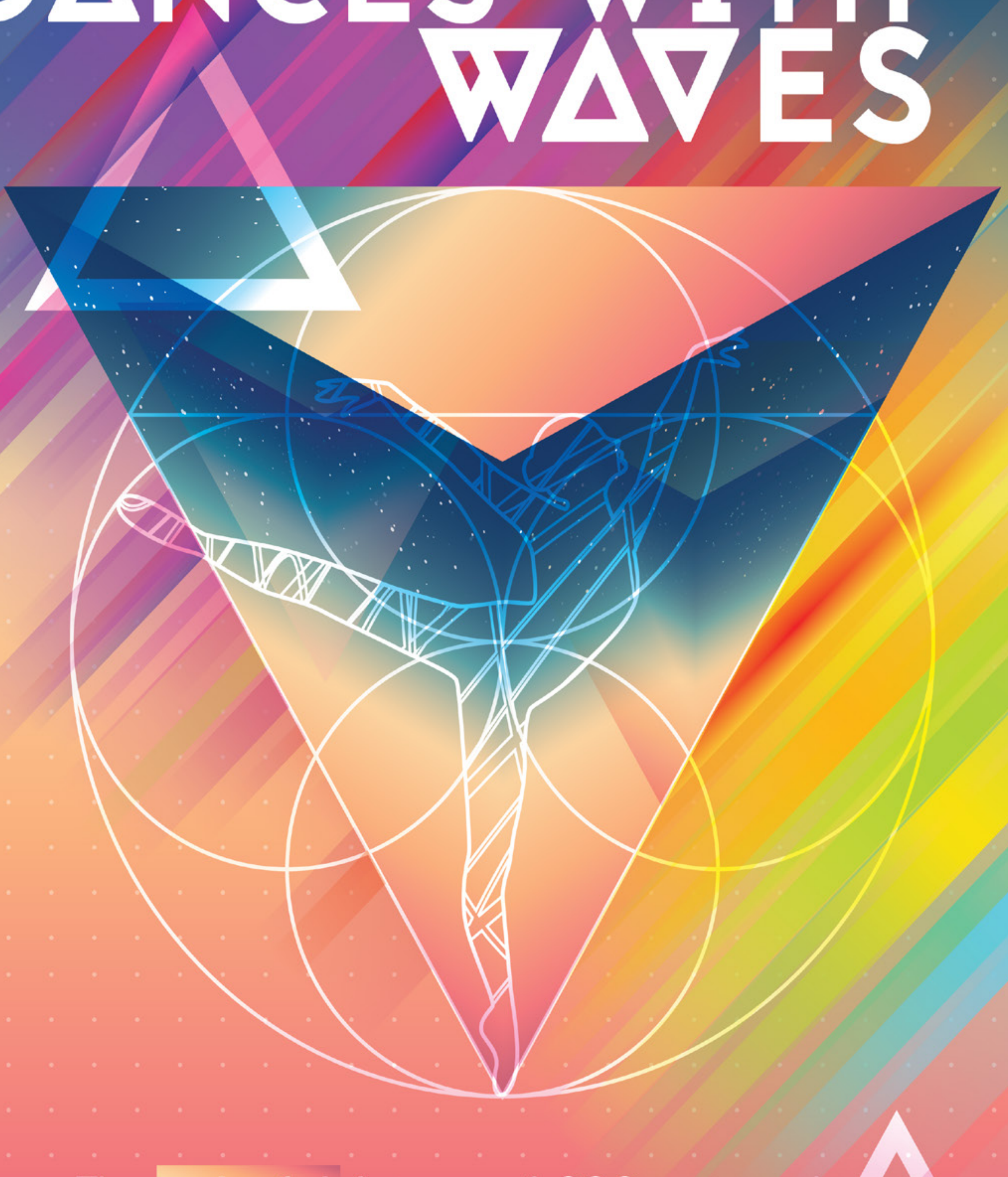
DANCES WITH WAVES



The colorful future of PON networks

WDM PON, XG-PON, NGA, NG-PON, TWDM PON, WDM1r, CEx, CEMx, etc.

1. Current state of optical access networks

The times of glory for copper transmission media such as coaxial cables and twisted pair are doubtlessly and irrevocably gone (even though in many places these media still resist, and will resist, the progress of civilization). Telecom operators who want to provide high-quality and reliable access to modern services (telephone, HD quality television, broadband internet, online games, etc.) must turn to new generation access networks (NGA) based on optical fibers. In most countries, the dominating technology for building optical access networks are passive optical networks (PONs), constructed in point-to-multipoint topology (Fig. 1). In such networks, the only active devices used are the optical line terminations (OLTs) located at the operator's end and optical network terminations (ONTs).

The main fiber connects the central OLT with a passive splitter (e.g. PLC), and only after that fibers are routed to each subscriber individually. Each OLT port can have up to 128 subscribers connected through splitters.

