Coherent Passive Optical Networks
100 Gbps Single-Wavelength PON

Coherent PON Architecture Specification

CPON-SP-ARCH-I01-230503

ISSUED

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Document Status Sheet

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Key to Document Status Codes

Work in Progress An incomplete document designed to guide discussion and generate feedback; may include several alternative requirements for consideration.

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Closed A static document that has been reviewed, tested, validated, and closed to further Engineering Change requests to the specification through CableLabs.

Trademarks

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1 SCOPE

1.1 Introduction and Purpose

This specification is part of the Coherent Passive Optical Network (CPON) family of specifications developed by Cable Television Laboratories (CableLabs). These specifications enable the development of interoperable transceivers using coherent optical technology over point-to-multipoint links. This specification was developed for the benefit of the telecommunications industry and includes contributions by operators and manufacturers from North and South America, Europe, Asia, and other regions.

This specification serves as a guide for the development of CPON systems though the following means:

- identifying use cases that CPON systems will support;
- identifying the optical distribution network (ODN) scenarios in which a CPON system is expected to operate, including the characteristics of those ODNs; and
- identifying operational needs in order to address use cases and ODN scenarios.

The resulting CPON system features symmetric line rates of at least 100 Gbps over a single wavelength. More significantly, it features an optical power budget up to 35 dB, which enables long link distance up to 80 km (with 1:16 split ratio) or high-split ratio up to 1:512 (with 20-km link distance). It will also support coexistence with any existing fiber-based technology (such as legacy PON systems or wave-division multiplexing (WDM) point-to-point links) and have the ability to stack multiple CPON wavelengths on a single fiber by using WDM.

Taken together, these features will allow for dramatically enhanced deployment flexibility across a wide variety of scenarios, ranging from high-density interconnect in a densely populated urban area to low-density deployments over wide areas. They will also support a wide range of applications, both those known today and the high-bandwidth, low-latency applications of the future. Additionally, given that some of these applications may be critical in nature, a redundancy mechanism to protect against optical line terminal (OLT) failure and feeder fiber failure will also be defined.

Figure 1 shows an example of multiple CPON wavelengths on a single fiber link to support mixed use cases or applications simultaneously.

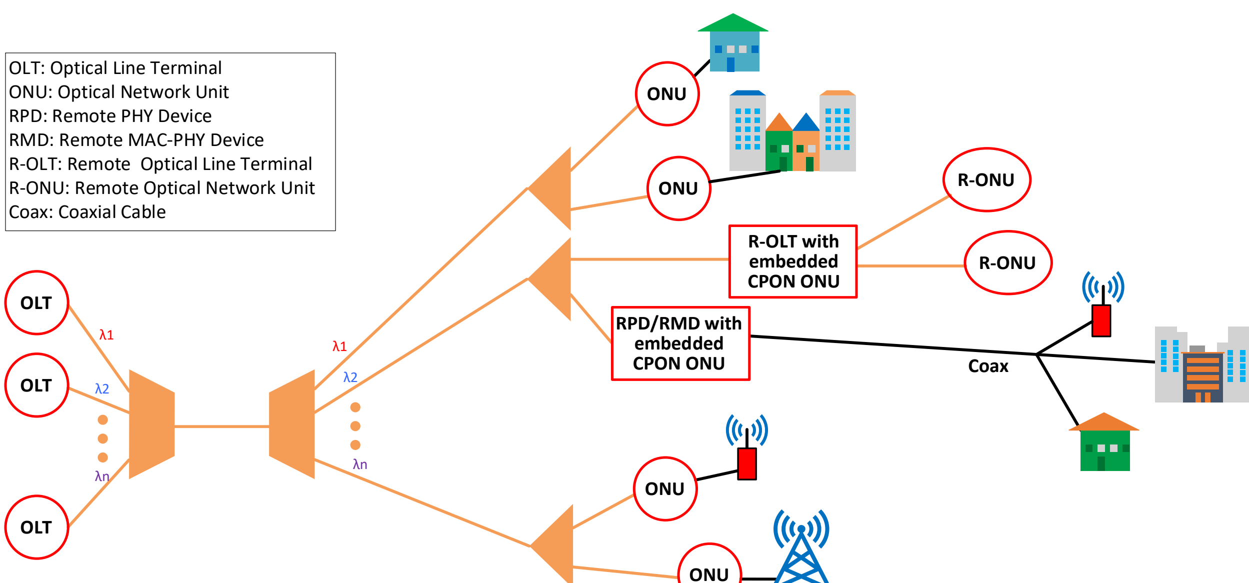


Figure 1 - CPON with WDM Supporting Various Applications

1.2 Background

Today's world relies heavily on a fast and reliable exchange of information. Ever-increasing demands for higher data rates continue to exceed currently installed system capacity. To date, passive optical network (PON) technologies have been one of the dominant architectures to meet the growth in capacity demand for the end users. As the PON evolves toward a data rate 100 Gbps or higher, PON technologies based on intensity modulation–direct detection (IM-DD) have been pushed to their limit to accommodate the fast-growing demands. In contrast, coherent optical technology is a very promising solution for 100 Gbps single wavelength PON because of its superior performance and vast potential.

Coherent optics technology is common in submarine, long-haul, and metro networks, but it has not yet been applied to access networks because of the relatively high cost of the technology for those applications. However, the access network differs from the other types of networks in the following ways:

- typically less than 80 km, much shorter than long-haul links,
- fewer transmission impairments because of the shorter link distance,
- use of fixed-wavelength optical passives, and
- typically extended from temperature-controlled environments out to the field where there are no temperature control facilities.

With these differences, the capabilities, performance, and features of transceivers can be relaxed in areas such as

- optical output power level,
- transmitter wavelength tunability requirements,
- fiber chromatic dispersion compensation,
- laser linewidth, and
- transmitter optical-to-signal-noise ratio (OSNR).

This allows for low-cost designs and the use of low-cost components in access networks relative to metro and long-haul networks. In a PON application, coherent optics can optimize optical power distribution, improve power/bit consumption, and provide longer link distances and/or high split ratios over existing PON technologies. The improved power budget of coherent optics in a PON application can effectively compensate for linear transmission impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD), enable out-of-band communication channel and frequency division multiplexing, and efficiently utilize the spectral resources by enabling single wavelength data rates of 100 Gbps and higher. Using coherent optics in the access network opens new possibilities for cable operators, telecommunication service providers, and data center operators. This CPON initiative is to bring coherent optics into access networks in an economically viable, cost-optimized manner.

1.3 Organization of Document

Section 1 of this document provides an overview of CPON technology and the objectives of this specification.

Sections 2–4 include the references, terms, and abbreviations used throughout this specification.

Section 5 provides a brief overview of PON technology, coherent optics technology, and how CPON brings them together.

Section 6 identifies several key use cases that are driving the development of CPON technology, as well as other use cases that it might potentially enable.

Section 7 describes the ODN scenarios that CPON systems will need to operate on, including their characteristics.

Section 8 identifies operational needs for satisfying the requirements of the use cases and ODN scenarios.

2 REFERENCES

2.1 Informative References

This specification uses the following informative references.

[3GPP TS 22.261]	3GPP TS 22.261, Service Requirements for the 5G System, August 2016
[ANSI/SCTE 158 2016]	ANSI/SCTE 158 2016, Recommended Environmental Condition Ranges for Broadband Communications Equipment, 2016
[ATIS-0600010.01.2008]	ATIS 0600010.01.2008, Temperature, Humidity, and Altitude Requirements for Network Telecommunications Equipment Utilized in Outside Plant Environments, 2008
[BBF TR-280]	Broadband Forum TR-280: ITU-T PON in the Context of TR-178, October 2016
[CPON Protection]	"Overview of Coherent PON Protection," February 2023, CableLabs R&D Wired, https://community.cablelabs.com/wiki/plugins/servlet/cablelabs/alfresco/download?id=85c5d4ba-d774-4e29-a1a2-e7b81b9bf36a
[Energy Star]	U.S. Environmental Protection Agency Energy Star program, https://www.energystar.gov/
[ETSI EN 300 019-1-3]	ETSI EN 300 019-1-3, Equipment Engineering (EE): Environmental Conditions and Environmental Test for Telecommunications Equipment—Part 1-3: Classification of Environmental Conditions: Stationary Use at Weather-Protected Locations, February 1992
[ETSI EN 300 019-1-4]	ETSI EN 300 019-1-4, Equipment Engineering (EE): Environmental Conditions and Environmental Test for Telecommunications Equipment—Part 1-4: Classification of Environmental Conditions: Stationary Use at Non-Weather-Protected Locations, February 1992
[EU Code of Conduct]	E3P EU Code of Conduct on Energy Consumption of Broadband Equipment, Version 8.0 (current version valid from January 1, 2021)
[IEEE 802.3-2022]	IEEE 802.3-2022, IEEE Standard for Ethernet, July 2022 —Includes IEEE 802.3ca-2020, Amendment 9: Physical Layer Specifications and Management Parameters for 25 Gb/s and 50 Gb/s Passive Optical Networks, June 2020
[IEEE 1904.1]	IEEE 1904.1, IEEE Standard for Service Interoperability in Ethernet Passive Optical Networks (SIEPON), July 2017
[ITU-T G.652]	ITU-T Recommendation G.652, Characteristics of a Single-Mode Optical Fibre and Cable, November 2016
[ITU-T G.657]	ITU-T Recommendation G.657, Characteristics of a Bending-Loss Insensitive Single-Mode Optical Fibre and Cable, November 2016
[ITU-T G.9804.1]	ITU-T Recommendation G.9804.1, Higher Speed Passive Optical Networks—Requirements—Amendment 1, August 2021
[ITU-T G Supplement 51]	ITU-T G-series Recommendations—Supplement 51, Passive Optical Network Protection Considerations, June 2017
[ITU-HDB-OUT]	ITU-T T-HB-OUT.10-2009-1, Optical Fibres, Cables, and Systems, October 2009, https://www.itu.int/dms_pub/itu-t/opb/hdb/T-HDB-OUT.10-2009-1-PDF-E.pdf
[MEF 64]	MEF Standard 64, Operator Layer 1 Service Attributes and Services, February 2020
[P2PCO-PHYv1.0]	P2P Coherent Optics Physical Layer 1.0 Specification, P2PCO-SP-PHYv1.0-I03-200501, May 1, 2020, Cable Television Laboratories, Inc.
[P2PCO-PHYv2.0]	P2P Coherent Optics Physical Layer 2.0 Specification, P2PCO-SP-PHYv2.0-I02-200501, May 1, 2020, Cable Television Laboratories, Inc.
[P2PCO-SP-ARCH]	P2P Coherent Optics Architecture Specification, P2PCO-SP-ARCH-I02-190311, March 11, 2019, Cable Television Laboratories, Inc.
[PON Evolution]	"Evolution of PON and Coherent Optics Technology in the Access Network," February 2023, CableLabs R&D Wired, https://community.cablelabs.com/wiki/plugins/servlet/cablelabs/alfresco/download?id=7af4c550-3c71-4df3-84d8-9b5f6d2b0f5f
[Telcordia GR-487]	Telcordia GR-487, Generic Requirements for Electronic Equipment Cabinets, Issue 6, December 2022

