible migration requires an NG-PON2 system that can also co-exist with GPON.

All-embracing migration

The highest level of flexibility is realized by an NG-PON2 system that enables co-existence of GPON, XG-PON1 and NG-PON2. The all-embracing option is the most challenging due to the wide range of optical wavelength bands required. The ability of NG-PON2 systems to co-exist with GPON and XG-PON1 systems will allow greater flexibility to upgrade to XG-PON1 in the near term and enable migration to NG-PON2 in the future. It will also enable migration from GPON directly to NG-PON2. This is the most desirable option as it makes the legacy ODN future proof and offers operators a high level of flexibility.

In any migration case including co-existence, the legacy ONU and OLT must remain unchanged and should not require any additional filters to protect them against NG-PON2 signals. In the event that extra filtering is required, this should preferably be at the OLT where access may be easier and not the ONU to avoid truck rolls. The attenuation of any additional devices, i.e., the CEx referenced in Figure 5-1, must also remain similar to that introduced by WDM1r devices in order not to compromise the legacy optical budget. Whichever migration scenario is chosen, it must be possible to migrate a customer from GPON/XG-PON1 to NG-PON2 through a replacement of the ONU.

6.3 Support for legacy ODN

The total expenditure for FTTH deployment is dominated by the infrastructure investments. Given that many networks already use power splitter based ODNs to carry Gigabit-class PON technology, it is mandatory that NG-PON2 systems be compatible with these legacy ODNs. Some ODNs use connectors extensively, with as many as nine connectors between the OLT and the ONU (eight angled physical contact (APC) connectors in the ODN and one ultra physical contact (UPC) connector at the OLT). NG-PON2 systems must be able to accommodate the resulting back reflections and connector loss impairments but does not require more stringent reflection tolerance than already defined in BPON/GPON standards; [ITU-T G.983.x], [ITU-T G.984.x]. The access infrastructure has a very long lifetime (20 years or more) and there must be an upgrade path for this deployed infrastructure throughout its life. It is advantageous for NG-PON2 systems to allow a system upgrade on existing infrastructure without any protracted service interruption. NG-PON2 systems must be able to accommodate flexibility in terms of stages and number of splits in each stage no matter what splitting technology is used (whether power splitting, wavelength splitting, or a combination of both).

A non-wavelength selective ODN may be preferred in order to obtain a system independent distribution network. With this approach there are no barriers for flexible wavelength upgrades and further usage of the fibre spectrum. Filters inside the ODN define wavelength windows that limit flexibility and can increase network planning complexity.

7 Service requirements

7.1 Service specific requirements

NG-PON2 systems are required to fully support various services for residential subscribers, business customers, mobile and fixed backhauling, and other applications through its high quality of service and high bit-rate capability, and must at least meet the system requirements as defined in clause 7 of [ITU-T G.987.1] (including synchronization, quality of service (QoS), etc.). Further, NG-PON2 systems may achieve better delay and jitter performance. NG-PON2 systems must support legacy services, such as POTS and T1/E1 using emulation and/or simulation, high speed private line (framed and unframed), and emerging packet-based services. The emulation option delivers packet-formatted traffic through the PON network, i.e., between the OLT and ONU, and possibly through some level of aggregation, then converts back to the relevant legacy format to hand it off to the legacy network. The simulation option is an end-to-end packet delivery starting at CPE terminal adaptation device or ONU, to the NG-PON access and the NGN packet network. An Ethernet packet size up to 9 000 bytes must be supported. Optical business services such as wavelength services and OTN must be supported.

7.2 User node interfaces (UNIs)

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

– interconnection between the access network and the customer;

– described by a well-known standard;

– includes a physical layer aspect.

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

Example of UNIs, physical interfaces and services that they provide are shown in Table 7-1.

Table 7-1 – Examples of UNI and services

UNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
10 Mbit/s/100 Mbit/s/1 Gbit/s Ethernet [IEEE 802.3]	10/100/1000BASE	Ethernet
MoCA 2.0	–	MoCA 2.0
1 Gbit/s fibre UNI	–	Ethernet
10 Gbit/s fibre UNI	10BASE	Ethernet
[b-ITU-T G.8261]; [b-ITU-T G.8262]	–	Synchronous Ethernet
[b-ITU-T Q.552]	–	POTS
ISDN [b-ITU-T I.430]	–	ISDN
[b-ITU-T V.35]	–	–
[b-ITU-T G.9960]	–	–

Table 7-1 – Examples of UNI and services

UNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
VDSL2 [b-ITU-T G.993.2], ADSL2plus [b-ITU-T G.992.5]	xDSL	xDSL
[b-ITU-T G.703]	PDH	DS3, E1, E3
[b-ATIS 0900102] and [b-ATIS 0600107]	PDH	T1, DS0, DS1, DS3
SDH/SONET		OC3-OC192, STM1-STM64
OTN [b-ITU-T G.872], [b-ITU-T G.709]		OTU1, OTU2
CPRI/OBSAI (Open Base Station Architecture Initiative)		
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.		

