Q2 Optical Access Networks

Work program review

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OFC

Overview of ITU-T PON Solutions

1 Gb/s per channel	2.5 Gb/s per channel	10 Gb/s per channel	25 Gb/s per channel	50 Gb/s per channel
Splitter-based ODN Single channel TDMA systems				
	G-PON G.984.x series 1	**XG-PON (NG-PON1)** G.987.x series 2 **XGS-PON** G.9807.x series 3		**50G-PON** G.9804.x series 5.1
Splitter-based ODN Multi-channel TWDM systems				
		NG-PON2 G.989.x series 4.1		**Nx50G-PON** G.9804.x series 5.2
Splitter-based ODN Multi-channel WDM Overlay				
NG-PON2 4.2 G.989.x series	**NG-PON2** 4.2 G.989.x series	**NG-PON2** 4.2 G.989.x series		
Wavelength multiplexed ODN with logical point to point connections (a.k.a. WDM-PON)				
For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15			**25GMW-PON** G.9802.x series 6	

1. G.984.x series – Gigabit-capable passive optical networks (G-PON)
Both symmetrical and asymmetrical nominal line rates of 1244.16 Mbit/s and 2488.32 Mbit/s in the downstream direction and 155.52 Mbit/s, 622.08 Mbit/s, 1244.16 Mbit/s and 2488.32 Mbit/s in the upstream direction.

2. G.987.x series - 10-Gigabit-capable passive optical networks (XG-PON)
Asymmetrical nominal line rate of 9.95328 Gbit/s in the downstream direction and 2.48832 Gbit/s in the upstream direction.

3. G.9807.x series - 10-Gigabit-capable symmetric passive optical networks (XGS-PON)
Symmetrical nominal line rate of 9.95328 Gbit/s in both the downstream and upstream directions.

4.1. G.989.x series - 40-Gigabit-capable passive optical networks (NG-PON2) - Splitter-based ODN Multi-channel TWDM systems
Nx10 Gbit/s with N = up to 4 TWDM channels , optional extended up to 8 TWDM channels
Downstream/Upstream nominal line rates (Gbit/s) per channel:
- Basic rate: 9.95328/2.48832
- Rate option 1: 9.95328 /9.95328
- Rate option 2: 2.48832/2.48832

4.2. G.989.x series - 40-Gigabit-capable passive optical networks (NG-PON2) - Splitter-based ODN Multi-channel WDM Overlay (PtP wavelength overlay channels)
Symmetric Downstream and Upstream nominal line rates per channel:
- Line rate class 1 from 1.2288 Gbit/s to 1.25 Gbit/s
- Line rate class 2 from 2.4576 Gbit/s to 2.666 Gbit/s
- Line rate class 3 from 6.144 Gbit/s to 11.09 Gbit/s

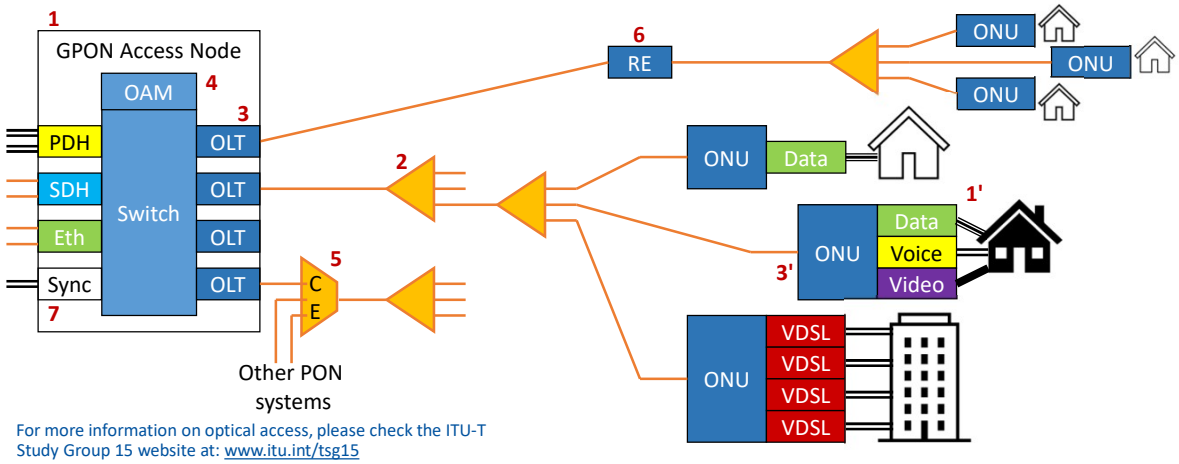
5.1. G.9804 series – Higher speed passive optical networks (HSP) - Splitter-based ODN Single channel TDMA systems
50 Gbit/s single channel TDMA-PON system with nominal line rates of 49.7664 Gbit/s in the downstream direction and 49.7664 Gbit/s, 24.8832 Gbit/s, or 12.4416 Gbit/s in the upstream direction

5.2. G.9804 series - Higher speed passive optical networks (HSP) - Splitter-based ODN Multi-channel TWDM systems
50 Gbit/s multiple channels TWDM-PON system with nominal line rates per channel of 49.7664 Gbit/s in the downstream direction and 49.7664 Gbit/s, 24.8832 Gbit/s, or 12.4416 Gbit/s in the upstream direction

6. G.9802.x series - Multiple-wavelength passive optical networks (MW-PON)
Channel count options of 12/20/40 wavelength channel pairs
Symmetric nominal line rate combination options per wavelength channel:
- 25 Gbit/s
- 10 Gbit/s
- open to other nominal line rates with individual evolution per OLT-CT

G.984: Gigabit Passive Optical Networks

- Full-service support – including voice, TDM, Ethernet (10/100/1000 BaseT), xDSL, leased lines, wireless extension and more
- Logical reach of up to 60 km. Basic physical reach 20 km, and reach extension provides 60 km physical reach
- Support for bit-rate options, the most important being 2.5 Gbit/s downstream and 1.25 Gbit/s upstream
- Strong Operation, Administration, Maintenance and Provisioning (OAM&P) capabilities for end-to-end service management
- Security at the protocol level for downstream traffic due to the broadcast nature of PON



For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15

1. G.984.1 – Gigabit-capable passive optical networks (G-PON): General characteristics Provides examples of services, User Network Interfaces (UNI) and Service Node Interfaces (SNI) that are required by network operators. In addition, it shows the principal deployment configuration. Wherever possible, this Recommendation maintains characteristics from the ITU-T G.982 and G.983.x series Recommendations in order to promote backward compatibility with existing Optical Distribution Networks (ODN) that comply with these Recommendations.

1'. ONU applications and services The G-PON system is intended to be a full-service access network. A key part of that is the extreme diversity of ONU types and form factors. The simplest optical network unit (ONU) would have a single data UNI. More elaborate ONUs can have multiple UNIs for the range of services consumed by a single user. A wide range of UNIs are possible, ranging from the simplest voice UNI to Ethernet, wireless data (802.11) and video (Coaxial networking) UNIs. Even more complex ONUs can have many interfaces to serve apartment buildings and businesses. It is also possible to serve wireless access networks (FTTwireless) and FTTdrop-point networks (not shown).

2. G.984.2 – Gigabit-capable passive optical networks (G-PON): Physical media dependent (PMD) layer specification Provides the physical layer requirements and optical specifications for the PMD layer. This Recommendation covers systems with nominal line rates of 2488.32 Mbit/s in the downstream direction and 1244.16 Mbit/s in the upstream direction, as well as other rates. The PMD is designed to operate bidirectionally over a single strand of single mode optical fibre (G.652). The downstream wavelength is 1480 to 1500 nm, and the upstream wavelength is 1300 to 1320 nm (plus other options). The ODN is composed of fibres, passive splitters and connectors.