Since some PON sections are common for all subscribers and use only one fiber for duplex transmission, a multiple access technique is needed in order to obtain a point-to-point logical topology overlaid on the point-to-multipoint physical topology. In the currently implemented PONs, the classic time division multiple access is used.

The data transmitted from an OLT is received by all ONTs, where it is filtered and portion of traffic dedicated to the given ONT is extracted.

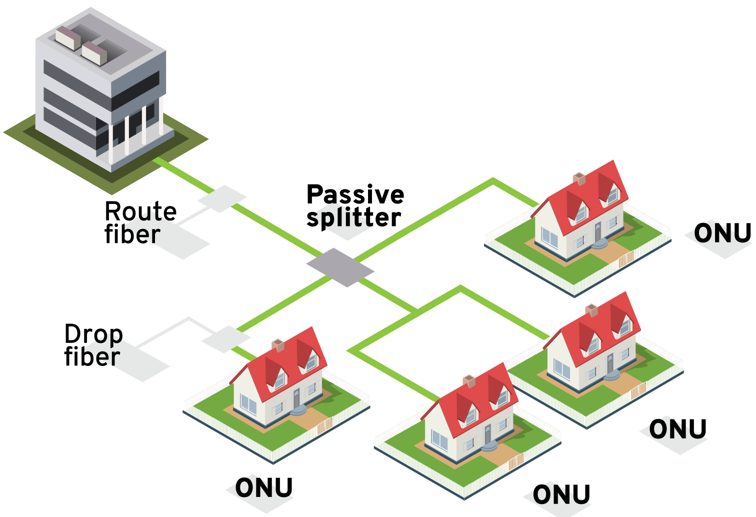


Fig. 1. Passive Optical Network scheme

Everything else between OLT and ONT is passive and doesn't require power supply. This has many advantages from the point of view of the operator. During construction or modernization of the network there are no problems with supplying power to an intermediate point that can be situated far from power lines. The costs of operating the network are lower because there is no need to pay electrical bills. Similarly, maintenance costs for PON networks are also very low, as for example there are no problems with electronics fried after thunderstorms. In PONs, the distribution part (the main fiber) is common for all customers.

For upstream communication, each subscriber transmits data in a specified (assigned by the OLT) time slot. PONs being built nowadays can use either the more popular (and having more capabilities) GPON standard, or the less frequently encountered (and less potent) GEPON standard.

2. GEPON vs GPON

The GEPON (Gigabit Ethernet Passive Optical Network) standard was developed by the American Institute of Electrical and Electronics Engineers (IEEE). It is implemented mostly in PONs built in Asia (Japan, South Korea, China). In the IEEE 802.3ah standard a passive optical access network with point-to-multipoint structure was described. Symmetrical (with the same throughput in both directions of transmission) capacity of 1 Gbit/s is available. The available bandwidth can be divided among at least 32 subscribers. The 802.3ah standard did not define the maximum split ratio (1:64 is usually used). The Ethernet protocol, well known to all (at least to the decent) network administrators, is used in the second layer.

Data in the second network layer is transmitted with GEM (GPON Encapsulation Method) protocol. It allows moving traffic of different origin/protocols (e.g. ATM, SDH), and not only Ethernet, as in the GEPON case. Additionally, GEM may contain additional correction data (FEC - Forward Error Correction), and, by sacrificing some of the available capacity, the receiver is able to correct corrupted bits that result from transmission errors. To increase security, the transmitted data is able to be additionally encrypted by 128-bit AES key.

In PONs working with GPON or GEPON protocol, apart from transmitting digital telecom traffic, it is also possible to broadcast TV services at a dedicated wavelength by using the so-called RF overlay. In this technology, it is necessary to use a 1550 nm CATV transmitter and (usually) an optical amplifier. Inserting the CATV signal into network requires a dedicated optical multiplexer, or the triplexer. This device is also indispensable for demultiplexing of the optical signal at the subscriber end. The triplexer is usually integrated into the ONU, but it can be also installed inside the customer outlet.

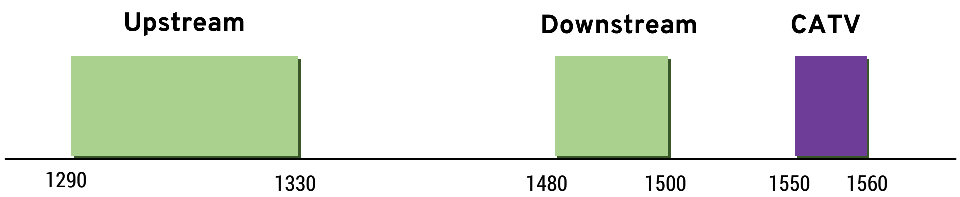


Fig. 2. Optical spectrum utilized in GPON/GEPON with implemented RF (CATV) overlay

The wavelength band of 1480-1500 nm is used for transmitting the signal from the OLT to ONU (downstream), and 1290-1330 nm (formerly 1260-1360 nm) band is used in opposite direction. This is of course a simple form of wavelength division multiplexing (WDM). Spectral bands used in passive optical networks compatible with GEPON standard are shown schematically in Fig.2.