2.2 Reference Acquisition

- 3GPP: The 3rd Generation Partnership Project, 3GPP Mobile Competence Centre c/o ETSI, 650 Route des Lucioles, 06921 Sophia Antipolis Cedex, France; https://www.3gpp.org/

- ATIS: Alliance for Telecommunications Industry Solutions, 1200 G Street, NW Suite 500, Washington, DC 20005; https://www.atis.org
- BBF: Broadband Forum, 5177 Brandin Court, Fremont, CA 94538; https://www.broadband-forum.org/
- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027; Phone +1-303-661-9100; http://www.cablelabs.com
- E3P: European Energy Efficiency Platform, European Commission—EU Science Hub, https://e3p.jrc.ec.europa.eu/
- ETSI: European Telecommunications Standards Institute, 650 Route des Lucioles, 06560 Valbonne - Sophia Antipolis, France; https://www.etsi.org
- IEEE: The Institute of Electrical and Electronics Engineers, 3 Park Avenue, New York, NY 10016-5997; https://www.ieee.org
- ITU-T: International Telecommunications Union, Telecommunication Standardization Sector; https://www.itu.int/en/ITU-T/Pages/default.aspx
- MEF: Metro Ethernet Forum, 12130 Millennium Dr, Suite 2-182, Los Angeles, CA 90094; https://www.mef.net
- SCTE: Society of Cable Telecommunications Engineers, 140 Philips Rd, Exton, PA 19341; https://www.scte.org/
- Telcordia (now *iconectiv*), 100 Somerset Corporate Blvd., Bridgewater, NJ 08807; https://iconectiv.com

3 TERMS, DEFINITIONS, AND SHAPES

3.1 Terms and Definitions

This specification uses the following terms.

aggregation node	A location where multiple traffic streams from groups of customers are combined using active and/or passive techniques to feed one or more hubs or central offices.
central office (CO)	A central facility for receiving, processing, and combining signals.
coexistence element (CEx)	A bidirectional functional element for connecting PON systems.
coherent optics	Encodes information in both in-phase (I) and quadrature (Q) amplitude components of an optical carrier.
CPON system	A system comprising an OLT and one or more ONUs connected via an ODN and utilizing CPON technology as defined in the CPON family of specifications.
customer premises equipment (CPE)	Device such as a cable modem or router at the subscriber's or other end user's location. May be provided by the end user or the service provider.
downstream	The direction of transmission from the hub/CO to the subscriber.
Ethernet	Computer networking protocol used to send frames between a source and destination address at OSI Layer 2.
forward error correction (FEC)	A method of error detection and correction in which redundant information is sent with a data payload to allow the receiver to reconstruct the original data if an error occurs during transmission.
fiber optic splitter	A passive optical component that can split an incident light beam into two or more light beams or combine two or more incident light beans into one light beam. Typically, an integrated device based on optical waveguides.
gigabit	10^9 bits
hub	A central facility that is used for receiving, processing, and combining broadcast, narrowcast, and other signals to be carried on a network.
hybrid fiber-coaxial (HFC)	A broadband bidirectional shared-media transmission system or network architecture using optical fibers between the headend and fiber nodes and coaxial cable distribution from the fiber nodes to the subscriber locations.
Internet Protocol (IP)	The computer network protocol (analogous to written and verbal languages) that all machines on the Internet need to know so that they can communicate with one another. IP is a layer 3 (network layer) protocol in the OSI model.
IQ modulation	A method of combining two input channels into one by multiplying the "in-phase" (I) channel by the cosine and the "quadrature" (Q) channel by the sine. This way, there is a phase of 90° between them; when added together, the modulator sends the combined signal through the output channel.
jitter	The fluctuation in the arrival time of a regularly scheduled event such as a clock edge or a packet in a stream of packets.
latency	The time taken for a signal element to pass through a device, system, or network.
layer	A subdivision of the Open System Interconnection (OSI) architecture, constituted by subsystems of the same rank.
media access control (MAC)	Used to refer to the OSI Layer 2 element of the system.
multiplexer/demultiplexer (MUX)	A multiplexer combines multiple lines-in to a single line-out, and a demultiplexer splits a single line-in to many lines-out.
muxponder	Combination transponder and multiplexer in a single Layer 1 device.
optical distribution network (ODN)	A point-to-multipoint optical fiber infrastructure.
optical line terminal (OLT)	A network element in an ODN-based optical access network that provides an optical access network service node interface.
optical network unit (ONU)	A network element in an ODN-based optical access network that provides an optical access network user-network interface.
physical layer (PHY)	Layer 1 in the Open System Interconnection (OSI) architecture; provides services to transmit bits or groups of bits over a transmission link between open systems and which entails optical, electrical, mechanical, and handshaking procedures (PHY).

passive optical network (PON)	A telecommunication network that transmits data over optical fiber links. It utilizes unpowered passive optical splitters to route data from a central location to multiple destinations.
quadrature amplitude modulation (QAM)	A modulation technique in which an analog signal's amplitude and phase vary to convey information, such as digital data. The name "quadrature" indicates that amplitude and phase can be represented in rectangular coordinates as in-phase (I) and quadrature (Q) components of a signal.
quadrature phase shift keying (QPSK)	A form of digital modulation in which four phase states separated by 90° support the transmission of two bits per symbol. Also called 4-QAM.
subscriber	End user or customer connected to a provider's network.
transceiver	A combination of transmitter and receiver in the same device or component.
upstream	The direction from the subscriber location toward the head-end.

3.2 Shapes Legend

This specification uses the following shapes in drawings throughout this document.

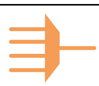
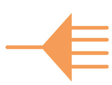
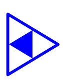
Symbols

λ	lambda (wavelength)

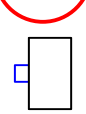
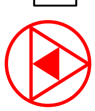
Cables

	coaxial
	fiber
	a connection that carries IP traffic

Components

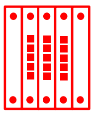
	optical multiplexer/demultiplexer
	optical splitter
	RF amplifier

Devices

	converged cable access platform core
	ethernet switch/muxponder
	fiber node
	optical line terminal

optical network unit

Remote PHY Device

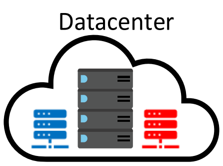

router/switch/aggregation device

Endpoints


base station


radio unit

business

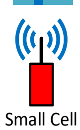


data center


residential


multiple dwelling unit


single family unit



small cell


Wi-Fi access point


fixed wireless access point


edge node

4 ABBREVIATIONS

This specification uses the following abbreviations.

AON	active optical network
BiDi	bidirectional
BM	burst mode
BPON	broadband passive optical network
CCAP	Converged Cable Access Platform
CD	chromatic dispersion
CEx	coexistence element
CM	cable modem
CMOS	complementary metal-oxide semiconductor
CMTS	Cable Modem Termination System
CO	central office
CPE	customer premise equipment
CPON	Coherent Passive Optical Network
C-RAN	Cloud Radio Access Network
DAA	Distributed Access Architecture
DBA	dynamic bandwidth allocation
DOCSIS	Data-Over-Cable Service Interface Specifications
DS	downstream
DSP	digital signal processing
DWDM	dense wavelength division multiplexing
E2E	edge to edge or end to end
EDFA	erbium-doped fiber amplifier
EPON	Ethernet passive optical network
FEC	forward error correction
FIT	failure in time
FTTH	fiber-to-the-home
FTTP	fiber-to-the-premises
Gb/s	gigabit per second
GHz	gigahertz
GPON	gigabit passive optical network
HE	head-end
HD-FEC	hard decision forward error correction
HFC	hybrid fiber-coaxial
Hz	Hertz
IQ	in-phase and quadrature
IEEE	Institute of Electrical and Electronics Engineers
IM-DD	intensity modulation and direct detection
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
km	kilometer

LO	local oscillator
MAC	media access control
MDU	multiple dwelling unit
MHz	megahertz
MTBF	mean time between failures
MTTR	mean time to repair
MUX	multiplexer
NG-PON2	next generation passive optical network 2
Nx25G-EPON	Nx25G Ethernet passive optical network
ODN	optical distribution network
OLT	optical line terminal
ONU	optical network unit
OSNR	optical signal-to-noise ratio
P2P	point-to-point
P2MP	point-to-multipoint
PHY	physical layer
PM	polarization multiplexing
PMD	polarization mode dispersion
PON	passive optical network
QAM	quadrature amplitude modulation
QPSK	quadrature phase-shift keying
R-MACPHY	Remote MAC-PHY
R-PHY	Remote PHY
R-OLT	remote optical line terminal
R-ONU	remote optical network unit
RF	radio frequency
RMD	Remote MAC-PHY Device
RPD	Remote PHY Device
Rx	receiver
SCTE	Society of Cable Telecommunications Engineers
SD	soft decision (FEC)
SFU	single-family unit
SNR	signal-to-noise ratio
Tbps	terabit per second
TDM	time-division multiplexing
TFDM	time-and-frequency-division multiplexing
TWDM	time-and-wavelength-division multiplexing
Tx	transmitter
US	upstream
WDM	wavelength-division multiplexing
XG-PON	10-gigabit-capable PON
XGS-PON	10-gigabit-symmetrical PON
50G-PON	50-gigabit-capable PON
xhaul	referring to fronthaul, midhaul, and backhaul

5 OVERVIEW

A passive optical network (PON) that leverages the benefits of point-to-multipoint (P2MP) passive topology for highly efficient fiber utilization has become one of the dominant optical access architectures for the operators in current fiber-to-the-premise (FTTP) deployments. To meet the increasing bandwidth demand driven by data intensive applications such as video streaming, 5G mobile Internet, and cloud networking, several generations of PON systems have been standardized through the efforts of two major organizations: the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) and the IEEE 802.3 Ethernet Working Group. More information regarding PON evolution can be found in a CableLabs white paper, [PON Evolution].