3. G.984.3 – Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification Provides the frame format and media access control method, including the means and policies of Dynamic Bandwidth Allocation (DBA). It describes the ranging and activation processes, and the physical layer management (PLOAM) functionality that supports them. Security and authentication are also described.

3'. ONU behaviour The approach taken in G.984.3 is to describe in detail the behaviour of the ONU, leaving the detailed behaviour of the OLT to the implementer. The approach makes it possible to test for ONU conformance to the specifications. This makes the interoperability of different vendor's ONUs on a single PON possible. There are conformance and interoperability testing programs organized by the Broadband Forum (BBF).

4. G.988 – ONU management and control interface (OMCI) specification Defines the managed entities of a protocol-independent Management Information Base (MIB) that models the exchange of information between the Optical Line Termination (OLT) and the ONU, not only for G-PON, but all PON systems standardized after G-PON. The MIB describes the wide range of UNIs that an ONU may support. It covers the ONT management and control channel, protocol and messages.

5. G.984.5 – Gigabit-capable passive optical networks (G-PON): Enhancement band Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength-division multiplexing (WDM) in future PONs for maximizing the value of ODNs. The details of both the coexistence element (CE) and the blocking filter at the ONU are described. As new PON systems are standardized, this standard is updated to account for them.

6. G.984.6 – Gigabit-capable passive optical networks (G-PON): Reach extension Outlines the architecture and interface parameters for G-PON systems with extended reach using a physical layer reach extension device, including regenerators or optical amplifiers. The maximum physical reach is up to 60 km, with loss budgets in excess of 27.5 dB being achievable in both spans. This new capability will allow operators to provide optical access service to areas that were previously out of reach, and also explore new network designs for greater central office consolidation.

7. Synchronization and timing have long been supported as part of the G-PON system. More recent amendments to G.984.3 and G.988 have included methods for transferring precision timing information over the PON system, avoiding the inherent TDMA timing asymmetry.

G.984.5: Gigabit Passive Optical Networks: Enhancement band and PON Coexistence

- G.984.5 defines wavelength ranges reserved for additional service signals to be overlaid via WDM with G-PON, including:
  - Wavelength ranges to be reserved as the enhancement band
  - Reference diagram of coexistence element, and sample parameters of a discrete WDM filter that enables PON evolution
  - Multi-PON modules with integrated WDM to support legacy PON and NG-PON coexistence
  - X/S tolerance in PON optical network units (ONUs) and PON optical line terminals (OLTs)
  - Methods for calculating required isolation for WDM/CE/CEM device

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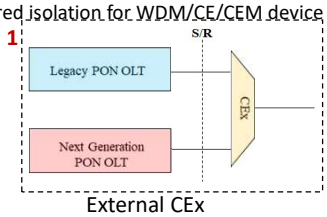
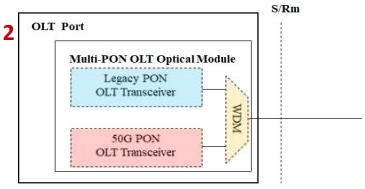
Two methods support for PON evolution: External CEx and MPM

1



External CEx

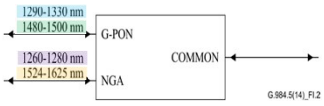
2



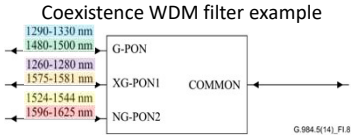
MPM

3

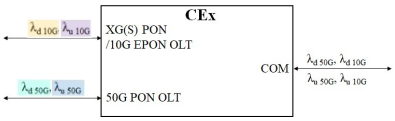
GPON and XG(S)-PON Coexistence WDM filter example



GPON , XG(S)-PON and NG-PON Coexistence WDM filter example



XG(S)-PON/10G EPON and 50G-PON Coexistence WDM filter example



The detail specification of the coexistence filter and the calculation method are defined in G.984.5

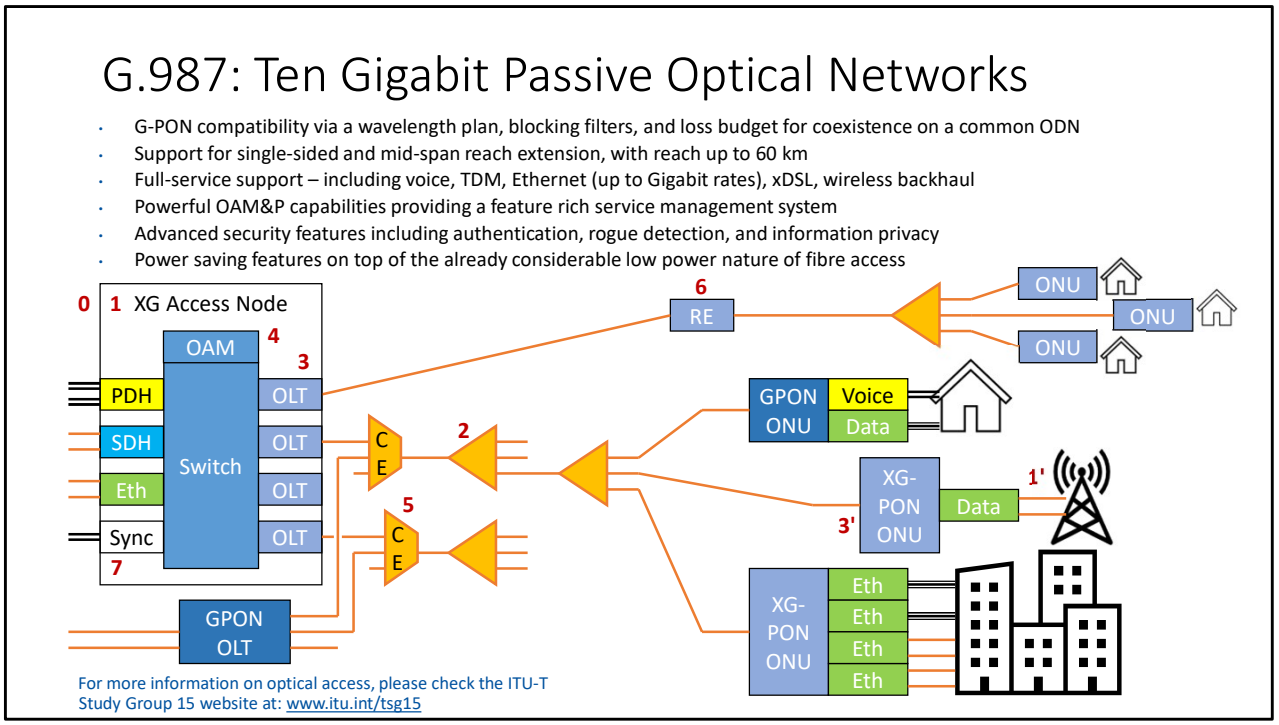
For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15

0. G.984.5 - Gigabit-capable passive optical networks (G-PON): Enhancement band Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength division multiplexing (WDM). Includes external coexistence element (CEx) and multi-PON module (MPM) methods to coexist multiple PON generations on a common optical distribution network (ODN) to reuse deployed fibre and splitters to evolve operator networks to higher capacity.

1. External coexistence element (CEx) The external CEx method enables multiple PON generations coexistence in one ODN via an individual device. Insertion loss parameters with isolation and directivity calculation are provided in several appendices.

2. Multi-PON module (MPM) with integrated WDM The optical line terminal (OLT) MPM contains an integrated WDM function. When a PON system is migrated from a legacy PON to a next generation (NG)-PON with the MPM method, operators can replace their existing legacy PON line cards with new line cards that support multiple PON technologies. This eliminates the need for an external CEx.

3. Examples of CEx are contained in G.984.5. Example specifications for these elements are given for commonly encountered coexistence situations.



0. G.987 – 10-Gigabit-capable passive optical network (XG-PON) systems: Definitions and abbreviations Establishes the common terms and acronyms used in the series, as well as delineating the various optical access topologies.