A standard with greater capabilities, the GPON (Gigabit Passive Optical Network), was proposed by the ITU-T and is defined in the G.984 series of recommendations. Data in GPON can be transmitted with a symmetrical capacity of 2.5 Gbps/2.5 Gbps, but usually the available bandwidth is asymmetrical: 2.5 Gbps downstream and 1.25 Gbps upstream. The available capacity can be divided among up to 128 subscribers. The maximal distance between OLT and ONU is 60 km, whereas the distance difference between ONUs connected to the same OLT port (so called network range) cannot exceed 20 km. In GPONs, the typical power budget is 28 dBm (B+ class), and can be increased up to 32 dBm (C+ class) by using special lasers. GPON standard uses the same spectral bands as GEPON (Fig. 2).

An alternative to RF overlay is the IPTV (Internet Protocol Television) service. In this method, the digital TV signal is transmitted by using the well-known IP protocol. A computer is not necessary to receive the TV signal, only a set-top box decoder (STB) is needed. Besides TV broadcasting, the IPTV can also provide access to modern services such as video on demand (VoD) and online games.

3. Quo vadis, PON?

The three standard wavelength bands available in GPON are clearly not enough to get interesting. That's why (and possibly also to increase the capacity of NGA) development of standards succeeding GPON and GEPON started very quickly.
In 2009, the 10-EPON (IEEE 802.3av) standard, GEPON's successor, was established. In one version of this standard, a symmetrical capacity of 10G/10G is available, and in the other – asymmetrical 10G/1G. The new protocol uses different wavelengths than GEPON (1575-1580 nm for downstream and 1260-1280 nm upstream), so compatibility is ensured. Additional equipment is required for GEPON and 10-EPON standards to coexist in one network. They are a passive multiplexer (at the operator's end) and demultiplexer (at subscriber's end).
In the case of the GPON standard, the work on its successor was divided into two stages, named NG-PON1 and NG-PON2. The approach was based on evolution instead of revolution. The first phase (NG-PON1) was focused on increasing the capacity to 10 Gbit/s (for at least one direction), while enabling coexistence with the present GPONs and making maximal use of the available passive infrastructure. NG-PON2s are designed to initially allow 40G/10G (downstream/ upstream) capacity that will eventually increase to 160G/40G.
In the case of NG-PON1, it was initially planned to design one standard divided into two speed categories: XG-PON1 (asymmetrical bandwidth of 10 Gbit/s downstream and 2.5 Gbit/s upstream) and XG-PON2 (symmetrical 10G/10G). Only the XG-PON1 has been officially standardized by the ITU-T (it was described as XG-PON in G.987 series recommendations), and the XG-PON2 is still waiting for standardization. GPON and XG-PON standards can coexist in one passive network (Fig. 3) because the new standard uses other bands than the GPON (specifically, 1575-1580 nm downstream and 1260-1280 nm upstream), only an additional appropriate WDM filter is needed.

To make things more complicated, in June 2016, ITU-T published the G.9807.1 recommendation, in which XGS-PON with 10G/10G symmetrical capacity was described.
It is formally not a part of XG-PON standard, but it implements requirements for XG-PON2. There are no dedicated new bands in optical spectrum for the XGS–PON standard. It uses wavelengths intended for the XG-PON (basic wavelength set) or for the GPON (optional wavelength set). It means that GPON, XG-PON, and XGS-PON standards cannot coexist in one passive network (at least without some additional time-division multiplexing).
During the development of the NG-PON2 standard, different technical solutions allowing for reaching the final capacity of 160G/40G (downstream/upstream) were taken into account. Ultimately, wavelength division multiplexing (WDM), a technique well-known in fiber-optic telecommunications (and aforementioned a few times) was decided on. The NG-PON2 was described in a series of ITU-T recommendations as G.989. The maximum network range is 40 km (twice larger than for GPON), with the split of at least 64 subscribers. Transmission is realized by using a few pairs of wavelengths (typically from 4 to 8), wherein one wavelength is used for transfer from OLT to ONT (downstream), and the other in opposite direction. Importantly, not all channel pairs need to be implemented in the network at the same time, there is a possibility of adding them as the demand for the bandwidth increases ("pay as you grow"), which is convenient for the telecom operator. Moreover, data in each channel can be transmitted with the following available capacities (upstream/downstream): 10G/10G, 10G/2.5G, and 2.5G/2.5G.