7.3 Service node interfaces (SNIs)

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

– interconnection between the access network and the service node;

– described by a well-known standard;

– includes a physical layer aspect.

Example of SNIs, physical interfaces and services that they provide are shown in Table 7-2.

Table 7-2 – Examples of SNIs and services

SNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
1 GigE [IEEE 802.3]	1000BASE	Ethernet
10 GigE [IEEE 802.3]	10GBASE	Ethernet
40 GigE [IEEE 802.3]	40GBASE	Ethernet
100 GigE [IEEE 802.3]	100GBASE	Ethernet
[b-ITU-T G.8261]; [b-ITU-T G.8262]	-	SyncE
[b-ITU-T G.965]	V5.2	POTS,
[b-ITU-T G.703]	PDH, STM-1e	DS3, E1, E3, STM-1, DS1, DS0
[b-ITU-T G.957]	STM-1,4,16,64	E1, E3, DS1, DS3, GFP, E4, STM-n, DS0
[b-ATIS 0600107]	PDH	DS0, DS1, DS3
SDH/SONET	SDH/SONET	OC3-OC192 , STM1-STM64
OTN [b-ITU-T G.872] and [b-ITU-T G.709]	OTN	OTU1, OTU2, OTU3

Table 7-2 – Examples of SNIs and services

SNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
CPRI/OBSAI (Open Base Station Architecture Initiative)		
NOTE 1 – There are many other services accommodated in XG-PON, but those services do not have specified SNIs. NOTE 2 – Each item in the "Physical interface" column is illustrated by the corresponding entry in the "SNI" column. NOTE 3 – The column labelled "Service" shows which services can be supported by the physical interface.		

7.4 Access node interfaces (ANIs)

Flexible system configurations are required to improve equipment utilisation and lower capital and inventory costs. To this end, NG-PON2 systems must support flexible and agnostic interfaces to the optical access network to enable the OLT network element to accommodate multiple access technologies. This objective may be achieved by using pluggable interfaces.

7.5 System flexibility

Leveraging next generation fibre infrastructure across many market segments, such as business, residential, and mobile backhaul will improve the system attractiveness. Therefore NG-PON2 systems must offer functionality suitable for residential multi-dwelling unit and single-family unit (MDU/SFU), business, and mobile backhaul customers and applications. Moreover, system flexibility must also be made possible by supporting different customer types on the same PON in a flexible way, which otherwise might need to be served separately using for example, point-to-point fibre deployment.

8 Physical layer requirements

8.1 Capacity (per feeder and per user)

NG-PON2 systems shall be capable of offering significantly more capacity per customer than current GPON and XG-PON1 systems. NG-PON2 systems shall be able to support at least 40 Gbit/s aggregate capacity per feeder fibre in the downstream direction and at least 10 Gbit/s aggregate capacity in the upstream direction. Up to 160 Gbit/s in the downstream direction and up to 80 Gbit/s in the upstream direction is a target ceiling capacity. Typically any NG-PON2 ONU shall be able to support at most 10 Gbit/s service, whereas the actual capability per ONU on the PON will depend on engineering choices concerning split ratio adopted and the application mix considered (e.g., FTTH, FTTB, Mobile backhaul). For example, some scenarios may require a 100 Mbit/s service to be effectively provided on the same PON as a 10 Gbit/s service. NG-PON2 systems shall be able to support ONUs with 10 Gbit/s symmetrical capacity. The NG-PON2 system must offer such service mixes to enable the sharing of common infrastructure. The system must provide efficient traffic sharing among residential, business, and other customers; and should offer an upgrade to greater bandwidths without foreseeable technology roadblocks or bottlenecks.

NG-PON2 system capacity requirements are driven by the various access services that could be delivered by such systems. The envisaged services drive the need for different sustained and peak data rates, as well as different symmetry ratios between upstream and downstream data rates. For example, business services or mobile backhaul will require sustained and symmetric 1 Gbit/s data rates or higher, whilst residential customers may be less bandwidth demanding and require the available peak bandwidths for short durations only. Overall, a move to more symmetric services is anticipated and NG-PON2 systems that increase the level of service rate symmetry, e.g., between 2:1 and 1:1 (downstream: upstream) service rates, are desirable. Furthermore, NG-PON2 systems must efficiently deliver service mixes consisting of services with both low and high levels of symmetry, which can be as high as 1:1 and as low as 100:1. NG-PON2 system will thus enable the provisioning of services that are tailored to meet different customers' needs over a common infrastructure.