1. G.987.1 – 10-Gigabit-capable passive optical networks (XG-PON): General requirements Provides examples of services, User Network Interfaces (UNI) and Service Node Interfaces (SNI) that are required by network operators. In addition, it shows the principal deployment configuration. Wherever possible, this Recommendation maintains characteristics from the ITU-T G.984.x series Recommendations. The most important requirement is the backward compatibility with existing Optical Distribution Networks (ODN) that comply with these Recommendations.

1'. ONU applications and services The XG-PON system is intended to be a full-service access network. A key part of that is the extreme diversity of optical network units (ONU) types and form factors. In addition to all the applications described for G-PON, the higher capacity of XG-PON opens new possibilities. Examples of these are serving 4G cell sites and various enterprises. Existing G-PON ONUs can remain in service alongside the XG-PON ONUs, allowing for easier system upgrades.

2. G.987.2 – 10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification Provides the physical layer requirements and optical specifications for the PMD layer. This Recommendation covers systems with nominal line rates of 9953.28 Mbit/s in the downstream direction and 2488.32 Mbit/s in the upstream direction, as well as other rates. The PMD is designed to operate bidirectionally over a single strand of single mode optical fibre (G.652). The downstream wavelength band is 1575 to 1580 nm, and the upstream wavelength band is 1260 to 1280 nm (with options). This wavelength plan allows coexistence with G-PON.

3. G.987.3 – 10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification Provides the frame format and media access control method, which are largely based upon the G-PON system with some field size adjustments. It describes the ranging and activation processes, dynamic bandwidth allocation (DBA), and the physical layer management (PLOAM) functionality that supports them. Security and authentication are also described.

3'. ONU behaviour The approach taken in G.987.3 is to describe in detail the behaviour of the ONU, leaving the detailed behaviour of the optical line terminal (OLT) to the implementer. The approach makes it possible to test for ONU conformance to the specifications. This makes the interoperability of different vendor's ONUs on a single PON possible. There are conformance and interoperability testing programs organized by the Broadband Forum (BBF).

4. G.988 – ONU management and control interface (OMCI) specification Defines the managed entities of a protocol-independent Management Information Base (MIB) that models the exchange of information between the OLT and the ONU, not only for XG-PON, but all PON systems. The MIB describes the wide range of UNIs that an ONU may support. It covers the ONT management and control channel, protocol, and messages.

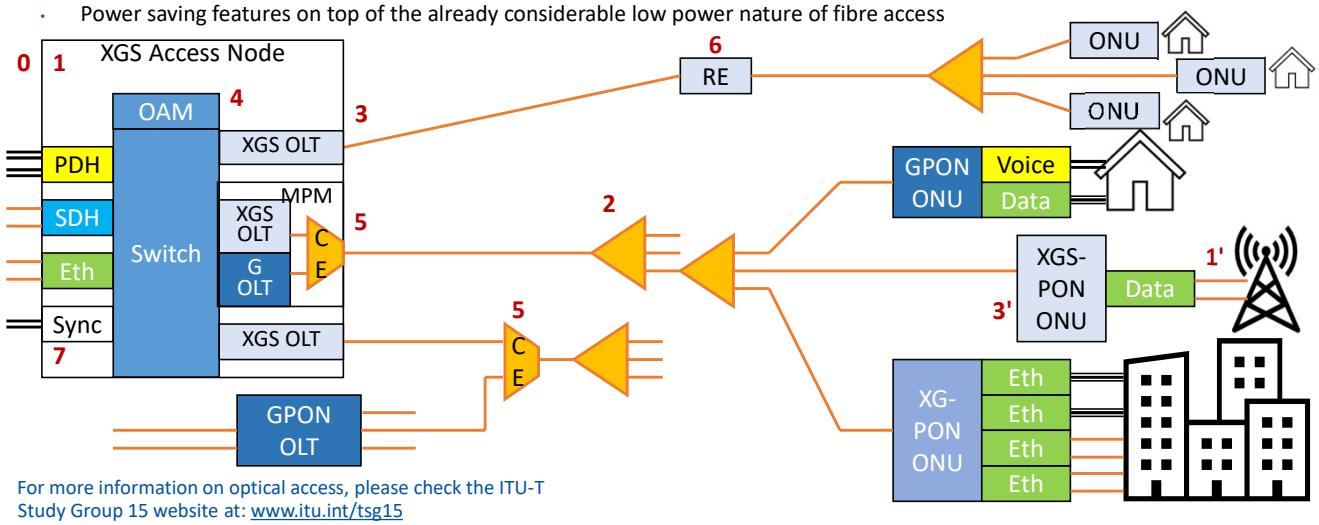
5. G.984.5 – Gigabit-capable passive optical networks (G-PON): Enhancement band Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength-division multiplexing (WDM) in future PONs for maximizing the value of ODNs. The details of both the coexistence element (CE) and the blocking filter at the ONU are described. As new PON systems are standardized, this standard is updated to account for them.

6. G.987.4 – 10-Gigabit-capable passive optical networks (XG-PON): Reach extension Outlines the architecture and interface parameters for XG-PON systems with extended reach using a physical layer reach extension device, including regenerators or optical amplifiers. The maximum physical reach is up to 60 km, with loss budgets in excess of 28.5 dB being achievable in both spans. This new capability will allow operators to provide optical access service to areas that were previously out of reach, and also explore new network designs for greater central office consolidation.

7. Synchronization and timing are supported as part of the XG-PON system. G.987.3 describes methods for transferring precision timing information over the PON system, avoiding the inherent TDMA timing asymmetry. This is increasingly important for various wireless applications.

G.9807: Ten Gigabit Symmetric Passive Optical Networks

- G-PON compatibility via a wavelength plan, blocking filters, loss budget for coexistence on a common ODN, and a combo OLT
- Support for single-sided and mid-span reach extension, with reach up to 60 km
- Full-service support with symmetric rate – including voice, TDM, Ethernet (up to Gigabit rates), xDSL, wireless xhaul
- Powerful OAM&P capabilities providing a feature rich service management system
- Advanced security features including authentication, rogue detection, and information privacy
- Power saving features on top of the already considerable low power nature of fibre access



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0. G.9807.1, Clauses 3-5 – 10-Gigabit-capable symmetric passive optical network (XGS-PON), definitions/ acronyms/ conventions Establish the common terms and acronyms used in the series, and delineate the various optical access topologies.

1. G.9807.1, Annex A – General requirements of XGS-PON Provides examples of services, User Network Interfaces (UNI) and Service Node Interfaces (SNI) that are required by network operators. In addition, it shows the principal deployment configuration. The most important requirement is the backward compatibility with existing Optical Distribution Networks (ODN) that comply with G.984.x, G.987.x and G.989.x series of Recommendations.

1'. ONU applications and services The XGS-PON system is intended to be a full-service access network. A key part of that is the extreme diversity of optical network unit (ONU) types and form factors. In addition to all the applications described for G-PON, the higher capacity of XGS-PON opens new possibilities. Examples of these are serving 4G cell sites and various enterprises. Existing G-PON ONUs can remain in service alongside the XGS-PON ONUs, allowing for easier system upgrades.

2. G.9807.1, Annex B – Physical media dependent (PMD) layer specifications of XGS-PON Specifies the physical layer requirements and specifications for the PMD layer. This Recommendation covers systems with nominal line rates of 9953.28 Mbit/s in both the downstream and upstream directions. The PMD is designed to operate bidirectionally over a single strand of single mode optical fibre (G.652). The basic wavelength plan specifies downstream wavelength band as 1575 to 1580 nm, and upstream wavelength band as 1260 to 1280 nm. This wavelength plan allows wavelength division multiplex (WDM) coexistence with G-PON and NG-PON2, and time division multiplex (TDM) coexistence with XG-PON and XGS-PON ONUs. The optional wavelength plan contains downstream wavelength band of 1480 to 1500 nm, and upstream wavelength band of 1300 to 1320 nm which allows WDM coexistence with XGS-PON and NG-PON2.