The existing PONs employ intensity modulation–direct detection (IM-DD) technology for a good balance of cost and performance. The main considerations of PON development efforts include increasing launched power, adopting better forward error correction (FEC), and using higher sensitivity receiver to fulfill a 29-dB loss budget and optical path penalty for higher data rate. This power budget is the basic requirement for coexistence with legacy PON or reuse of the deployed ODN because deploying fiber infrastructure is by far the biggest investment. However, this trend no longer simply holds true when the data rate per wavelength goes over 25 Gbps because IM-DD technology is coming up against physical challenges that will require higher device costs and power consumption for overall system architecture and optical design.

- A high sampling rate digital-to-analog converter and analog-to-digital converter (DAC/ADC) are required for signal processing in the digital domain.
- Digital signal processing algorithms are needed to compensate the device bandwidth limitation and mitigate transmission impairments.
- Limited link budgets require optical amplification in both centralized optics and customer premise equipment.
- Wavelength plan and resource management becomes more difficult because of the congestion in the O-band for both downlink and uplink.
- Higher bandwidth opto-electronic components are needed to reduce implementation penalty.

Coherent optical technology has completely transformed optical transmission systems and enabled a widespread upgrade and new deployment of dense wavelength division multiplexing (DWDM) networks to speeds of 100 Gbps, 200 Gbps, and 400 Gbps per wavelength. Over the past decade, coherent optics has moved beyond its long-haul application origins and is now used in metro networks. Further development in complementary metal-oxide semiconductor (CMOS) manufacturing, design simplification, cost reduction of opto-electronic components, and the need for more efficient optical transport technologies have been factors driving coherent solutions into new market applications, specifically short-haul applications in edge and access networks. This technology migration from long-link distance to short-link distance model has been demonstrated in the optical industry before: the DWDM system technology started in long-haul and subsequently migrated to metro and edge access. Benefiting from initial long-haul technology development, coherent optics for access networks will follow the same natural progression.

Coherent PON (CPON) is the result of applying the concept of coherent optical transmission to PON. CPON provides many advantages that are desirable in access networks.

- The multi-dimensions (optical amplitude, phase, and polarization) are multiplexed to encode information, allowing for increased data rates that can be processed with low-bandwidth analog and digital signal processing methods.
- A local oscillator is used to provide coherent gain for superior receiver sensitivity and high-power budget without the need of high launched power.
- The recovered signal enables digital compensation of linear transmission impairments including chromatic dispersion and polarization-mode dispersion with negligible optical path penalty, allowing ultra-long optical PON.

There are several benefits for operators that differentiate CPON technology from IM-DD technology.

- Higher link budgets expand use cases and coverage areas possible for their ODNs.
- Costly facilities (such as hubs) for distant communities can be scaled back or eliminated.
- Wavelength stacking in the C-band allows for subscriber counts to be grown without a linear increase in fiber usage.
- The flexibility and capability allow to significantly expand PON's applications beyond traditional residential deployment to support convergence needs at the network edge.

By leveraging high sensitivity and digital equalization of fiber transmission impairments, CPON offers flexibility in terms of transmission distances and split ratios. Figure 2 below shows a target power budget curve for 100 Gbps CPON based on laboratory measurements plus an implementation margin. The three cases identified in the figure are described in the text below and can be found in Figure 3, Figure 4, and Figure 5.

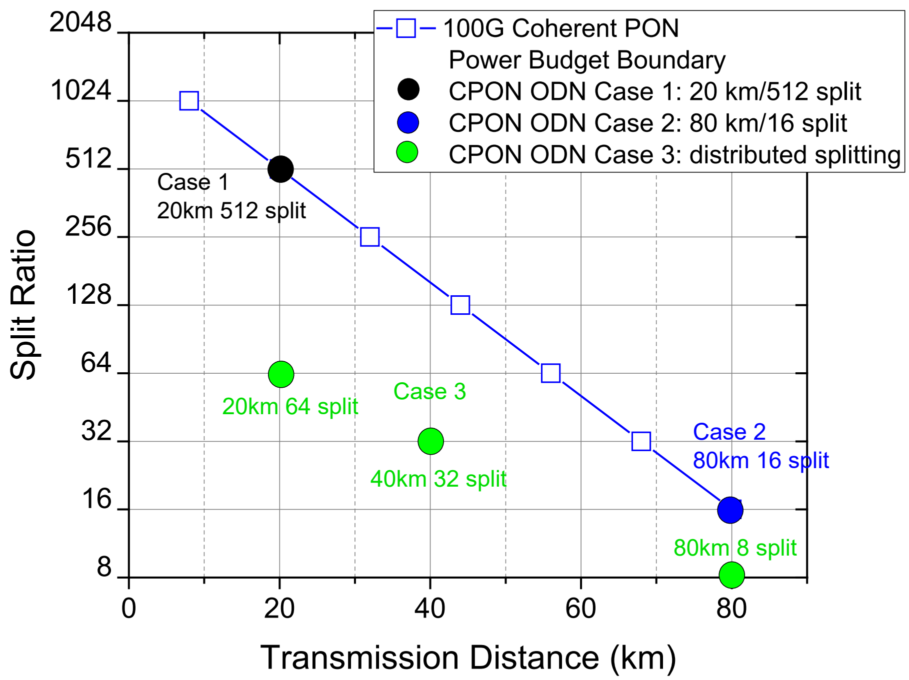


Figure 2 - 100 Gbps CPON Power Budget Curve

The following three cases provide examples of how an operator might leverage this capability of CPON technology.

Case 1—An operator could build an ODN with up to 512 customer connections with a maximum distance of 20 km, suitable for MDU high-rises or SFU new housing developments in a city, as demonstrated in Case 1 (Figure 3). The configuration shown in Figure 3 could also be used where developers construct new MDUs inside neighborhoods with established ODNs on IM-DD PON, thereby avoiding costly additional backbone fiber construction.

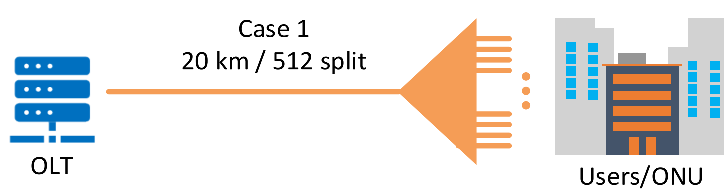


Figure 3 - CPON ODN Case 1: 20-km Link Distance with 512 Split

Case 2—An operator could build an ODN with up to 16 customer connections with a maximum distance of 80 km, suitable to connect remote pockets in low-density or rural areas, as demonstrated in Case 2 (Figure 4). With overlay of CPON signals on a common single fiber, an operator could thereby serve a distant town with a small number of fibers without costly fiber or facilities builds.

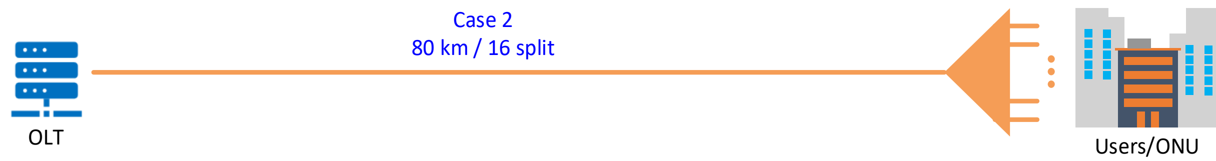


Figure 4 - CPON ODN Case 2: 80-km Link Distance with 16 Split

Case 3—An operator could build an extension to an existing ODN by using distributed splitting along the path if there is fiber congestion near the hub/central office (CO), as demonstrated in Case 3 (Figure 5). This could allow an operator to stage the rollout of their FTTP deployments without front-loading the costs of the fiber builds, enabling the operator to use a pay-as-you-grow approach in a piecemeal fashion without an all-or-nothing revenue model. In Figure 5, a CPON is first tapped at 20 km with a 90/10 passive splitter to support 64 customers, then tapped at 40 km with a 75/25 passive splitter to support another 32 customers, and finally tapped at 80 km to support the last set of 8 customers.

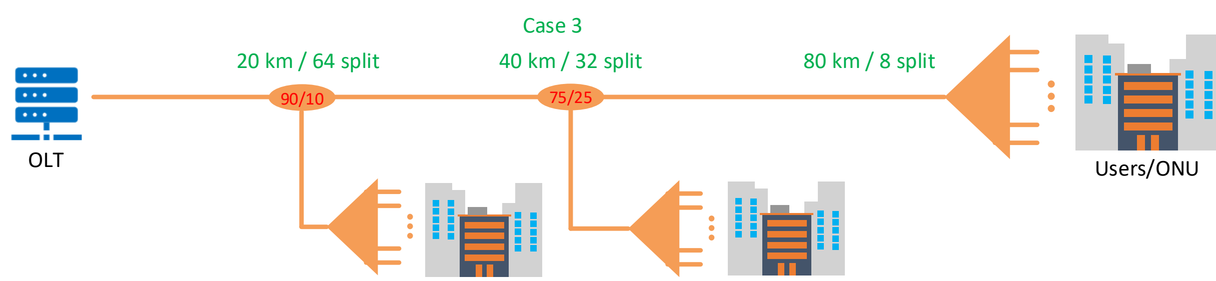


Figure 5 - CPON ODN Case 3: Distributed Splitting

These three examples showcase the benefits of CPON. A more complete subset of use cases is given in Section 6.

Coherent optical technology deployed in today's P2P long-haul optical systems uses best-in-class photonics and electronic components, but key components including lasers, modulators, and detectors are benefiting from optimization and simplification for metro optical systems. Additional cost-saving measures for P2MP access networks are expected to be possible for minor acceptable tradeoffs in performance.