Example services demanding higher data rates include serving MDUs, enterprise connectivity, distributed eNodeB, and mobile backhaul. With respect to mobile backhaul, increased capacity is required to meet expected LTE data rates in the region of up to 300 Mbit/s and increasing to 1 Gbit/s for LTE-Advanced. In addition, it may be cost effective and increase mobile capacity of the wireless infrastructure to introduce a distributed eNodeB architecture. In supporting distributed eNodeB applications, it may be beneficial to leverage NG-PON2 systems to support the high speed transport (e.g., CPRI with up to 9.83 Gbit/s) between BBU (Baseband Unit) and RRUs (Remote Radio Unit).

It is impossible to precisely predict what service evolution will occur over the next decade given the number of unknown factors and the many global markets and deployment models. Therefore, NG-PON2 systems must be scalable enough to support any reasonably expected outcome.

8.2 Fibre reach (passive and active)

NG-PON2 systems must support a fibre reach of at least 40 km without mid-span reach extenders. NG-PON2 systems also need to support the maximum differential fibre distance of up to 40 km, with configurable maximum differential fibre distances as 20 km and 40 km. NG-PON2 systems must also be backward compatible with already deployed infrastructure (CO locations, ducts, fibre cables, etc.)

NG-PON2 systems must also be capable of reaching 60 km with reach extenders if needed. Even longer reach (e.g., 60-100 km) NG-PON2 systems could facilitate CO consolidation and other network architectures and capabilities.

8.3 Split ratio (ONUs per ODN)

Optical distribution networks exploiting power splitters are typically deployed today with a split ratio in the range of 1:16 to 1:128. NG-PON2 systems may run over legacy power split ODNs, wavelength routing, or combinations of wavelength routing and power splitting. NG-PON2 systems should be flexible enough to support cost-effective deployments over a variety of ODNs. NG-PON2 OLTs must support a split ratio of at least 1:256. Specific application and network engineering choices may require higher split ratios; therefore, the NG-PON2 OLT core design should not preclude supporting higher split ratios.

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

8.4 Optical spectrum issues and availability

Access networks largely employ ITU-T G.652 single mode fibres (SMFs). As is well known, the characteristics of SMF are wavelength dependent. Figure 8-1 shows the attenuation of SMF over wavelength range of interest along with the defined ITU-T bands. The attenuation of an optical signal is lowest in the C-Band and lower L-Band.

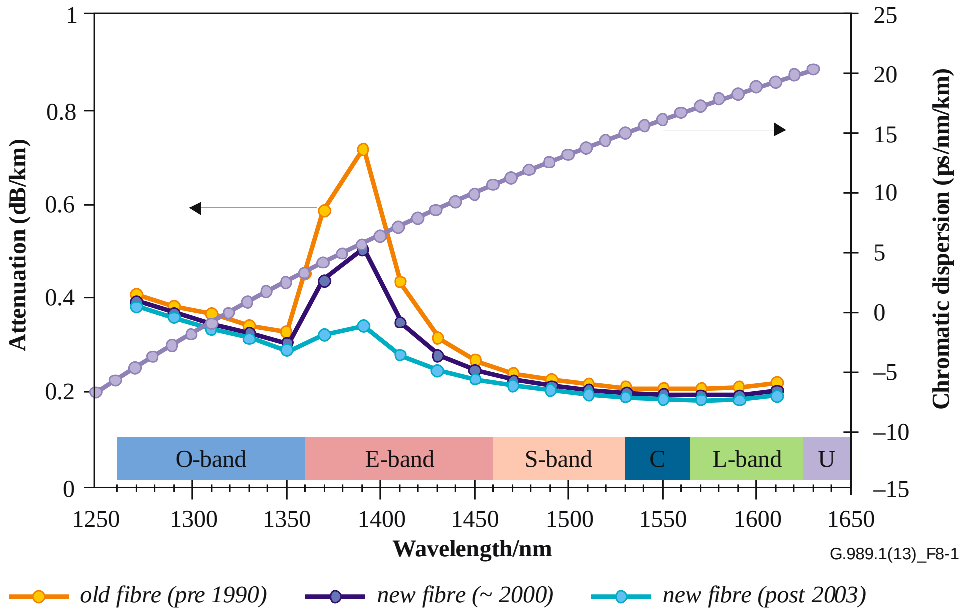


Figure 8-1 – Single mode fibre attenuation and chromatic dispersion

Chromatic dispersion (CD), which can limit system reach as signal line rates increase, is also wavelength dependent with a zero value at ~1310 nm for SMF. The wavelength variation of CD is also shown in Figure 8-1.