3. G.9807.1, Annex C – Transmission convergence layer specification of XGS-PON Defines the frame format and media access control method, which are largely based upon the XG-PON system with small adjustments for 10G symmetry. It describes the ranging and activation processes, dynamic bandwidth allocation (DBA), and the physical layer management (PLOAM) functionality that supports them. Security, power saving, protection, and rogue ONU mitigation are described.

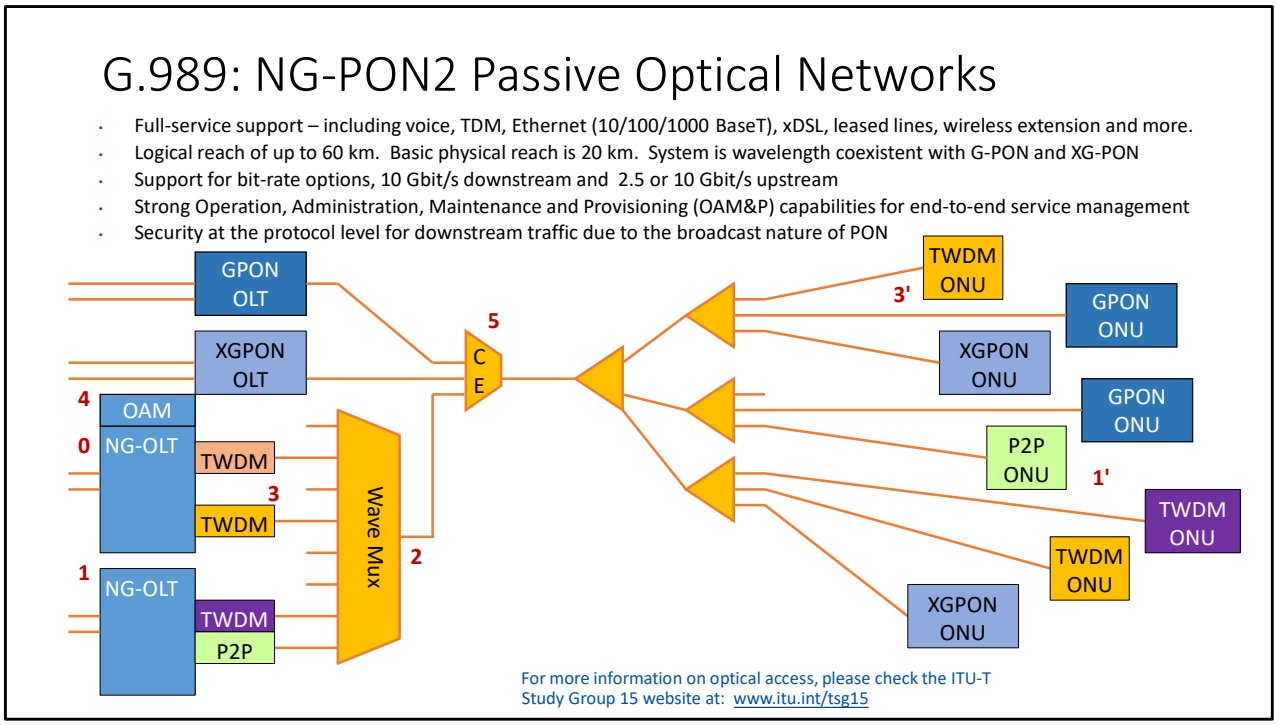
3'. ONU behaviour The approach taken in G.9807.1, Annex C is to describe in detail the behaviour of the ONU, leaving the detailed behaviour of the optical line terminal (OLT) to the implementer. The approach makes it possible to test for ONU conformance to the specifications. This makes the interoperability of different vendor's ONUs on a single PON possible. There are conformance and interoperability testing programs organized by the Broadband Forum (BBF).

4. G.988 – ONU management and control interface (OMCI) specification Defines the managed entities of a protocol-independent Management Information Base (MIB) that models the exchange of information between the Optical Line Termination OLT and the ONU, not only for XGS-PON, but all PON systems. The MIB implicitly describes in detail the wide range of UNIs that an ONU may support. It covers the ONT management and control channel, protocol and detailed messages.

5. G.984.5 – Gigabit-capable passive optical networks (G-PON): Enhancement band Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength-division multiplexing (WDM) in future PONs for maximizing the value of ODNs. The details of both the coexistence element (CE) and the blocking filter at the ONU are described. As new PON systems are standardized, this standard is updated to account for them.

6. G.9807.2 – 10 Gigabit-capable passive optical networks (XG(S)-PON): Reach extension Outlines the architecture and interface parameters for XGS-PON systems with extended reach using a physical layer reach extension device, including regenerators or optical amplifiers. Wavelength converting, continuous mode, 1:N and combination type reach extenders (REs) are also described. The maximum reach is up to 60 km with loss budgets in excess of 28.5 dB being achievable in both spans. This new capability will allow operators to provide optical access service to areas that were out of reach, and explore new network designs for greater central office consolidation.

7. Synchronization and timing are supported as part of the XGS-PON system. G.9807.1 Annex C describes methods for transferring precision timing information over the PON system. This is important for various wireless applications.



0. G.989 – 40-Gigabit-capable passive optical networks (NG-PON2): Definitions and abbreviations Establishes the common terms and acronyms used in the series, as well as delineating the various optical access topologies.

1. G.989.1 – 40-Gigabit-capable passive optical networks (NG-PON2): General requirements Provides examples of services, User Network Interfaces (UNI) and Service Node Interfaces (SNI) that are required by network operators. In addition, it shows the principal deployment configuration. Wherever possible, this Recommendation maintains characteristics from the ITU-T G.987.x series Recommendations. The NG-PON2 system contains both a time and wavelength division multiplexed (TWDM) capability as well as a point to point (P2P) capability. Several OLT styles are supported (single chassis, multi-chassis, integrated multi-channel line cards, and pay-as-you-grow pluggable line cards).

1'. ONU applications and services The NG-PON2 system is intended to be a full-service access network. A key part of that is the extreme diversity of ONUs coexisting on a common PON. G-PON and XG-PON legacy ONUs are supported, as well as TWDM ONUs (with tunable burst mode optics) and P2P ONUs (with tunable continuous mode optics). Each of those ONU types can then support many different UNIs, making NG-PON2 the 'Swiss army knife" of PON Recommendations.

2. G.989.2 – 40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification Provides the physical layer requirements and specifications for the PMD layer. This Recommendation covers systems with nominal line rates of 9953.28 Mbit/s in the downstream direction and either 9953.28 Mbit/s or 2488.32 Mbit/s in the upstream direction, as well as other rates. The PMD is designed to operate bidirectionally over a single strand of single mode optical fibre (G.652). The downstream wavelengths are in the L-band and the upstream wavelengths are in the C-band. A channel grid is defined in these bands, which is physically realized in the wavelength multiplexer (WM) device. The ODN is composed of fibres and passive optical splitters and connectors.

3. G.989.3 – 40-Gigabit-capable passive optical networks (NG-PON2): Transmission convergence layer specification Defines the frame format and media access control method, and all the usual functions that have been described in previous PON generations. New additions here are the many new PLOAM messages to handle the set-up and operation (e.g., tuning) of the multi-channel system. Support for multiple TWDM-PON OLTs sharing the same ODN is described, as well as new forms of wavelength protection.

3'. ONU behaviour The approach taken in G.989.3 is to describe in detail the behaviour of the optical network unit (ONU), leaving the detailed behaviour of the optical line terminal (OLT) to the implementer. The approach makes it possible to test for ONU conformance to the specifications. This makes the interoperability of different vendor's ONUs on a single PON possible. There are conformance and interoperability testing programs organized by the Broadband Forum (BBF).