An important aspect of CPON networks is coexistence with legacy IM-DD PON networks. This coexistence allows an operator to move burdensome traffic flows over to the new CPON network while easing congestion on the existing IM-DD PON network. This allows the operator to defer the burden for a widescale migration of CPE until the operator is satisfied with performance, cost structure, and operations of the CPON while leveraging the existing investments in the ODNs.

6 USE CASES

The following section describes a series of use cases in which CPON technology might be utilized to provide data transport across an operator's ODN.

The use cases and examples listed are not meant to be exhaustive. The performance benefits of CPON lend itself to being adaptable to an increasing customer base with diverse behaviors while simultaneously enabling new services leveraging evolving technologies.

6.1 Residential/FTTU MDU

CPON supports the use case of fiber to the unit (FTTU) in multiple dwelling units (MDUs) where each suite in the building is a separate distinct customer and each customer is served by a single fiber drop and an ONU. Figure 6 shows a system in which the CPON OLT is located at the hub/CO, the splitter is located the building complex, and multiple ONUs are fed through drops connected via riser cabling in the building with a single splitting point. The location of the passive splitter inside the building does not change the architecture of the design. For example, a single centralized splitter inside an electrical or utility room may be used. Another option is to use one splitter per building floor, with the entry splitter located in the basement of the building.

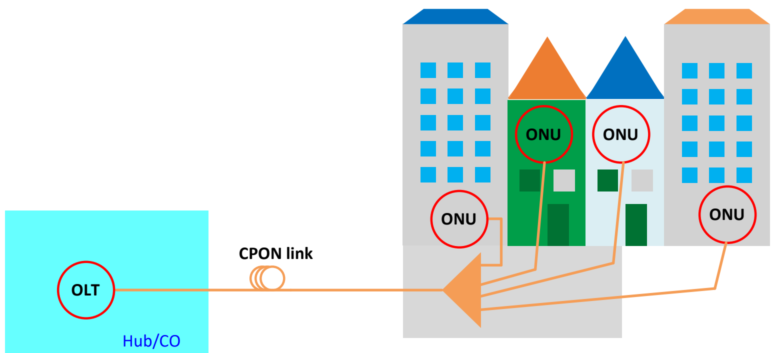


Figure 6 - Residential/FTTH MDU Use Case

A benefit for this use case is that less fiber and fewer CO ports are required to get into larger buildings with passive connections because of the larger CPON link budgets that allow for large split ratios and long link distances. For comparing CPON to IM-DD PON with remote OLTs, CPON networks also use less space in electrical or utility rooms and simplify the operations of the network because physical access to these electrical rooms is not required as frequently without active electronics being hosted in that facility.

A subset of this use case would be MDUs with a single organization handling the customer billing for the tenants, such as a long-term care home for seniors, a seasonal facility like a summer camp, a campus or university dormitory, or some other institution that has moderate tenant churn and simple best-effort traffic demands. In these situations, CPON can be used with a low number of ONUs to deliver connectivity with a simplified service delivery model and lower costs than a dedicated wavelength service or active Ethernet service and without all of the headaches for the operator that would come with having a temporary or transient customer base at that location.

6.2 Residential/FTTH SFU

CPON also supports fiber-to-the-home (FTTH) connectivity for single-family units (SFUs). Figure 7 shows an OLT at a hub/CO connected through the ODN to multiple SFUs, each with its own ONU. In greenfield deployments without existing services, a single technology for the PON would ease operations in future years. In brownfield deployments with existing IM-DD PON, a CPON network could be overlayed using coexistence (CEx) modules, allowing the operator to gracefully migrate certain customers to increase revenue opportunities or lower congestion for other customers on the ODN.

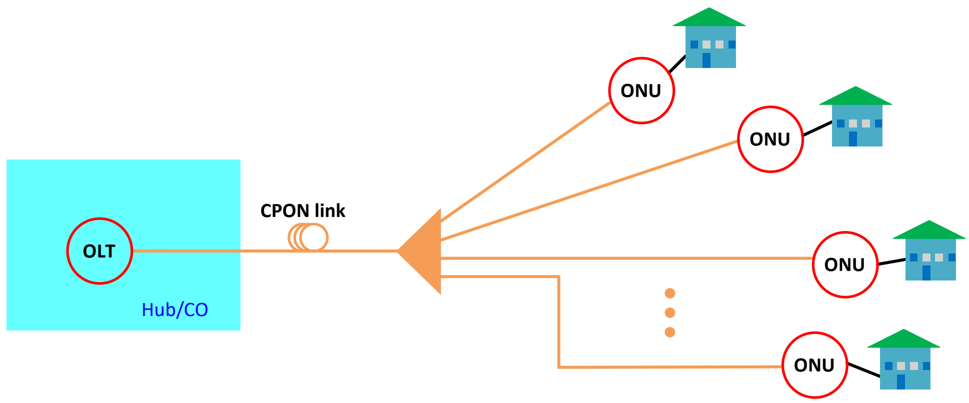


Figure 7 - Residential/FTTH SFU Use Case

6.3 Aggregation Connectivity

CPON can also support backhaul connectivity of remote devices on an operator's network.

6.3.1 Remote OLT

CPON can provide connectivity and backhaul of remote OLT traffic. Because of link budget, impairment, fiber attenuation, and insertion loss of passive devices, distance between the OLT and ONUs using IM-DD is typically limited to 20 km. To overcome this limitation, a remote OLT (R-OLT) can be deployed to extend the link distance of legacy PON. An R-OLT moves the OLT out of the hub/CO to an aggregation node location that is located close to ONUs. Each aggregation node can contain multiple OLTs, and the connection between the hub/CO and the aggregation node can leverage CPON. Figure 8 shows an R-OLT use case example where the aggregation node contains multiple remote OLTs, each R-OLT is connected or integrated with a CPON ONU, and the hub/CO and the aggregation node are interconnected by an ODN. The R-OLT usually is in the aggregation node, but it could be deeper in the access network to meet legacy PON optical budget rules. Like traditional PON, each R-OLT can service 16 to 32 or more remote ONUs (R-ONUs). In Figure 8, R-OLTs and R-ONUs can be optics based on IM-DD, where the OLT located in the hub/CO and the ONUs in the aggregation node are coherent optics. This R-OLT case could be an important bridge for applications where the distance exceeds IM-DD limits but where the capacity does not yet exceed the offerings of an IM-DD PON service. Given the nature of burst of traffic, R-OLT could support residential traffic, but it may not be very suitable for mobile backhaul services and the like.

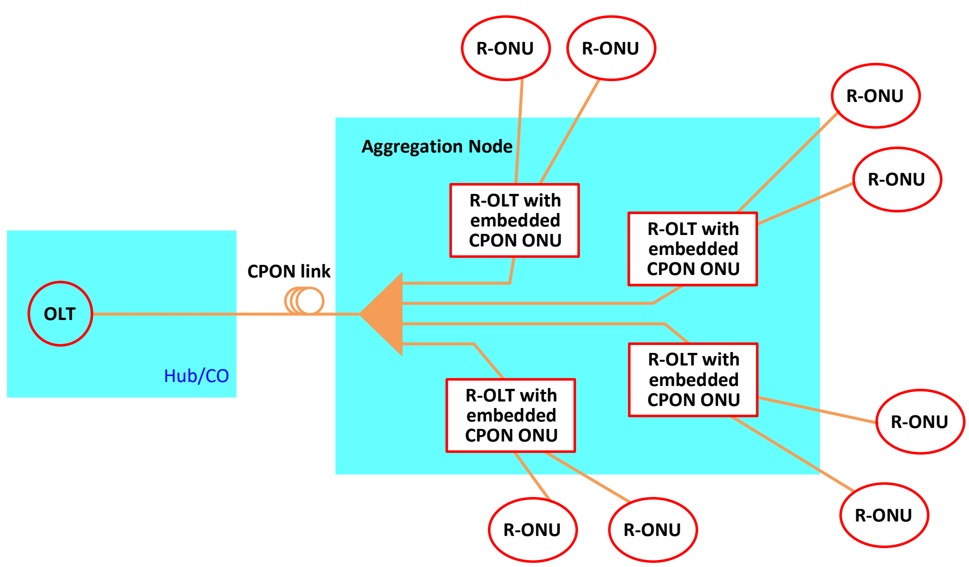


Figure 8 - Remote OLT Use Case

6.3.2 Distributed CCAP

CPON can provide connectivity and backhaul of distributed Converged Cable Access Platform (CCAP) architecture traffic collected from Remote PHY devices (RPDs) and Remote MAC-PHY devices (RMDs). Over the past few years, cable access technologies have evolved from centralized CCAP to distributed CCAP architectures, which offer operators great flexibility and low-cost deployment benefits. In this use case, a termination device that integrates RPD or RMD with a coherent ONU at the aggregation node or original fiber node location terminates the downstream CPON link that originated at the hub/CO. The termination device outputs multiple optical or electrical Ethernet interfaces operating at lower data rates to connect devices that are co-located with the aggregation node and/or exist deeper in the network. Figure 9 shows the CPON use cases of supporting RPD/RMD backhaul, with a variety of possible different devices (such as RPDs or RMDs) integrated with coherent ONUs in the aggregation node. The CPON optic link goes from the hub/CO device with a P2MP coherent optic transmitter to the termination device in the aggregation node with a P2MP coherent optic receiver. The termination device terminates the P2MP coherent optic link and performs an optical/electrical/optical process to convert the P2MP coherent optic link into several Ethernet links. Although 10-Gb Ethernet (10GE) connections serve this use case today, future RPDs/RMDs with DOCSIS 4.0 service are expected to exceed the capabilities of a single 10GE interface. The economics of connecting multiple RPDs/RMDs with a single CPON network appear attractive in migration scenarios as the RPDs/RMDs are upgraded. Cooperative scheduling and transport are needed to mitigate service latency and optimize connection efficiency.