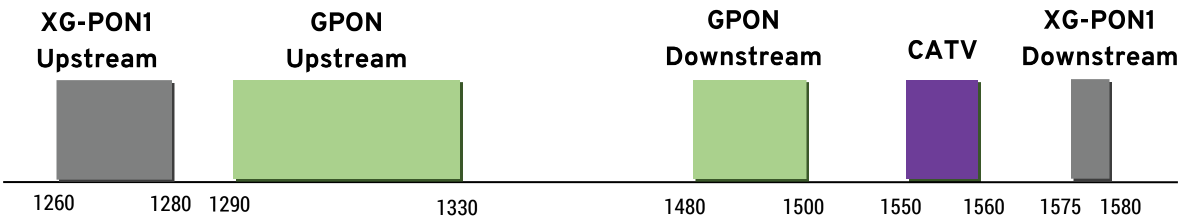


Fig. 3. Optical spectrum utilized in passive optical network with implemented GPON and XG-PON1 standards and RF overlay for broadcasting TV service (CATV)

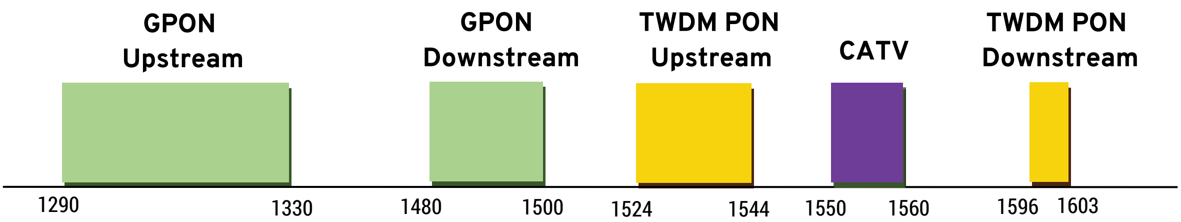
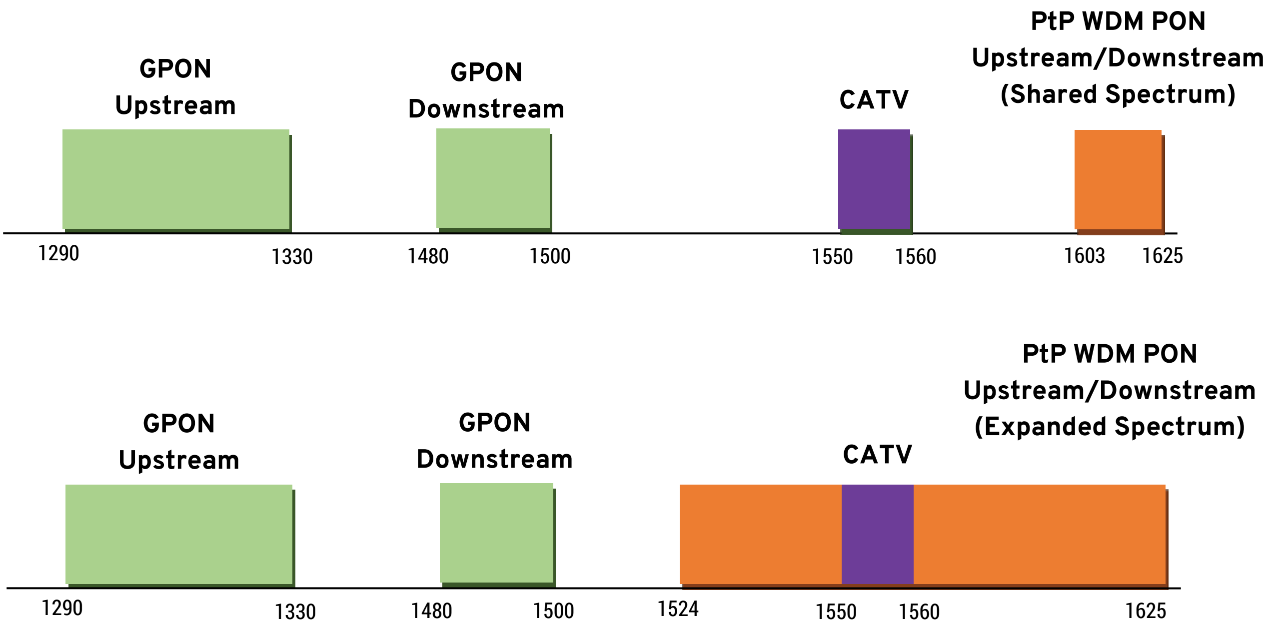


Fig. 4. Optical spectrum utilized in passive optical network with implemented GPON and NG-PON2 (TWDM PON) standards (Wide Range option for upstream transmission) and CATV overlay

The NG-PON2 standard uses different spectral bands than GPON and XG-PON, so they can coexist in one passive network (Fig. 4). In the case of the TWDM PON technique, downstream transmission is implemented in the 1596-1603 nm band. In the opposite direction, data can be transmitted in one of the three bands: 1524-1544 nm (Wide Range option), 1528-1540 nm (Reduced Range option), or 1532-1540 nm (Narrow Range option). With the PtP WDM PON technique (Fig. 5), transmission can be implemented in one of the two following bands: 1603-1625 nm (Shared Spectrum option) or 1524-1625 nm (Expanded Spectrum option).