4. G.988 – ONU management and control interface (OMCI) specification Defines the managed entities of a protocol-independent Management Information Base (MIB) that models the exchange of information between the OLT and the ONU, not only for G-PON, but all PON systems standardized after G-PON. The MIB implicitly describes in detail the wide range of UNIs that an ONU may support. It covers the ONT management and control channel, protocol and messages.

5. G.984.5 – Gigabit-capable passive optical networks (G-PON): Enhancement band Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength-division multiplexing (WDM) in future PON for maximizing the value of ODNs. The details of both the coexistence element (CE) and the blocking filter at the ONU are described. As new PON systems are standardized, this standard is updated to account for them.

G.988: ONU Management and Configuration Interface

- The OMCI is the recommended way to manage ONU equipment via the OLT, and is the key to ONU interoperability
- Support for ONU configuration, fault reporting, performance monitoring, and security in an extensible manner
- Over 341 managed entities and their relationships defined covering a wide range of ONU services and interfaces
- Defines a message set and message exchanges for all OMCI functions, allowing for easier implementation
- Alternative management methods are supported, as well as extra features such as protection, bonding, and more

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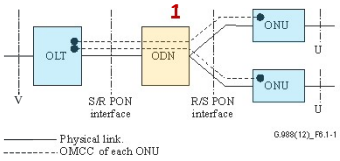


2

9.1.1 ONU-G

This ME represents the ONU as equipment. The ONU automatically creates an instance of this ME. It assigns values to read-only attributes according to data within the ONU itself.

This ME has evolved from the ONT-G of [ITU-T G.984.4].

Relationships

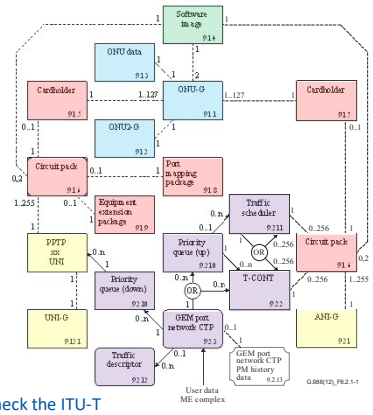
In ITU-T GTC based PON applications, all other MEs in this Recommendation are related directly or indirectly to the ONU-G entity.

Attributes

Managed entity ID: This attribute uniquely identifies each instance of this ME. There is only one instance, number 0. (R) (mandatory) (2 bytes)

Vendor ID: This attribute identifies the vendor of the ONU. It is the same as the four most significant bytes of the ONU serial number as specified in the respective transmission convergence (TC) layer specification. (R) (mandatory) (4 bytes)

3



4

Field	Byte	8	7	6	5	4	3	2	1	Comments
Transaction correlation identifier	1-2									
Message type	3	0	1	0						DB = 0, AR = 1, AK = 0 bits 5-1: action = create
Device identifier	4	0	0	0	0	1	0	1	1	Extended OMCI = 0x0B
Managed entity identifier	5-6									Entity class
	7-8									Entity instance
Message contents length	9-10									Size of message contents field, bytes
Message contents	11-n									Value of first set-by-create attribute, NOT the ME ID (size depending on the type of attribute)
										...
										Value of last set-by-create attribute
MIC										Message integrity check, 4 bytes

For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15

1. G.988 – ONU management and control interface (OMCI) specification Describes everything about how an optical line terminal (OLT) equipment can manage its subtending optical network units (ONUs). An important feature of the OMCI is that the OLT acts as a proxy for all of its ONUs. In this way, the element management system only needs to manage one OLT rather that 4000 ONUs. This greatly improves scalability.

The basic connectivity of the OMCI is a one-to-one connection between each ONU and its representation in the OLT. The OLT maintains a copy of each ONU's Management Information Base (MIB), and one of the tasks of the OMCI is to synchronize the MIBs. Because the OLT has this MIB, an ONU can be pre-provisioned even before it is attached to the PON or equipped with new line-cards. This expedites deployment.

2. Managed entity (ME) The basic data unit in the OMCI is the managed entity (ME). Every ME instance has a unique combination of ME-type and an ME-ID. Some MEs are created by the ONU by virtue of what functions and interfaces it has. Others are created by the OLT to establish services. Some MEs have alarms to signal specific events occurring in the ONU. Some ME's have test actions associated with them to allow the OLT to run functional tests on the ONU.

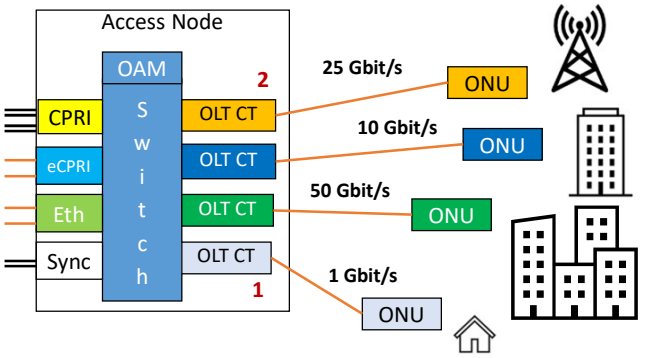
Each ME contains up to 16 attributes, each of which has certain read, write, and set-by-create properties. Many attributes a tied to a particular service configuration value or performance monitoring counter. Others are pointers that indicate relationships between the MEs. Attributes can also have threshold crossing alarms. The original gangsta attribute is limited to 25 bytes, but this has been extended in several ways. Table attributes are also supported to provide even larger storage capabilities.

3. Managed entity (ME) relationship The MEs in an ONU are interconnected to indicate their relationship. Most of these associations are explicit pointers, but some are implicit and based on the ME-IDs. There are several major ME relationship groups, the ONU core and the Layer 2 bridging being very central to how an ONU creates connections and manages traffic. In general, there is a ME relationship group for each kind of UNI, and then these UNIs connect into the bridging complex which in turn connects into the ONU core. By constructing this sort of connection, a user service is defined.

4. Messages definition The detailed messages are defined by the OMCI as the ONU management and control channel protocol specification. This defines all the messages that can be sent between the OLT and ONU to the bit and byte level, as well as the specific interactions (the sequence of messages to cause a particular outcome).

G.986: 1 Gbit/s point-to-point optical access system
G.9806: Higher-speed bidirectional point-to-point

- Single fibre, point-to-point bi-directional (BiDi) transmission suite of recommendations for 1, and 10, 25 and 50 Gbit/s
- Optical budget classes cover up to 40 km with a minimal number of module types to simplify inventory and avoid gaps
- Full-service support with symmetric rates compatible with various wireless xhaul functional splits among other applications
- Powerful OAM&P capabilities providing a feature rich service management system to maximize commonality with PON operation
- A silent start feature to avoid alien ONU behaviours disturbing PONs when inserted by mistake