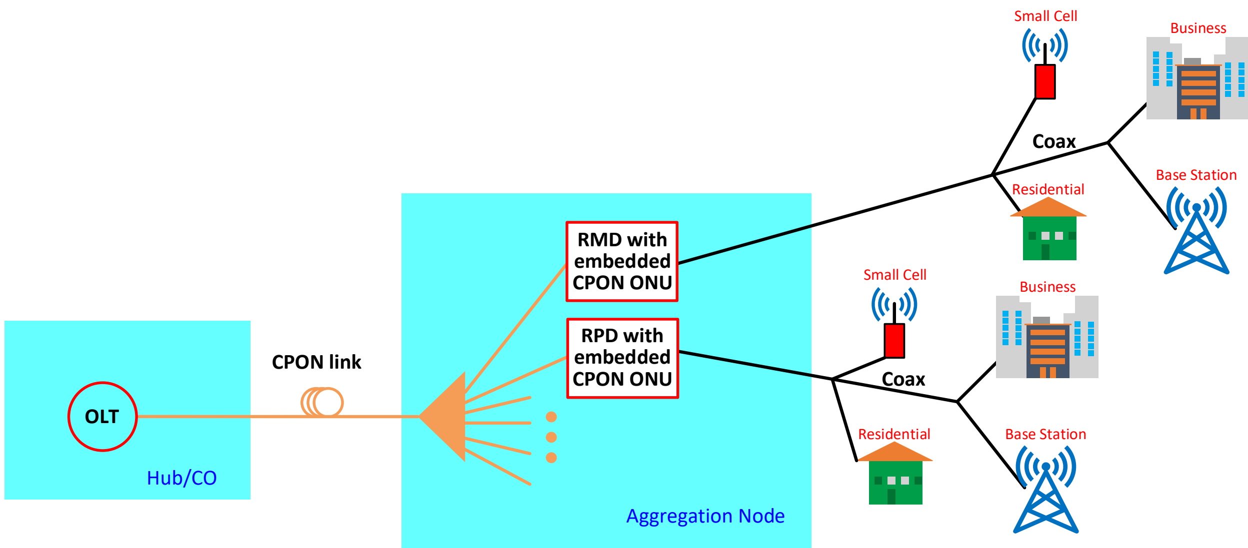


Figure 9 - RPD/RMD Connectivity and Backhaul Use Case

6.4 Mobile Xhaul

Another use case for CPON is to provide mobile xhaul services.

Figure 10 shows an example of mobile back-hauling using CPON to provide base station connectivity and carry backhaul traffic. The system contains a coherent OLT, usually located at the CO, and several dispersed coherent ONUs. The OLT and ONUs are interconnected by an ODN-based topology with the OLT at the hub/CO. To backhaul the mobile services, each ONU connects to a mobile base station providing network access for mobile terminals (i.e., user equipment).

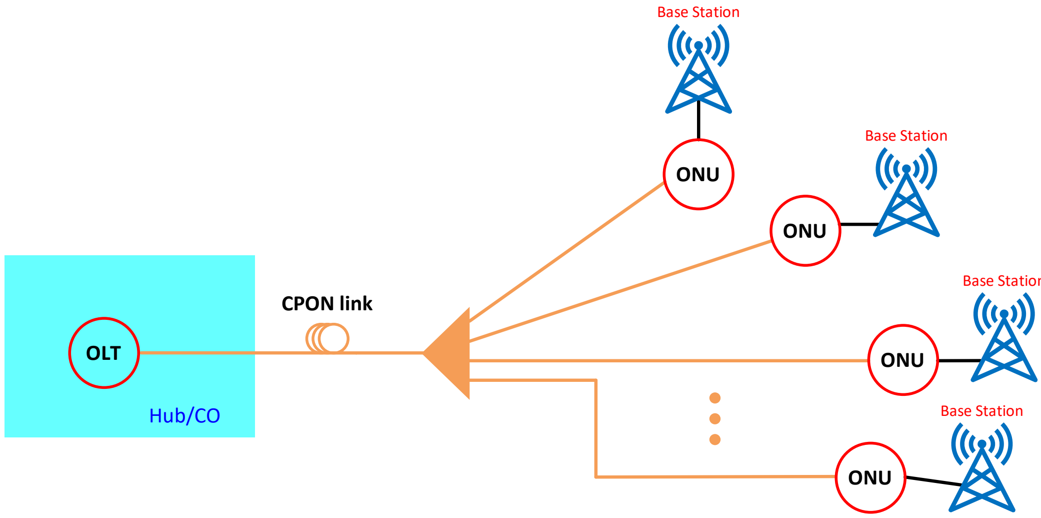


Figure 10 - Mobile Backhaul Use Case

The use cases of CPON also include carrying traffic from the midhaul/fronthaul segment of mobile/wireless networks, meeting their low-latency requirements. Figure 11 shows an example of using CPON to support fronthaul connectivity in a 5G radio access network (RAN). In Figure 11, each radio unit (RU) is attached to a coherent ONU, where the centralized unit (CU) and distributed unit (DU) are co-located in the CO and attached to a coherent OLT. The OLT and ONUs are interconnected by an ODN-based topology with the OLT at the hub/CO. The CPON system is applied in the fronthaul of the RAN to support multiple remote sites, with up to 100 Gbps capacity. Similarly, a CPON link can also provide midhaul connectivity between a CU and multiple DUs, under the cases when CU and DU are not in the same location. An advantage of using CPON is its logical nature and the flexibility it provides. Though fronthaul and midhaul applications require constant capacity that can be carved out from CPON resources to stream from the DU to the RU, or from the CU to the DU, as the radio location increases in capabilities and demand, the flexibility of CPON allows it to follow such demand throughout the growth phases of the radio units, reducing truck rolls and downtime.

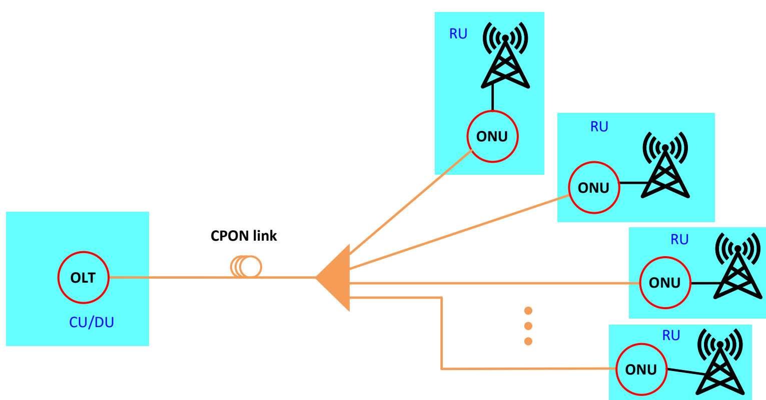


Figure 11 - Mobile Fronthaul Use Case

The flexibility and capacity of CPON could provide cost-effective solutions for xhaul (i.e., fronthaul or midhaul) requirements in time-limited high-traffic situations like live sporting or entertainment events (such as concerts, festivals, or sporting playoff events with temporary venues).

6.5 Mixed Use Cases

Note that CPON deployment in a specific location is not limited to one of the aforementioned use cases. CPON can support mixed use cases or applications concurrently (Figure 12), as it is a network capable of supporting differentiated services with the proper quality of service (QoS) enforcement mechanisms in place.

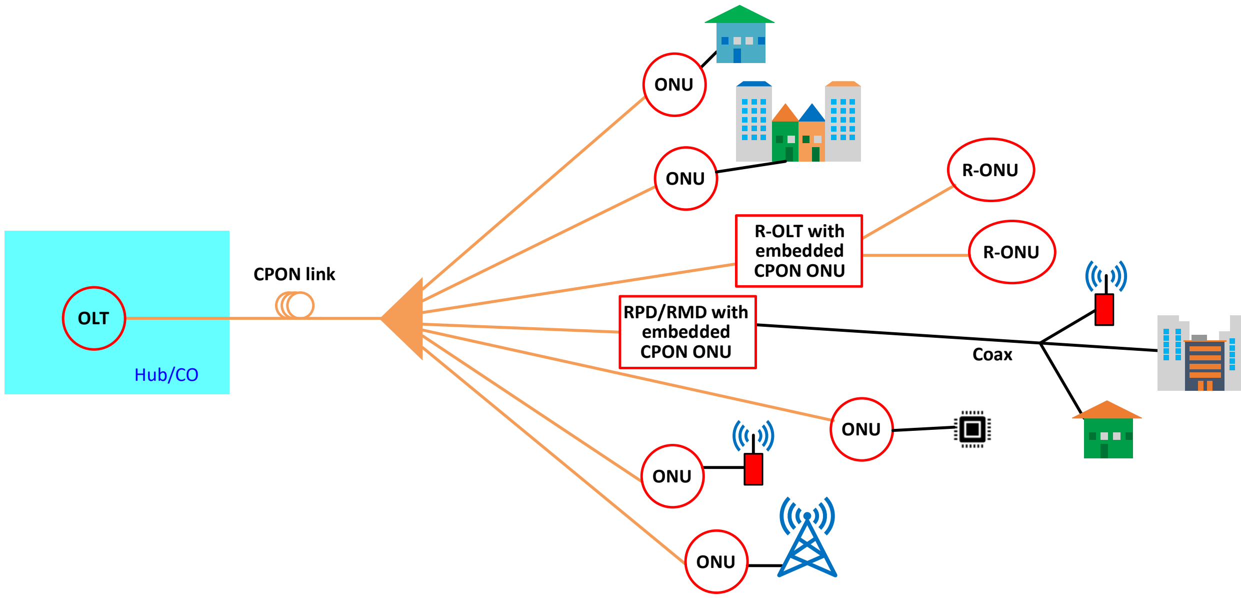


Figure 12 - CPON Support of Mixed Use Cases

6.6 Additional Use Cases

Though the above use cases serve as the primary business drivers for the development of CPON technology, there are a number of other use cases that a CPON system is expected to be able to support.

- *Network as a Platform*—Communication, processing, and security functionality based on CPON and other connectivity elements enable the flexible setup of networks among a group of users and a potential orchestration of services.
- *Wi-Fi Backhaul*—CPON provides access point connectivity to carry Wi-Fi traffic.
- *Edge Computing*—CPON connects users to edge computing nodes/devices located in hub/CO locations or provides connectivity from hub/CO locations to edge computing platforms such as edge nodes that are in closer proximity to users/subscribers.
- *Fixed Wireless Backhaul*—CPON link supports fixed wireless backhaul and provides radio connectivity to carry fixed wireless traffic.
- *Datacenter Connectivity*—CPON can manage connectivity for traffic routing among servers located in the same rack or in different racks for next-generation intra-datacenter interconnect (DCI).
- *Passive Optical Local Area Network*—Point-to-multipoint indoor network infrastructure such as a passive optical local area network (POLAN) can leverage CPON to deliver data to multiple end users within campuses or buildings.
- *IoT-Based Smart City*—CPON can support a large number of Internet of Things (IoT) devices, enabling smart city initiatives worldwide.