Increasing the available capacity in NG-PON2s was accomplished by adding supplementary wavelength division multiplexing. Such transmission can be implemented in two ways: using TWDM PON or PtP WDM PON. In the first case, a group of channels is shared among many subscribers, and multiplexing in both the time- and wavelength-domain is used to achieve multiple access. It is also possible to construct a virtual point-to-point connection (Ptp WDM PON – Point to Point WDM PON), in which data is transmitted in one channel dedicated to a given ONU (and not shared with other subscribers). The implementation of NG-PON2 standard in passive network results in high requirements for active devices, for both OLT



Rys.5. Optical spectrum utilized in passive optical network with implemented GPON and NG-PON2 (PtP WDM PON) standards: a) Shared Spectrum version, b) Expanded Spectrum version

The bands used should be chosen depending on the type of protocol to be implemented: it can be either only the NG -PON2 standard or also other (e.g. XG-PON). It is important to note that for point-to-point connection there is no distinction between downstream and upstream bands.

(transmitting at different wavelengths at the same time) and ONU (“colorless transceiver” – possibility of transmitting and receiving in the whole spectral range).

4. GPON, NG-PON1, NG-PON2 – mutual coexistence

Typically, PON networks are built using the standard G.652.D fiber (with reduced water peak) but increasingly the G.657.A1 and A2 fibers (with reduced bending radius) are used. The available spectral bandwidth of these fibers covers at least the 1270-1610 nm range. In PONs with only the GPON protocol the 1290-1330 nm (upstream), 1480-1500 nm (downstream), and sometimes the 1550-1560 nm (RF overlay for CATV service) bands are used. This means that there is quite a lot of optical spectrum left unused. Hence the ITU-T G.984.5 recommendation redefined the bands used in GPON. The band used for OLT to ONU communication (downstream), is now called the Basic Band.

The band used for the upstream transmission has been divided into three sub-segments of different width: 1260-1360 nm (Regular Band), 1290-1330 nm (Reduced Band), and 1300-1320 nm (Narrow Band). New bands were also specified and called Enhancement Band so that new protocols and services can be implemented in the existing GPON networks as an WDM overlay. This requires specialized xWDM (or xPON) multiplexers and demultiplexers, as described below. The ITU-T G.984.5 recommendation calls them the Coexistence Elements. It is important to note that these multiplexers are, in many cases, technologically challenging as they need to feature some very wide and steeply-sloped channels and the spectral map leaves only narrow buffer bands. Additionally, some of the new services use fairly unusual spectral bands, compared to what used to be the norm in telecommunications. Moreover, some of the protocols for duplex transmission require the total spectrum consisting of two separate sub-bands, which doesn't make things any easier.

The ITU-T G.984.5 recommendation describes about a dozen example configurations of xWDM (xPON) multiplexers, which covers practically all paths for PON evolution, as considered today.

By installing xPON multiplexers now, telecom operators can make sure that their networks will be ready in the future for seamless transition or upgrade when they decide what evolution path to take or what additional solutions (for example CATV service, OTDR monitoring channel, or implementation of 40G NG-PON2) to add.

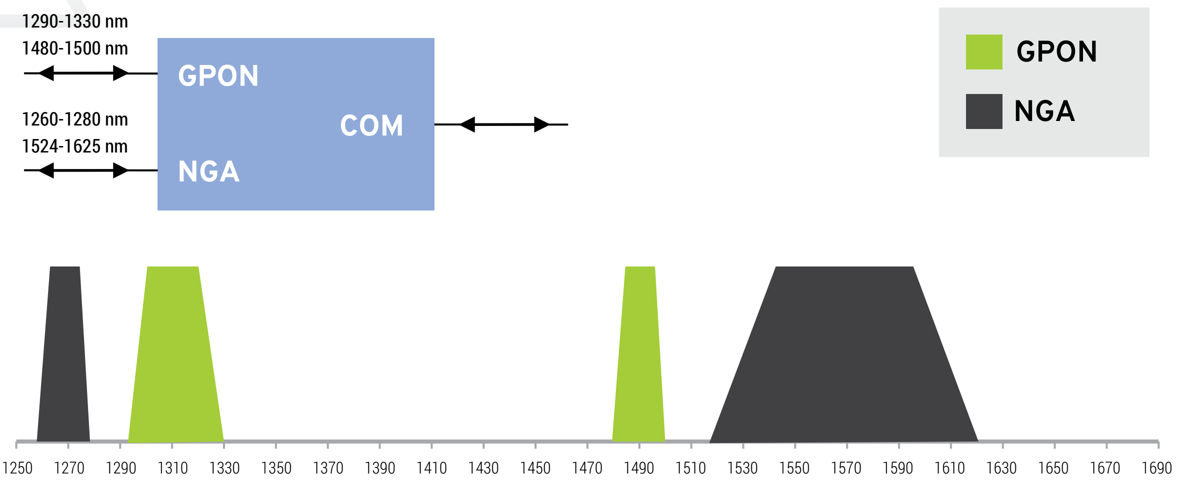
In the ITU-T recommendation, xWDM multiplexers are divided into three main groups, depending on the services or standards they support. The WDM1r multiplexers should be used when adding new-generation services (e.g. HD quality television) is planned in an existing GPON. The CEx multiplexers can be applied in implementations of new NG-PON1 standards (XG-PON or XGS-PON) and NG-PON2 in passive networks. The most advanced CEMx multiplexers allow for future implementation of wavelength division multiplexing, that is the NG-PON2 standard (TWDM PON or PtP WDM PON approaches). Schemes and basic parameters of xWDM multiplexers compliant with the ITU-T G.984.5 recommendation requirements are shown in the figures and tables below. Tab. 1 compiles the major ITU-T recommendations relevant for implementing new protocols or services in PON network. Fibrain offers a complete portfolio of xWDM and xPON multiplexers, terminated with any type of fiber connectors and in a wide range of housings (for example ABS blackbox, LGX modules, PZXW patch panels).