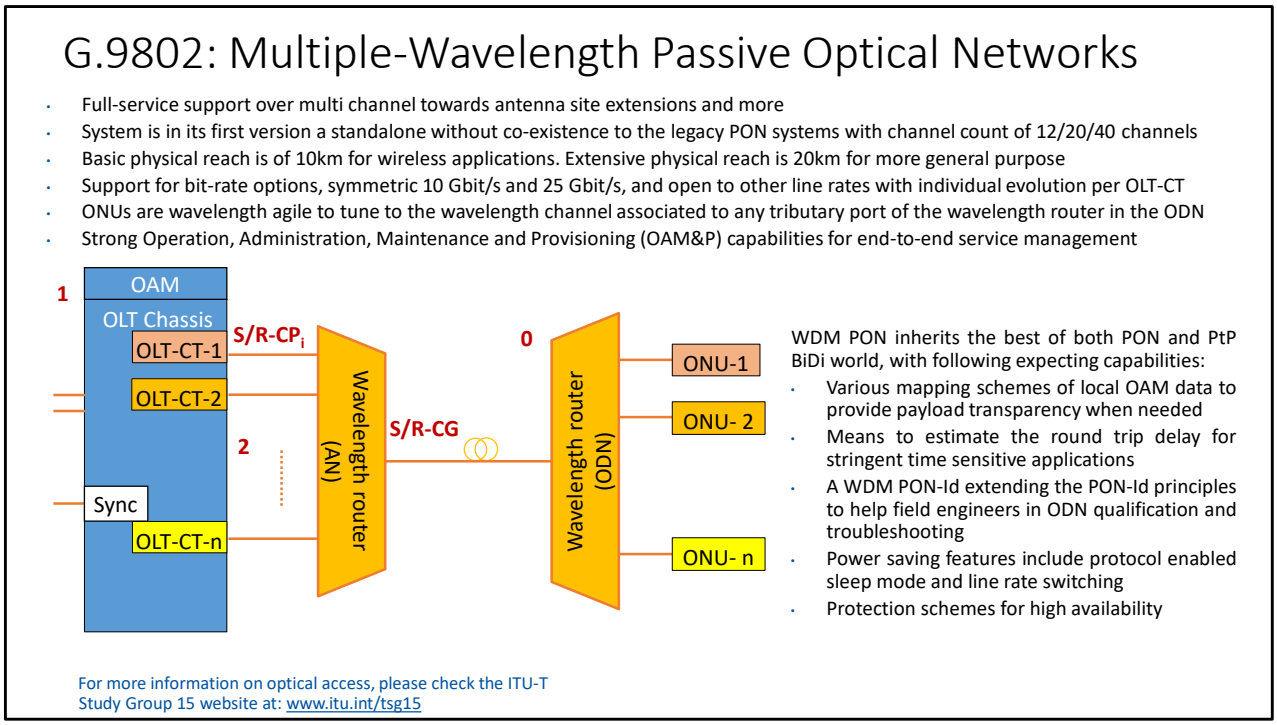
Additional functions added in G.9806:

- Various mapping schemes of local OAM data provide payload transparency when needed
- Means to estimate the round trip delay for stringent time sensitive applications
- A point-to-point Id mimicking the PON-Id to help field engineers in ODN qualification and troubleshooting
- A power saving feature, i.e., line rate switching, enables dynamic adjustment of the line rate to the actual payload
- Maximal convergence in specifications with 802.3 broadens the optical component market

For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15

1. G.986 – 1 Gbit/s point-to-point Ethernet-based optical access system Describes a 1 Gbit/s point-to-point Ethernet-based optical access system for the optical access services including the optical distribution network (ODN) specification, the physical layer specification and the operation, administration and maintenance (OAM) specification.

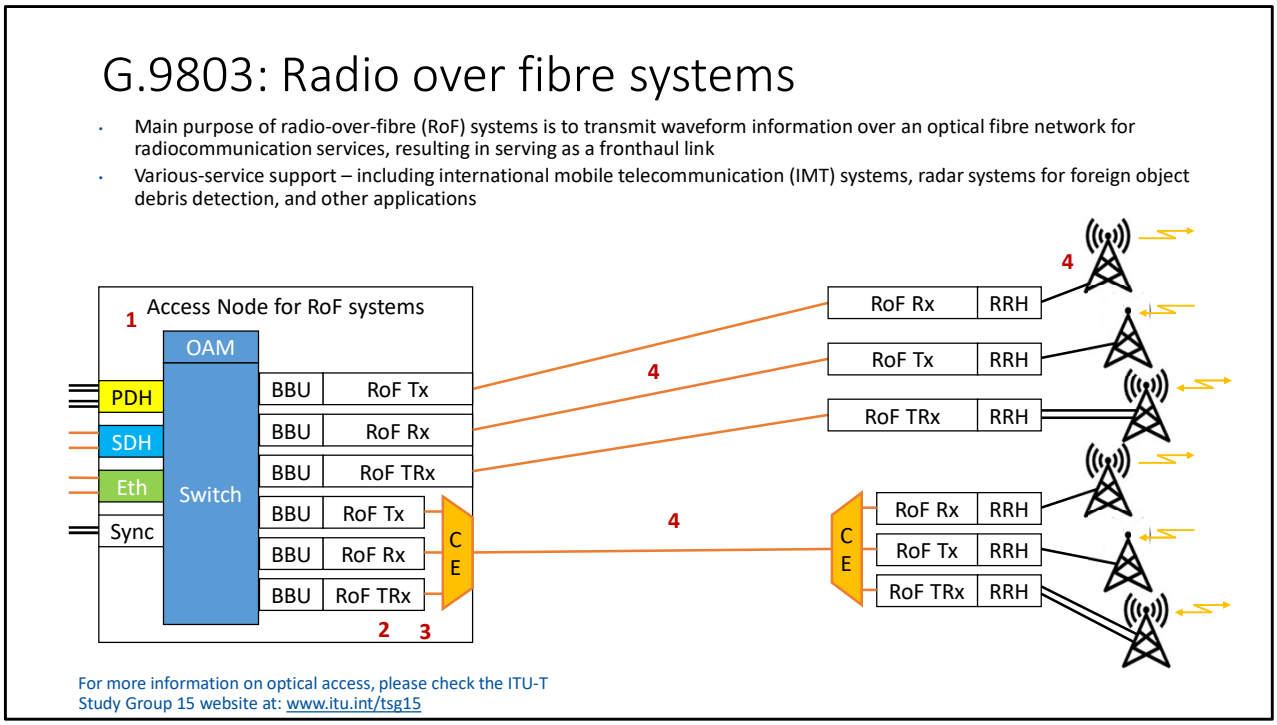
2. G.9806 – Higher-speed bidirectional, single fibre, point-to-point optical access system (HS-PtP) Describes a higher speed bidirectional single fibre point-to-point optical access system than the data rate in existing ITU-T point-to-point access systems. It supports 10 Gbit/s, 25 Gbit/s and 50 Gbit/s for the optical access services including the optical distribution network (ODN) specification, the physical layer specification, services requirements and the operation, administration and maintenance (OAM) specification.



0. G.9802 - Multiple-wavelength passive optical networks (MW-PONs) Describes the general requirements and architecture of PON systems that support multiple wavelengths. It specifies the mechanism of wavelength assignment, wavelength tuning, and wavelength maintenance in MW-PON systems. The functionalities of wavelength resource management and wavelength channel performance monitoring and supervision are also included within the scope of this Recommendation.

1. G.9802.1 - Wavelength division multiplexed passive optical networks (WDM PON): General requirements Defines the general requirements of WDM PON using wavelength routed optical distribution network (WR-ODN), i.e. based on a wavelength multiplexer in the ODN. It provides requirements of WR-ODN based WDM PON, including general system architecture, service requirements, physical layer requirements (e.g., reach, channel count options), system level requirements (e.g., line rates, coexistence), and operational requirements (e.g. guidelines for provisioning, monitoring, energy efficiency).

2. G.9802.2 - Wavelength division multiplexed passive optical networks (WDM PON): Physical media dependent (PMD) layer and transmission convergence (TC) layer specification Gives detailed descriptions of both the physical media dependent (PMD) and transmission convergence (TC) layers of WR-ODN based WDM PON. The PMD layer specification will include the reference logical architecture, wavelength plan, optical path loss, transmitter and receiver specifications, compatible ODN etc. The TC layer specification will include the FEC code, implementation methods of the management channel, management functions, a set of processes and messages, etc. to provide similar operation experience as legacy PON systems, e.g., silent start and capability to map a local PLOAM channel.



1. G.9803, Clauses 6&7 – RoF systems fundamental architecture and requirements Clause 6 provides RoF systems architectures in the types of simplex, duplex and complex. Clause 7 specifies requirements on radio signal quality, latency, eye safety, and interoperability, and describes waveform information and signal processing in RoF system.