7 OPTICAL DISTRIBUTION NETWORK

This section describes some of the ODN scenarios in which a CPON system is expected to operate when providing the services described in the use cases from Section 6, including the characteristics of those ODNs. Note that in many cases it will be advantageous to leverage already deployed fiber, which will influence the nature of the ODN scenarios.

7.1 ODN Scenarios

7.1.1 High-Density Connectivity

The evolution of PON technology has been driven by capacity demand in the access network. Bandwidth requirements in densely populated metro areas have considerably increased over the past few years. In legacy IM-DD PON, upgrading the capacity of metro networks involves lighting spare fibers, adding new wavelengths, or building a new fiber, which can be costly. In contrast, leveraging the high receiver sensitivity and power budget enabled by coherent technology, CPON can provide a much higher capacity for the various service types to a larger number of subscribers in densely populated areas.

In a metro area, fiber link lengths between an OLT and its corresponding ONUs are relatively short compared to rural area deployment cases, i.e., usually less than 40 km, sometimes within 20 km. The number of subscribers in a dense service area, however, can be very high, up to 512 for a single CPON network. With its high capacity and high-split ratio, CPON can support a wide range of applications in densely populated areas, including FTTH, xhaul (fronthaul, midhaul, and backhaul) transport of mobile networks, enterprise and business, and access aggregation architecture. Figure 13 shows CPON for metro area connectivity with a high-split ratio and supporting various applications.

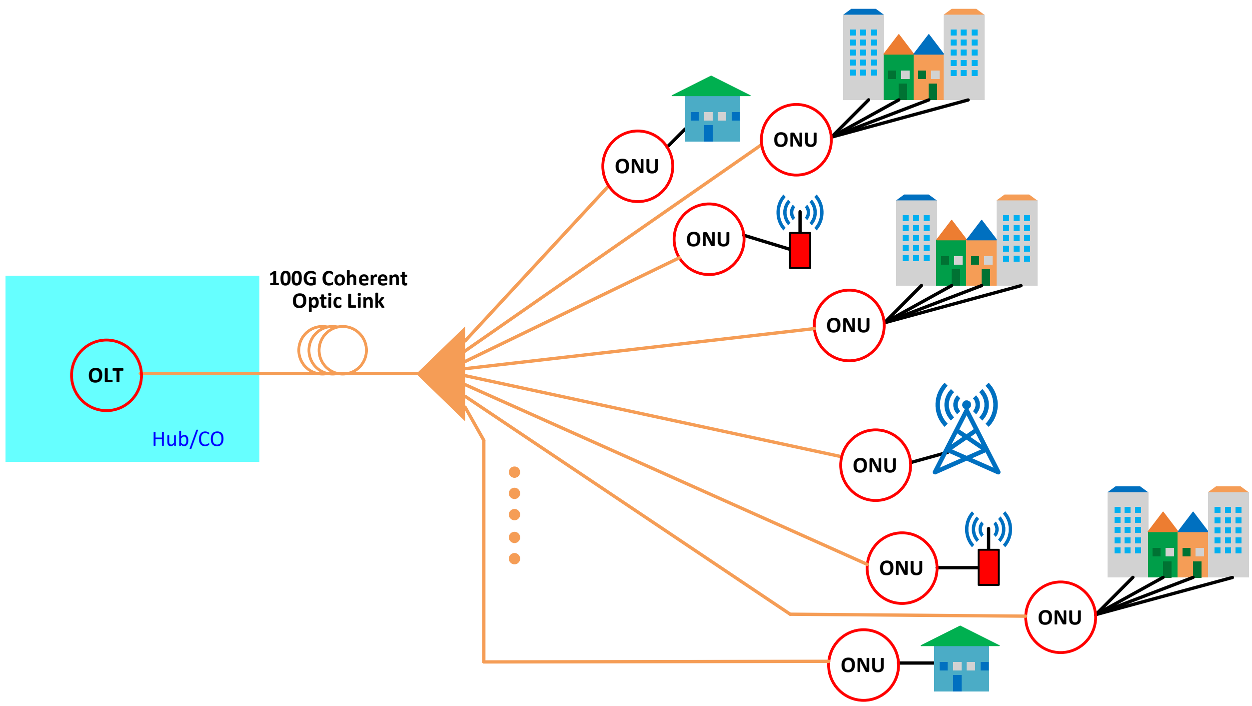


Figure 13 - CPON for High Split Ratio Connectivity in a Metro Area

7.1.2 Sparse Connectivity with Long Link Distance

To meet the growing demands from subscribers in rural areas and other sparse or lower penetration environments, CPON can provide long link distance connectivity with a smaller split ratio, i.e., an 80-km link with a split ratio of 16. Figure 14 shows an example of rural area connectivity with centralized splitting and a balanced split ratio. In this CPON configuration, after a long link distance fiber link, a passive optical splitter is used to distribute the downstream signals passively to the end users.

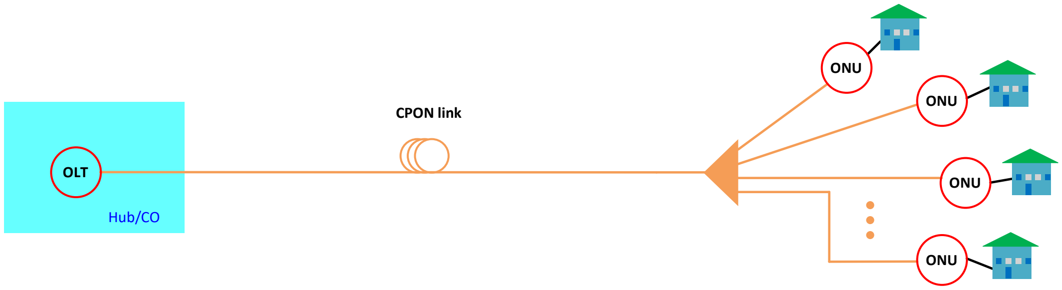


Figure 14 - Centralized Splitting with Balanced Split Ratio

7.1.3 Distributed Splitting

Centralized power splitting with a balanced split ratio in rural areas and some urban scenarios may not always be the optimal solution for signal distribution, especially under sparsely populated locations and low-penetration scenarios. Figure 15 shows a distributed splitting configuration, where the splitting points can be distributed across different locations to meet the connectivity needs. The passive splitters here have a symmetric splitting ratio.

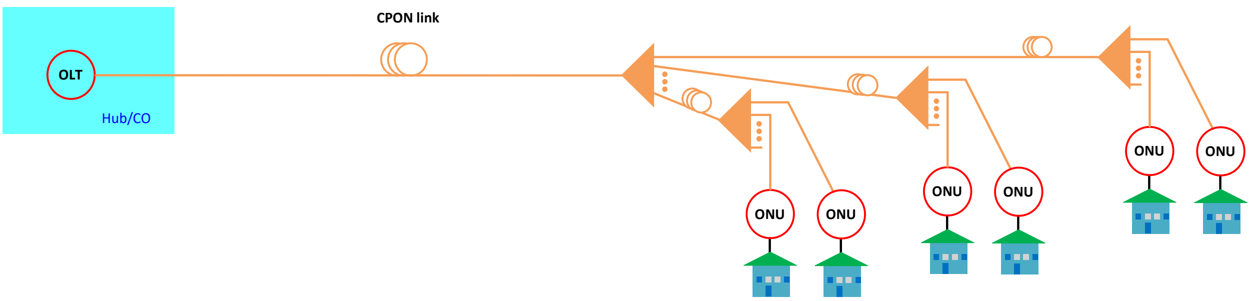


Figure 15 - Distributed Splitting with Balanced Split Ratio

Another configuration to consider in rural areas, shown in Figure 16, utilizes distributed splitting and asymmetric splitters/optical taps to better accommodate the connectivity requirements in sparse housing areas by providing greater flexibility. The asymmetric splitter, e.g., in a 1×2 configuration, can use a range of power split ratios, for example, from 1/99% to 40/60%. Distributed splitting with an asymmetric split ratio can provide more flexibility in planning the location of passive nodes and potentially reduce fiber deployment cost. If asymmetric splitting is used, CPON provides additional link budget margin to accommodate unexpected extra drops or splits in the ODN.

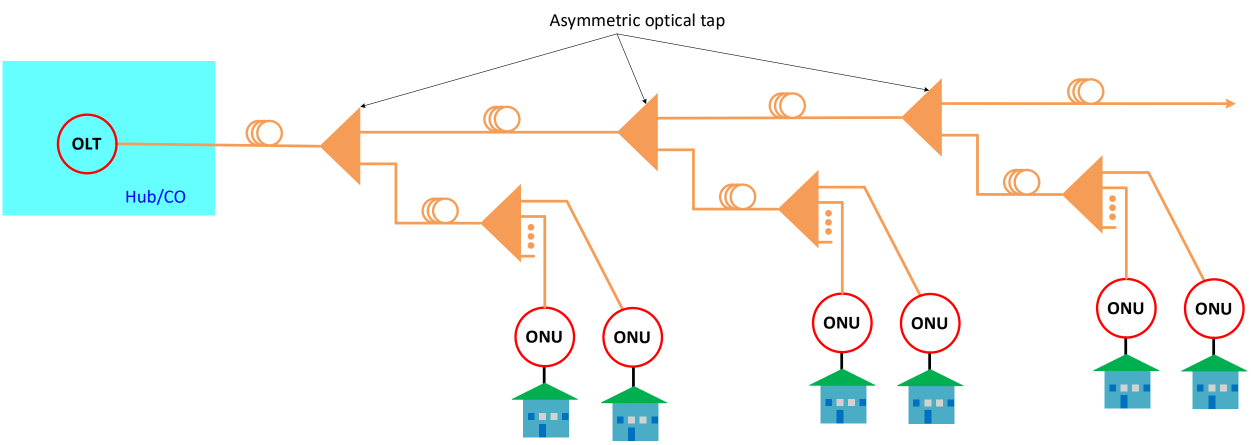


Figure 16 - Distributed Splitting with Asymmetric Split Ratio

CPON can also be used in asymmetric splitting instances in small towns to connect R-OLTs serving IM-DD PON to a central facility through a common fiber. As shown in Figure 17, customers that generate higher traffic and potentially more revenue could be moved from a remote ONU connected to the R-OLT to a coherent ONU connected directly to the CPON network, if warranted. This would lower traffic use on the R-OLT and extend its intended service lifecycle.