Please visit our xWDM/xPON products website for detailed information

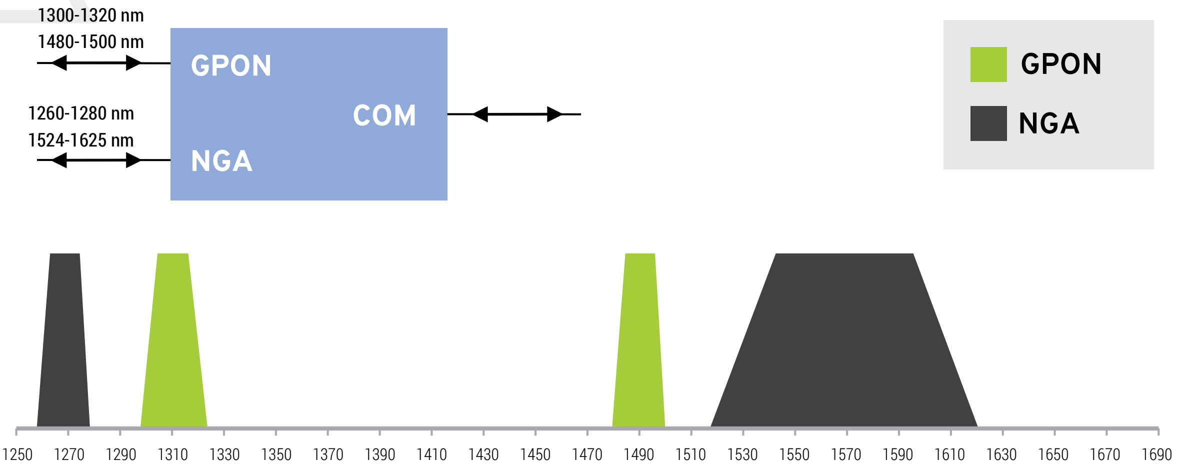
Tab. 1. List of major ITU-T recommendations

Recommendation	Title
G.984.1	Gigabit-capable passive optical networks (GPON): General characteristics
G.984.2	Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification
G.984.5	Gigabit-capable passive optical networks (G-PON): Enhancement band
G.987.1	10-Gigabit-capable passive optical networks (XG-PON): General requirements
G.987.2	10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification
G.9807.1	10-Gigabit-capable symmetric passive optical network (XGS-PON)
G.989.1	40-Gigabit-capable passive optical networks (NG-PON2): General requirements
G.989.2	40-Gigabit-capable passive optical networks (NG-PON2): Physical media dependent (PMD) layer specification