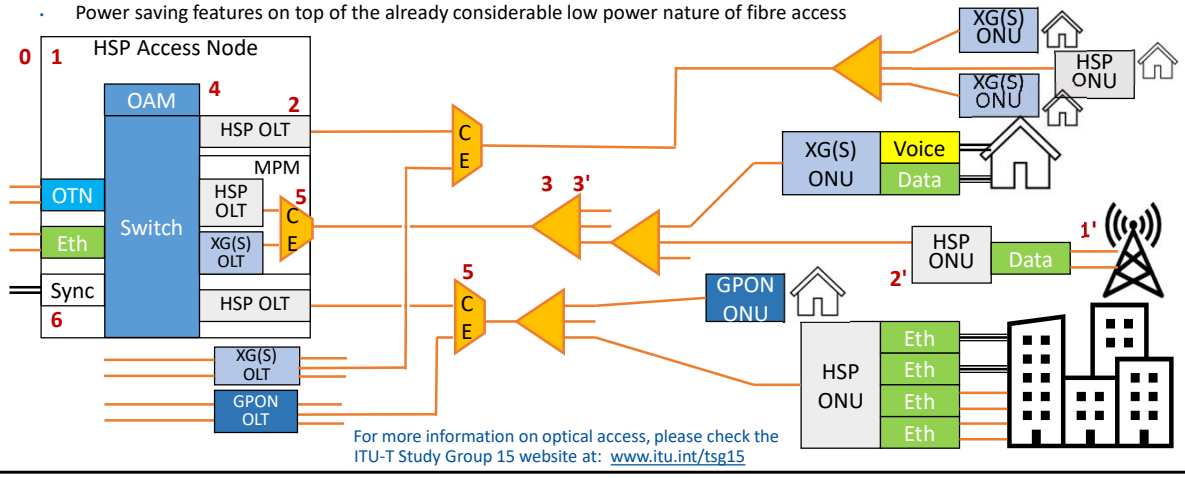
2. G.9803, Annex A – Analog RoF system supporting IMT system over ODN Specifies reference interfaces and points of using RoF system supporting IMT systems over ODN. Annex A provides reference configurations with point-to-point or point-to-multipoint links and defines service node interfaces (SNIs), user network interfaces (UNIs), physical layer requirements, as well as system OAM.

3. G.9803, Annex B – RoF system supporting foreign object debris (FOD) detection system Describes reference configuration of using the RoF system for FOD in a point-to-multipoint network architecture. Annex B provides typical examples on functional specifications and interface parameters.

4. G.9803, Appendices – RoF systems use cases, services, and frequency bands The Appendices introduce typical use
cases of wireless fronthaul, indoor distributed antenna system (DAS), and other applications. They summarize RoF systems frequency bands defined by IMT, ITU-R, IEEE, and candidate bands for applications of last-mile wireless connectivity, radiolocation, and railway radiocommunication.

G.9804: Higher Speed Passive Optical Networks (HSP)

- Full-service support – including voice, TDM, Ethernet (10/100/1000/10G/25G BASE), xDSL, wireless xhaul
- Basic physical reach is 20 km. Logical reach of up to 60 km. System is wavelength coexistent with G-PON, XG(S)-PON, 10G-EPON
- Support for bit-rate options, 50 Gbit/s downstream and 12.5 or 25 or 50 Gbit/s upstream
- Powerful OAM&P and system protection capabilities providing a feature rich and reliable service management system
- Advanced security features including authentication, rogue detection, and information privacy
- Power saving features on top of the already considerable low power nature of fibre access



For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15

0. G.9804.1, Clauses 3-5 – Definitions, acronyms, conventions Establish the common terms and acronyms used in the series, as well as delineating the various optical access topologies.

1. G.9804.1 – Higher speed passive optical networks – Requirements Provides examples of services, User Network Interfaces (UNI) and Service Node Interfaces (SNI) that are required by network operators. In addition, it shows the principal deployment configuration. The most important requirement is the backward compatibility with existing Optical Distribution Networks (ODN) that comply with G.984.x, G.987.x and G.9807.x series of Recommendations.

1'. ONU applications and services The HSP system is intended to be a full-service access network. A key part of that is the extreme diversity of optical network unit (ONU) types and form factors. In addition to all the applications described for G-PON, XG-PON, and XGS-PON, the higher capacity of HSP opens new possibilities. Examples of these are serving diverse 5G cell sites and various enterprises. Existing G/XG(S)-PON ONUs can remain in service alongside the HSP ONUs, allowing for easier upgrades.

2. G.9804.2 – Higher Speed Passive Optical Networks: Common Transmission Convergence Layer Specification Defines the HSP frame format and media access control method, which are based upon those of XG(S)-PON and NG-PON2. The protocol units and information exchange between the optical line terminals (OLT) and ONUs are generalized to be future proof. It describes the ranging and activation processes, dynamic bandwidth allocation (DBA), physical layer management (PLOAM), security, power saving, system protection, channel management, and rogue behaviour mitigation.

2'. ONU behaviour The approach taken in G.9807.3 is to describe in detail the behaviour of the ONU, leaving the detailed behaviour of the OLT to the implementer. The approach makes it possible to test for ONU conformance to the specifications. This makes the interoperability of different vendor's ONUs on a single PON possible. There are conformance and interoperability testing programs organized by the Broadband Forum (BBF).

3. G.9804.3 – 50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification Defines the optical requirements and specifications for the 50 Gb/s single channel PMD layer. This Recommendation covers systems with nominal line rates of 49.7664 Gbit/s in the downstream, and the upstream line rate options are 49.7664 Gbit/s, 24.8832 Gbit/s, or 12.4416 Gbit/s. The PMD is designed to operate bidirectionally over a single strand of single mode optical fibre (G.652). The wavelength plan specifies downstream wavelength band as 1340 to 1344 nm, and upstream wavelength band as Option 1 (1260 to 1280 nm) and Option 2 (1290 to 1310 nm). Option 1 or option 2 allows wavelength division multiplex (WDM) coexistence with G-PON or XG(S)-PON, respectively.

3'. G.9804.4 – Time and Wavelength multiplexed passive optical networks (TWDM-PON): Physical media dependent (PMD) layer specification Defines the optical requirements and specifications for the higher speed variant of the TWDM-PON system. This Recommendation covers systems with nominal channel line rates of 49.7664 Gbit/s in the downstream, and the upstream line rate options are 49.7664 Gbit/s, 24.8832 Gbit/s, or 12.4416 Gbit/s. The PMD is designed to operate bidirectionally over a single strand of single mode optical fibre (G.652).

4. G.988 – ONU management and control interface (OMCI) specification Defines the managed entities of a protocol-independent Management Information Base (MIB) that models the exchange of information between the OLT and ONU, for all PON systems specified in ITU-T. The MIB describes the wide range of services and UNI types that an ONU may support.

5. G.984.5 – Gigabit-capable passive optical networks (G-PON): Enhancement band Defines wavelength ranges reserved for additional service signals to be overlaid via wavelength-division multiplexing (WDM) in future Passive Optical Networks (PON) for maximizing the value of ODNs. The details of both the coexistence element (CE) and the blocking filter at the ONU are described. As new PON systems are standardized, this standard is updated to account for them.

6. Synchronization and timing are supported as part of the HSP system. G.9804.3 specifies methods for transferring precision timing information over the PON system, avoiding the inherent TDMA timing asymmetry. This is increasingly important for various wireless applications especially services with low latency requirements.