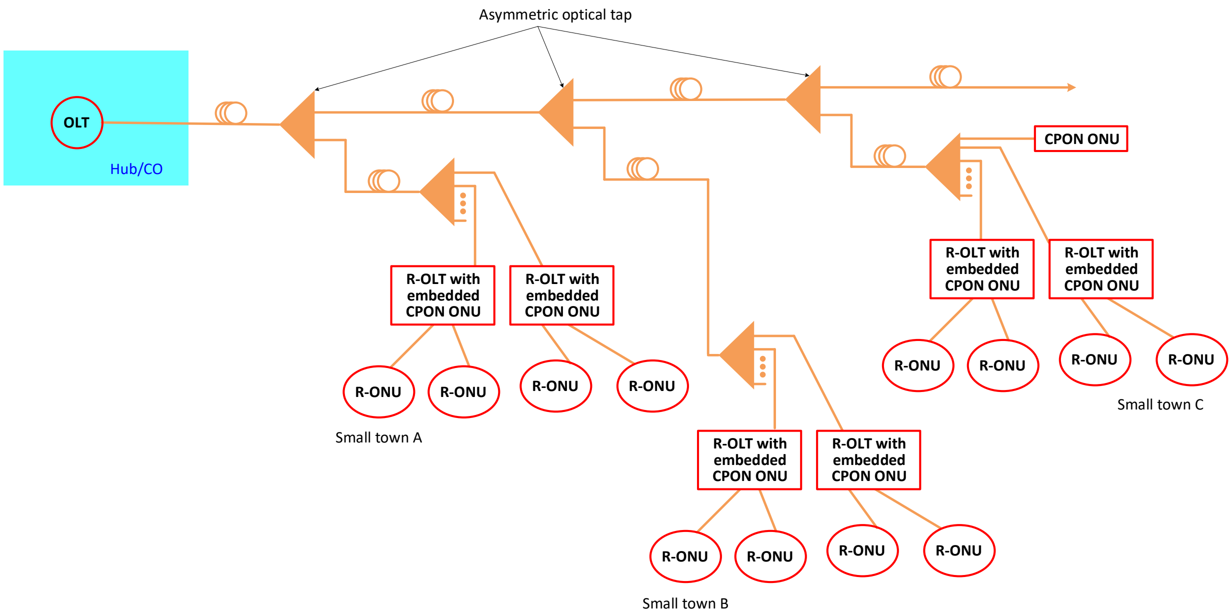


Figure 17 - Distributed Splitting with Remote OLTs

Similarly to the R-OLT case, a CPON network can be used with asymmetric splitting to connect RPDs/RMDs in small towns in a linear chain, for example down a highway. There would be little gain for doing so if the RPDs/RMDs are already connected, but if the distance or link budget limitations prevented the original larger RF analog optical node to be DAA-converted into multiple RPDs/RMDs, then CPON could support the DAA conversion process by providing the backhaul necessary for these multiple RPDs/RMDs to connect back to their CIN routers and vCCAP servers.

7.2 Fiber Characteristics

The minimum requirement of CPON systems is support for the fiber types described in [ITU-T G.652].B attributes and [ITU-T G.652].D attributes.

8 OPERATIONAL NEEDS

This section identifies operator business needs and requirements for a CPON system in order to support the use cases and ODN scenarios identified in Sections 6 and 7, respectively.

8.1 Interoperability

CPON-compliant devices—OLTs and ONUs—are required to be interoperable with each other regardless of manufacturer. This means that any CPON-compliant ONU will operate with any CPON-compliant OLT and that a single CPON-compliant OLT will support CPON-compliant ONUs from multiple manufacturers simultaneously.

Ensuring cross-vendor interoperability is an essential motivation for the development of CPON specifications.

8.2 Distance and Split Ratio

In order to support the identified ODN scenarios, it will be important for a CPON system to support devices at a variety of distances with varying split ratios. Those business requirements will in turn serve as key drivers for the link budget required for the system, defined as the amount of acceptable insertion loss of a CPON ODN in order to operate properly.

In this specification, the maximum link distance is defined as the maximum overall length of fiber distance between a CPON OLT and the corresponding ONU optical transmit/receive interfaces (defined in [P2PCO-PHYv1.0], Section 5.2). The split ratio is the average individual power output divided by the total power output of all split ports. This parameter defines the maximum number of ONUs supported by a single OLT port. Note that the distance and split ratio defined here support both single centralized split and distributed/cascaded split ODN architectures.

In order to reach at least 95% of customers using currently deployed cable operator ODNs, CPON systems will need to have a reach of approximately 80 km (dramatically greater than the 20-km limit of many IM-DD PON technologies). At that distance, given that it will typically be for lower density deployments, a split ratio of 1:16 is acceptable. This will address the growing demands from subscribers in rural areas and other sparse or lower penetration environments cost effectively (see Section 7.1.2).

Additionally, in metro areas and/or in MDUs, distances are substantially shorter but with much higher densities. In order to effectively support these scenarios over the same distances covered by existing IM-DD PON deployments (20 km), CPON systems will need to support a 1:512 split ratio. This will allow operators to support more customers with fewer ports, reducing capital equipment costs.

Table 1 summarizes these requirements and gives an interim data point.

Table 1 - Distance and Split Ratio Requirements

Split Ratio	Link Distance
1:512	20 km
1:64	50 km
1:16	80 km

The maximum link distance defined here will provide connectivity to small communities in rural areas. It can be challenging to use IM-DD PON to support communities with lower population densities in areas separated by large geographical distances. With IM-DD PON, multiple ODN deployments may be required to cover rural areas, but the 80-km link distance of CPON potentially reduces deployment cost for rural area applications. The longer link distance also aligns distance limits that cable system operators have for >90% of their existing HFC networks.

Alternately, in dense urban areas, a high split ratio can be used to minimize the number of OLT ports required and simplify ODN design.

As an example, a link budget of 35 dB would support the above requirements and should be achievable at reasonable cost. This is demonstrated in Figure 18 below.

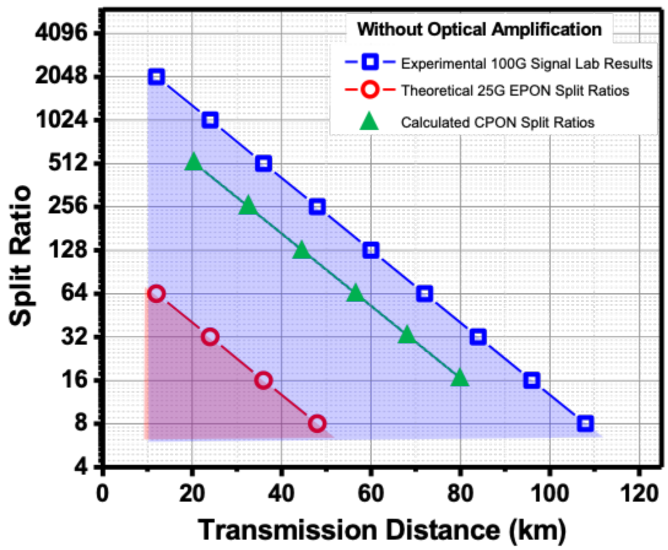


Figure 18 - Split Ratio vs. Transmission Distance for Different Types of Signals

The blue line represents the experimental results obtained in the lab using best-in-class opto-electro components, which feature high-sampling rate and high-bandwidth ADC/DAC devices. Here the line rate of the signal is 100 Gbps.

The green line represents the example 35 dB link budget, minus 1 dB of splitter loss and 2 dB of margin. As can be seen, this meets the split ratio requirements identified above and, as an offset from "best-in-class" components, supports the development of devices at a reasonable cost.

The red line represents an expression of the link budget target for 25G-EPON, demonstrating the significantly enhanced design flexibility that CPON technology will provide.

8.3 System Capacity

Line rate is defined as the bit rate of the signal that is transmitted on the optical channel and includes all overheads, such as FEC, framing, and encoding. It is directly related to the symbol rate, which is the number of symbols transmitted per unit time. For example, with dual-polarization QPSK, there are 4 bits per symbol; therefore, the line rate is 4× the symbol rate.

In contrast, the data rate is the bit rate of the data that are transmitted on the optical channel after FEC, framing, and encoding overheads are removed.

Note that, conventionally, the transmission rate for each generational PON standard is the line rate: for example, the line rate is 10 Gbps for XGS-PON (8.667648 Gbps net data rate) and or 25 Gbps for Nx25G-EPON (21.2246 Gbps data rate). In contrast, for a current P2P system such as commercial coherent optical systems, the transmission rate is defined as the data rate: for example, for 100 Gbps (data rate) coherent optics, the line rate is 128 Gbps.

To support the previously defined use cases, a CPON system will need to support line rates as indicated in Table 2.

Table 2 - Minimum Downstream and Upstream Line Rate Requirement

Parameter	Minimum Requirement
Line rate	~100 Gbps for downstream
	~100 Gbps for upstream

This represents a minimum requirement; as such, CPON systems may support higher line rates. Higher line rates are desirable from a capacity perspective, but the tradeoff is that higher line rates need more power for a given signal sensitivity, which may subtract from the available link budget. Higher line rates may also have a cost delta impact for DSP chip and opto-electronic devices.

8.4 Coexistence

This section defines CPON coexistence requirements. Coexistence here refers to the ability for two or more different optical systems or generations to operate simultaneously on a common ODN. This helps to minimize infrastructure cost and enable a smooth and non-disruptive migration toward CPON deployments.

Three different forms of coexistence are required for CPON systems:

- coexistence with IM-DD (legacy) PON systems,
- coexistence with P2P DWDM systems, and
- coexistence with other CPON systems (aka CPON stacking).

Coexistence with P2P CWDM systems is not required.

8.4.1 CPON Coexistence with IM-DD (Legacy) PON Systems

CPON systems are required to be capable of operating on the same ODN as IM-DD (legacy) PON systems without impacting the operation of those legacy PON systems. This is facilitated by the use of a coexistence element (CEx) device that is compatible with both their legacy PON system and their target CPON wavelengths, as shown in Figure 19 and defined in [ITU-T G.9804.1].