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

Wavelength plans (Figure 8-2) of the legacy PON systems that NG-PON2 systems may need to co-exist with must be considered relative to migration and co-existence requirements.

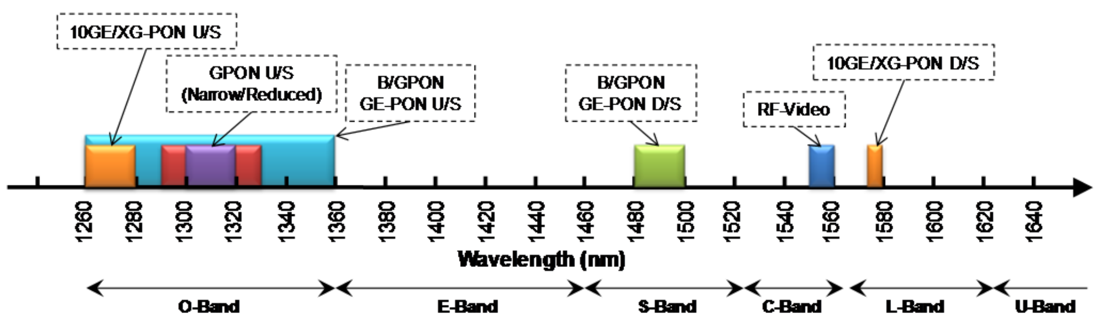


Figure 8-2 – Wavelength plans of legacy PON systems

A further factor that limits the available spectrum are the legacy filter characteristics built into deployed systems. Most significant may be the RF-video filter which may require guardbands that occupy most of the C-band where the fibre loss is low and EDFAs could be used.

9 System requirements

9.1 Colourless ONUs

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

9.2 Spectral flexibility

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

To meet the above requirements, the NG-PON2 system must offer the possibility to access multiple wavelengths, groups of wavelengths, or wavelength bands that can be physically and logically separated and driven independently, either by a single OLT or by multiple independent OLTs, with fully independent operation. This requirement should not increase complexity in system not requiring such flexibility options.

9.3 Rogue ONU/OLT detection and mitigation

NG-PON2 systems should be able to monitor transmissions at the OLT and ONU to guard against ONUs or OLTs that exhibit rogue behaviour (e.g., an ONU transmitting in another ONU's timeslot/wavelength or an OLT transmitting in another OLTs wavelength band). The rogue ONU prevention, detection, isolation and mitigation guidelines defined in [b-ITU-T G-Sup.49], should be followed. Further considerations may be required for the OLT.

9.4 Resilience and redundancy requirements

PON resilience will become more important in supporting business applications and high value consumer applications, such as IPTV, especially in the node consolidation scenario. Node consolidation/bypass creates a high number of subscriber lines on the highly centralized access node. A redundancy mechanism is required to avoid service disruption to potentially thousands of users in the event of fibre cable or equipment failure. Besides the usual hardware redundancy requirements at the OLT and in the backhaul transmission equipment (towards the metro/core), networks require feeder and/or OTL line redundancy options to avoid large scale customer outages as well as full redundancy for business services requiring end-to-end type C protection. NG-PON2 systems must support the resilience options defined in clause 14 of [ITU-T G.984.1] including duplex and dual parenting duplex system configuration as well as the extensions described in

Appendices II and III of [ITU-T G.984.1]. For PON redundancy, use cases and guidelines are defined in [b-ITU-T G-Sup.51].

Figure 9-1 shows an example of fibre path diversity ensuring resilience against cuts in the most vulnerable part of the access network. The redundant feeder fibre could terminate at a diverse CO location, or at the same CO location as the primary OLT.

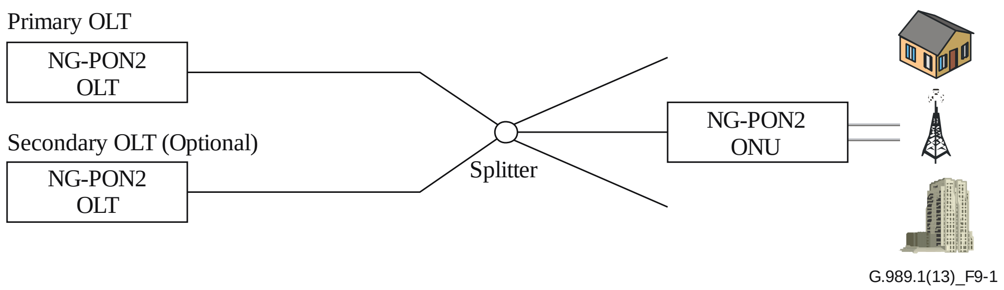


Figure 9-1 – NG-PON2 resilience scenario

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

9.5 Reach extender requirements

NG-PON2 systems must also be capable of reaching 60 km with reach extenders if needed. Preferably this could be achieved whilst maintaining passive outside plant, however, it is recognized that this may be technically challenging so options for mid-span reach extenders may be needed.