G Suppl. 66: 5G wireless fronthaul in a PON context

- First ITU-T study that synthesizes specifications from recent 5G standards into practically realizable access network solutions
- Consider transport requirements from the 5G New Radio (NR) functional split architectures
- Review 5G wireless transport requirements for services, transport capacity, latency, and synchronization
- Discuss PON system designs to meet these requirements
- Provide practical PON implementation examples for back/midhaul (F1) and fronthaul (Fx) interfaces using TDM-PON and WDM-PON

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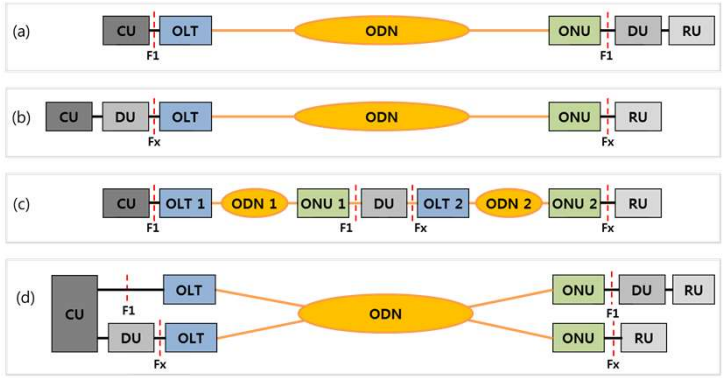

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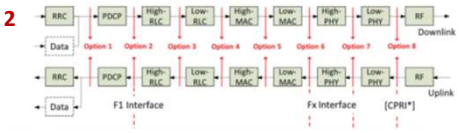

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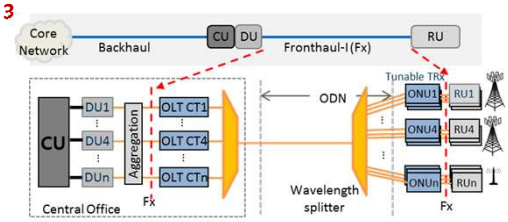


For more information on optical access, please check the ITU-T Study Group 15 website at: www.itu.int/tsg15

1. G Suppl. 66 - 5G wireless fronthaul requirements in a passive optical network context Describes the mapping of the wireless CU/DU/RU system to the PON in optical fronthaul architecture. The central unit (CU) / distributed unit (DU) / radio unit (RU) belong to the radio network layer, while optical line terminal (OLT) / optical network unit (ONU) belong to the transport network layer. Four use case scenarios were analysed: high-layer split; b) low layer split; c) cascaded split; and d) parallel split.

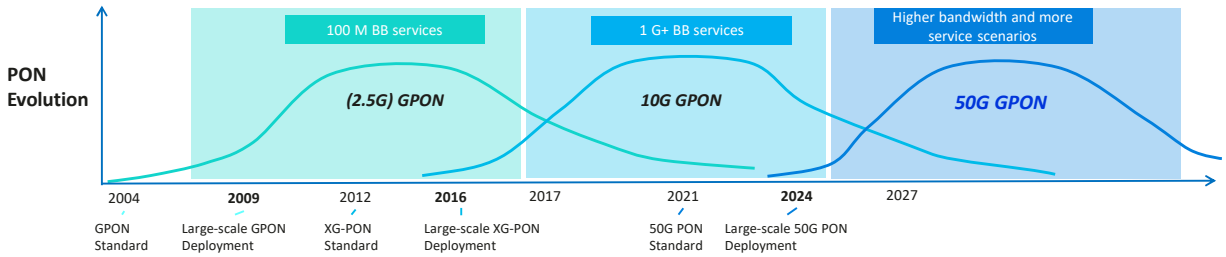
2. Functional split options G Suppl. 66 also examines the different wireless functional interfaces in its signal processing chain, and outlines two major types of functional split. The F1 (high-layer split) is defined by 3GPP. Fx (low-layer split) is used in G Suppl. 66 as the generic notation for the two low-layer split points (option 6 or 7). Different signal processing functions reside in the central unit (CU), distributed unit (DU), or remote unit (RU), depending on the split points. CPRI is one possible transport protocol for Option 8.

3. Example of WDM-PON implementation for Fx fronthaul interface G Suppl. 66 gives an example of WDM-PON implementation for Fx fronthaul transport. In this system, signals from the OLTs, each on a different wavelength channel, are combined in a wavelength multiplexer before transmitting to the cell sites. In the optical distribution network (ODN), a wavelength multiplexer, typically an array waveguide grating (AWG) device, routes the individual wavelengths to different ONUs, each of which is connected to an RU supporting one of the three sectors of an antenna.

Major recent consented documents

- G.9802.1: WDM-PON: General requirements
- G.9804.1 Amd.1: Higher speed PON: Requirements
- G.9804.2: Higher speed PON: Common TC layer specifications
- G.9804.3: Higher speed PON: 50Gb/s PMD specifications
- G.9806 Amd.2: Bidirectional point to point PHYs
- G.sup.CoDBA: OLT Capabilities for supporting CO DBA

The access network upgrade cadence



- The operators that deployed most of the PON in the world have clear requirements
  - Access network deployment pace is 8 to 10 years. Going any faster cannot be supported economically or operationally
  - Bandwidth must be upgraded by at least 4 times. Anything less than this is not worth the cost and effort
- 50G-PON is technically achievable in the required time
  - Majority system will be 50G down / 25G up
  - The introduction of DSP and soft FEC brings large improvements
  - Given the ~4 years before significant volume, we have the time

15

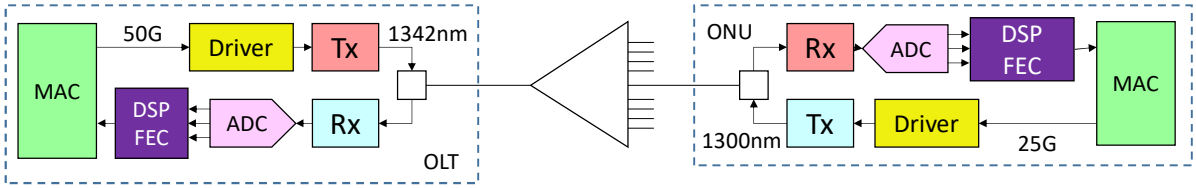
G.9804.1: Higher speed PON requirements

- Higher speed PONs share many requirements with existing systems
  - Must reuse the fiber plant based on splitters and G.652 fiber
  - Must support the same loss budgets and distances
  - Must coexist with existing systems in a passive way
- System must have 50 Gb/s per channel downstream
  - The current deployment of 10G systems means that the HSP system will be deployed in 2024, and must have at least 4x capacity of the 10G system
  - The upstream can be a lower rate, 25 Gb/s looks attractive
- G.9804.1 was approved in Dec 2019, and amended Apr 2021

G.9804.2: Higher speed Common TC

- The common TC is intended to be used for PON 50G and up
- It is largely based upon XGS-PON protocol constructs, with enhancements
  - A better LDPC FEC code, which allows raw BER of 1e-2 or more
  - Interleaving to further condition burst errors
  - Allowance for contention-based transmission for efficient low latency signaling
  - Cooperative DBA, so that bursty low latency services can be supported
  - Better transport security with longer keys and multiple algorithms
  - Multiple upstream rates, allowing for link budget adaptation

G.9804.3: Specifications of fixed 50G PMD



- Single channel system for low cost overall
- Simple way to reach 50G loss budget: Use a stronger Tx at the OLT
- Use DSP in both directions for equalization, burst mode reception, low density parity check (LDPC) code with soft decoding for high sensitivity, and flexible rate decoding for link budget elasticity
  - Once we have an ASIC, its cost quickly tends to zero with 100M volumes
- Wavelength plan reuse of 802.3ca and coexistence with either G-PON or XG-PON

Summary

- Q2/15 is the standing group that works on optical access networks, with a wide range of projects spanning several PON generations
- Substantial work plan on higher speed (>10G) access
- Aim is to make this the “Last PON”
  - Common requirements and TC layer that is scalable to any reasonable rate combination
  - Many PMD projects to allow development at the pace of the technology (The PMD is generally the gating item on systems)