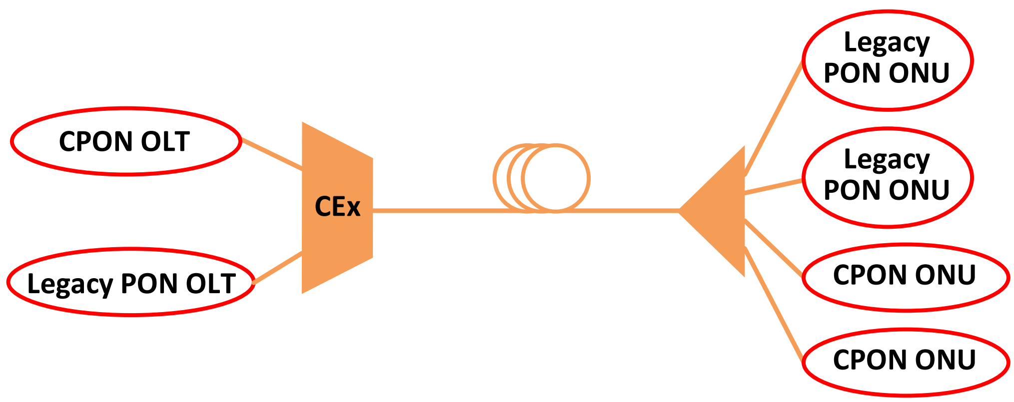


Figure 19 - CPON Coexistence with a Legacy PON Through CEx

8.4.2 CPON Coexistence with P2P DWDM Systems

CPON systems are required to be capable of operating on the same ODN as P2P DWDM links without impacting the operation of those legacy links. Coexistence of CPON with P2P DWDM links can be achieved by using passive DWDM devices, as shown in Figure 20.

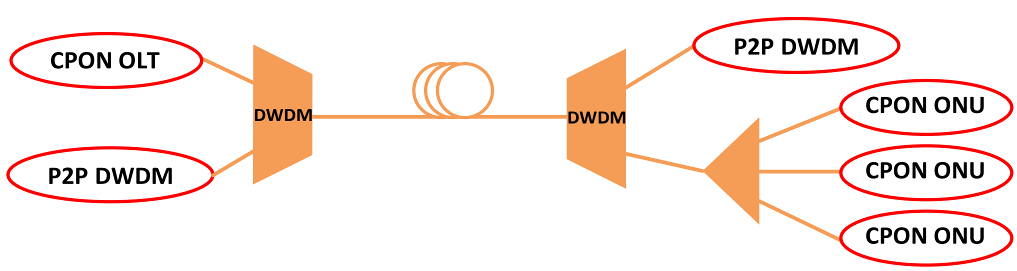


Figure 20 - CPON Coexistence with a P2P DWDM System Through Passive DWDM Device

8.4.3 Coexistence with Multiple CPON Signals (CPON Stacking)

CPON systems are required to be capable of operating on the same ODN as other CPON systems without impacting the operation of those other CPON systems. As a result, the capacity of the ODN can be further expanded by stacking multiple CPON wavelengths on a single fiber link.

- CPON stacking can permit traffic growth to be handled by allocating a new wavelength to specific service types dominating the original wavelength, such as adding new and moving some existing mobile xhaul services to their own wavelength or grooming enterprises onto their own CPON lambda.
- CPON stacking can also permit smaller rural communities that have limited existing fiber routes or limited ability to have fiber deployed to stack different CPON signals on the same fiber at different wavelengths.

Therefore, though a CPON signal might only serve a maximum of 16 ONUs at the distance of 80 km, it is anticipated that stacking multiple CPON signals at different wavelengths could serve a much higher number of ONUs at the same distance. This multiplexing use can alleviate the need for additional facilities at remote locations and thereby provide an overall total cost of ownership benefit.

Further, although the above figures only show a single CPON coexisting with other systems, multiple CPON wavelengths can be stacked together on the same fiber while coexisting with legacy PON systems or P2P DWDM links, such as in the mixed-use case described in Section 6.5.

8.5 QoS and Network Slicing

In order to support the use cases identified previously, CPON systems will need to support a robust set of QoS controls, enabling operators to manage parameters such as maximum traffic rate, minimum reserved traffic rate, and traffic priority. Further, CPON systems will need appropriate QoS mechanisms to support the creation of network slices for specific customers and/or services.

8.6 Operations, Administration, and Management

Operators need the ability to operate, administer, and maintain their networks through standard and existing protocols supported in the OLT and ONU, through in-band or out-of-band connections.

8.7 Power Consumption

CPON OLT and ONU transceivers need to work with the electrical power available at existing hubs/COs and power insertion locations in the field (i.e., fiber node locations), such as -48V DC, 120V AC, and 220V AC, sharing with other HFC or PON devices that may be present.

Power saving in PON components and systems has drawn increasing attention over the past decade, targeting operational expenditure reduction and environmental protection. CPON systems need to be designed in the most energy efficient way to accommodate power-saving requirements while maintaining compatibilities with service requirements. An energy saving or sleep mode is optional; it should be incorporated into CPON devices and systems upon the operator’s request, allowing power reduction during low network usage time frames. For example, see [EU Code of Conduct] for details regarding the approach the European Commission recommends to vendors and operators to minimize power draw over time. See [Energy Star] for details regarding U.S. vendors and operators partnering with the U.S. Environmental Protection Agency to develop cost-saving energy efficiency solutions.

8.8 Security

PON is fundamentally based on the shared medium of the ODN. Consequently, CPON needs to include measures to ensure the privacy of end users while protecting the network from malicious actors, regardless of whether the actor is unaware (customers with systems infected by DDoS agents or other malware) or if they are intentionally attempting to gain illicit service from an unprotected endpoint (theft of service through cloning or tampering of ONUs) or disrupt service. Given that these networks will be used for mobile backhaul as well as residential and business broadband, CPON will likely also be a target for cyberwarfare to interrupt communication capabilities.

CPON networks need to implement the controls listed as parameters in Table 3 to protect both the operators and the customers, ensuring privacy and security remain robust while conforming with local lawful intercept requirements.

Table 3 - Security Requirements for CPON

Parameters	Requirements
Mutual authentication	Ensure that only authorized devices are granted network access.
Encryption	Customer traffic will be transported securely to keep customer traffic confidential.
Secure storage of credentials; secure provisioning and configuration; secure firmware update and configuration; trusted boot; access control	Architecture will be resistant to service theft and device tampering locally and remotely.
Secure firmware update and configuration	Ensure resistance to privilege escalation or unauthorized downgrading.
Ability to disable ONU participation in the PON	Ensure resistance to misbehaving devices that impacts performance of other devices.
Secure management channels (authentication, encryption, access controls)	Management and control planes will be secure from unauthorized access or use.
Security information and event monitoring	Ensure support for security monitoring that is interoperable with security operations.

8.9 Protection and Resiliency

In a CPON system, a very large number of subscribers or business/mobile backhaul services can be supported. The failure of any key network component or fiber link interrupts such critical service. These failures include fiber cuts and failure in the OLT, ONU, power splitter, or optical amplifier, if employed. This makes CPON protection important for a variety of use cases.

There are many protection schemes that can be applied to CPON, and they offer different levels of protection to ensure network reliability and resiliency, such as PON protection Type B and Type C as described in [ITU-T G Supplement 51] and [IEEE 1904.1]. Protection of PON components includes any or all of the feeder fiber, drop fiber, OLT equipment, and ONU equipment. Figure 21 shows two CPON protection configurations. Figure 21A provides protection to the OLT and feeder fiber, where no redundancy is provided in the ONUs or drop fibers. The OLT in different chassis can be in the same or different geographic locations. Figure 21B provides full protection to the OLT, feeder fiber, splitter, ONU, and drop fiber.

Depending on the ONU and OLT implementation, the protection covers

- only the optical transceiver, while sharing the MAC layer and associated MAC clients, or
- the optical transceiver and the MAC layer with associated MAC clients.

The latter option provides a more reliable protection scheme, providing protection against failure in the optical transceiver as well as the ASIC, whereas the former option provides protection against the most common source of failures, i.e., the optical transceiver and the associated fiber plant.

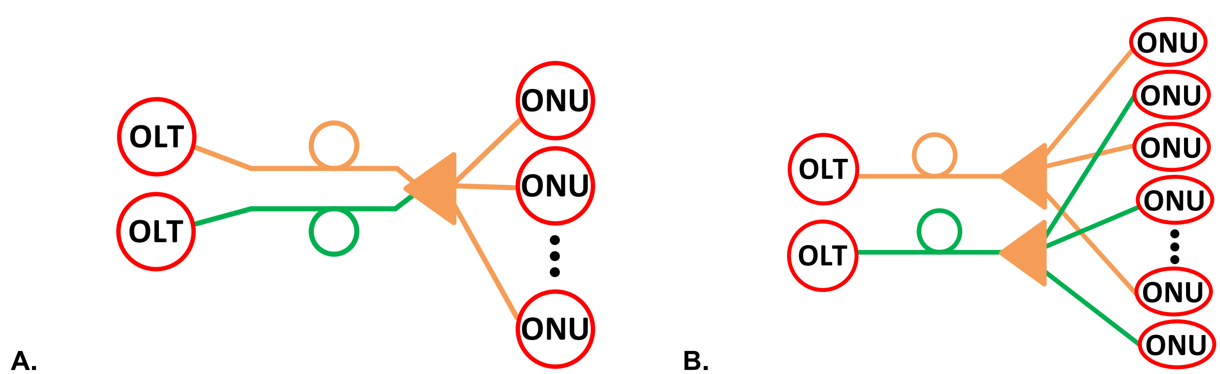


Figure 21 - Examples of CPON Protection Architecture: A, Protection Against OLT and Feeder Fiber Failure; B, Protection Against OLT and Entire ODN Failure

To balance the cost and level of protection in CPON, the minimum requirement for redundancy/protection is to protect against OLT failure and feeder fiber failure, like the protection scheme in Figure 21A or other variations that offer the same level of protection. Full protection against OLT and entire ODN failure, as the protection scheme in Figure 21B or other variations that offer the same level of protection, is optional. Note that CPON protection can potentially help avoid planned maintenance outages, reduce disruption of service, and allow maintenance to proceed during normal business hours. More network protection design examples can be found in a CableLabs white paper [CPON Protection].

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