Use of a reach extender should not necessitate that the OLT or the ONU be different or modified. Thus NG-PON2 systems must provide PMD and TC layers capable of working transparently with and without a reach extender. Mid-span reach extenders must be remotely manageable through an OLT to enable configuration and monitoring functions for maintenance and fault location. Additionally reach extender based scenarios must also be compatible with co-existence scenarios, resilience and redundancy options.

Furthermore, being remotely located in the outside network, the reach extender should have minimal power requirements and must be able to operate over outdoor temperature ranges. The following are informative examples of environmental requirements:

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

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

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

9.6 Power reduction

Power saving in telecommunication network systems has become an increasingly important concern in the interest of reducing operational costs and reducing the network contribution to greenhouse gas emission. NG-PON2 systems must be designed in the most energy-efficient way. This applies to the OLT side and even more to the ONU side since the energy consumption is not shared at the ONU except for FTTC/B. In some instances, the primary objective of the power saving function in access networks is to maintain the lifeline service(s), such as a voice service, as long as possible through the use of a backup battery when electricity service goes out. A lifeline interface must be sustainable for at least eight hours after mains power outage, and options such as allowing four hours of talk time while an ONU is in sleep mode for an extended period (e.g., one week) should be offered. Therefore, the NG-PON2 system shall support improving energy efficiency whilst maintaining compatibility with the service requirements. Mechanisms derived from [b-ITU-T G-Sup.45] and specified in [ITU-T G.987] series may be appropriate or new mechanisms may be required depending on the chosen technology. NG-PON2 systems must aim to reduce power consumption during normal operation without sacrificing service quality and user experience.

9.7 OAM functions

High levels of security are required from NG-PON2 systems and these systems must be at least as secure as XG-PON1. In multiple service applications, enhanced security may be required to distinguish data between services in the OLT and ONUs must be subject to more secure authentication. The NG-PON2 ONUs must be remotely manageable and support auto-configuration functions. The NG-PON2 system must provide full FCAPS (Fault, Configuration, Accounting, Performance, and Security) management capability for the ONU.

The TWDM channels in the NG-PON2 system must support DBA for efficient sharing of bandwidth. This is not required for the PtP WDM channels.

NG-PON2 systems must support PON supervision features that enable enhanced customer experience through early identification and location of faults (including splitter) at the physical, PON and service layers. This could include as examples ODN monitoring/checking and end-to-end performance monitoring up to the Ethernet layer. Optical layer monitoring must not impact PON operation nor limit co-existence with legacy PON systems and their associated monitoring systems e.g., OTDR.

9.8 Provisioning and management

Given the significant effort already expended in defining a converged management framework across optical access systems, ONU management in NG-PON2 systems must be based on OMCI [ITU-T G.988] suitably augmented with NG-PON2 specific MEs.

9.9 Environmental and physical requirements

Outdoor operation may be needed in many of the envisaged applications for NG-PON2 systems; thus ONUs shall operate over outdoor temperature ranges. The following are informative examples of environmental requirements:

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

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

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

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

9.10 Eye safety

With the capacity increases and demands on enhanced loss budgets it is expected that an NG-PON2 system could launch significantly higher total power into the feeder fibres when compared to previous PON generations. All necessary mechanisms must be provided to ensure that no eye damage can be caused to end users unaware of the risks associated with a fibre termination inside the home or customer premises, including labelling and safety locking mechanisms if necessary. The system must meet all applicable requirements for the classification, service group designation, and accessibility to ensure the safe operation and servicing of the optical fibre communication system at each node. Since the NG-PON2 system could co-exist with other PON generations and RF video, the total optical power resulting from all the different wavelengths on the fibre must be within the safe operation range specified at each location, for example Class 1M at restricted access areas (OLT and RE) and Class 1 at unrestricted access areas such as the home (ONU) shown in [IEC 60825-2].

9.11 Interoperability

The NG-PON2 standard must support interoperability between the OLT and ONU. All relevant interfaces to facilitate interoperability shall be defined in the appropriate ITU-T Recommendations.

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