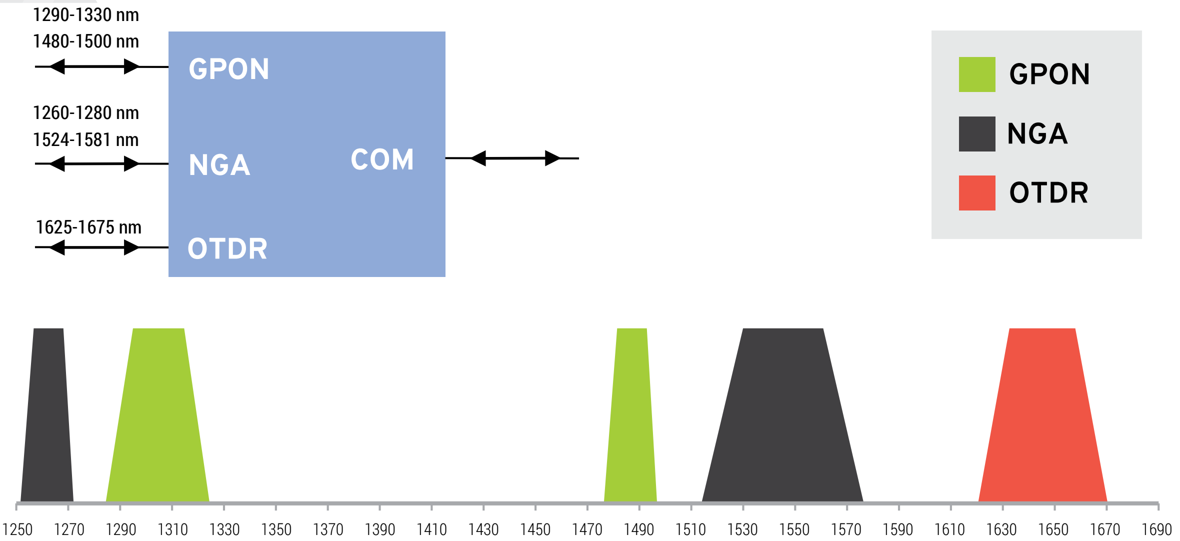
WDM1r.1

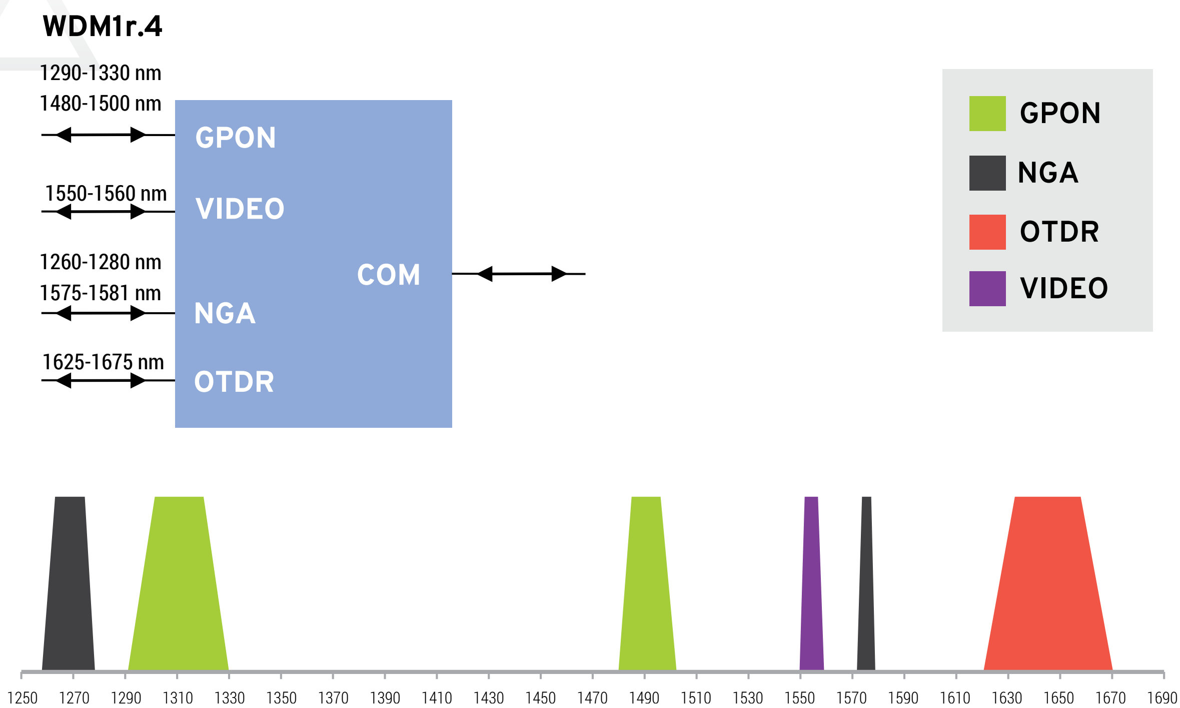


WDM1r.2



WDM1r.3



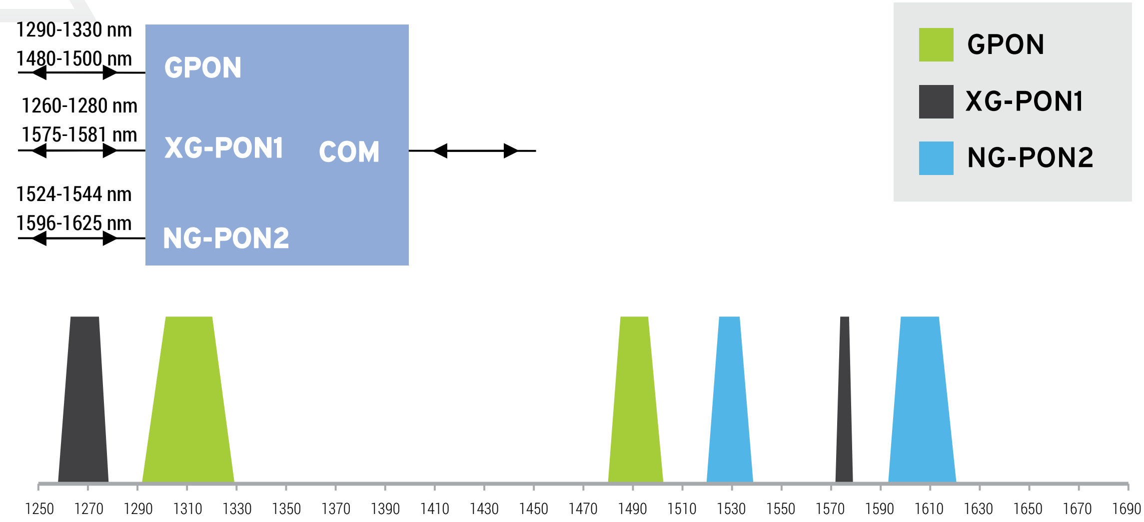


Tab. 2. WDM1r multiplexer parameters (according to ITU-T G.984.5 recommendation):

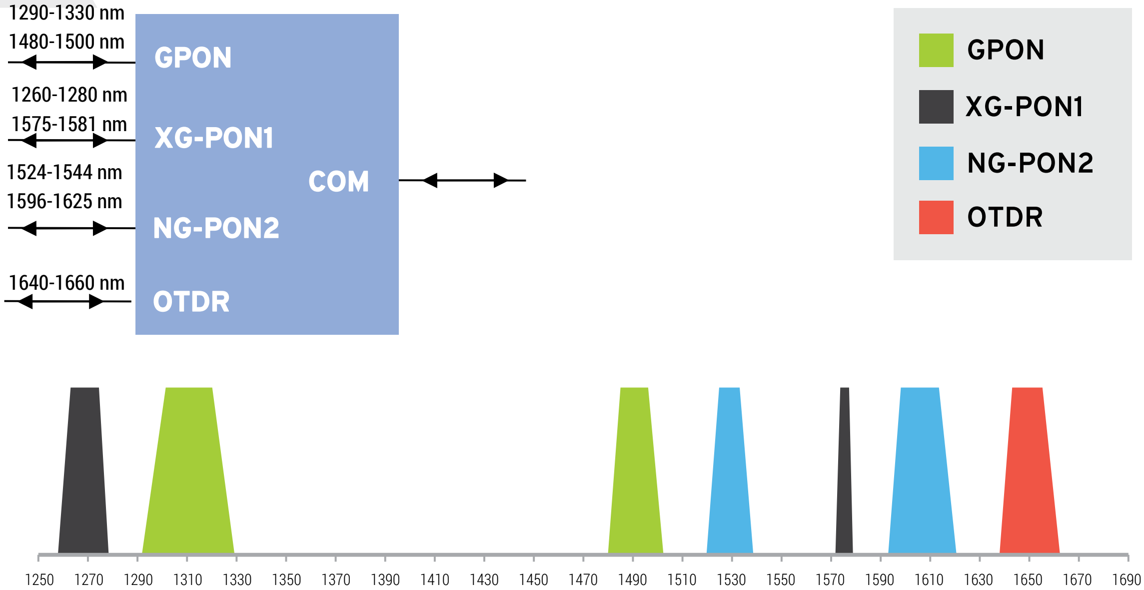
Multiplexer	Protocol/service	Range	IL_{max}*
WDM1r.1	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	NGA	1260-1280 nm 1524-1625 nm	<1.0 dB
WDM1r.2	GPON	1300-1320 nm 1480-1500 nm	<0.8 dB
	NGA	1260-1280 nm 1524-1625 nm	<1.0 dB
WDM1r.3	GPON	1290-1330 nm 1480-1500 nm	<1.0 dB
	NGA	1290-1330 nm 1480-1500 nm	<1.2 dB
	OTDR	1625-1675 nm	<1.1 dB
WDM1r.4	GPON	1290-1330 nm 1480-1500 nm	<1.0 dB
	NGA	1260-1280 nm 1575-1581 nm	<1.5 dB
	VIDEO	1550-1560 nm	<1.7 dB
	OTDR	1625-1675 nm	<1.1 dB

* - Without connectors

CEx.1


1290-1330 nm
1480-1500 nm
1260-1280 nm
1575-1581 nm
1524-1544 nm
1596-1625 nm
GPON
XG-PON1
NG-PON2
COM
GPON
XG-PON1
NG-PON2
1250 1270 1290 1310 1330 1350 1370 1390 1410 1430 1450 1470 1490 1510 1530 1550 1570 1590 1610 1630 1650 1670 1690

CEx.2


1290-1330 nm
1480-1500 nm
1260-1280 nm
1575-1581 nm
1524-1544 nm
1596-1625 nm
1640-1660 nm
GPON
XG-PON1
NG-PON2
OTDR
COM
GPON
XG-PON1
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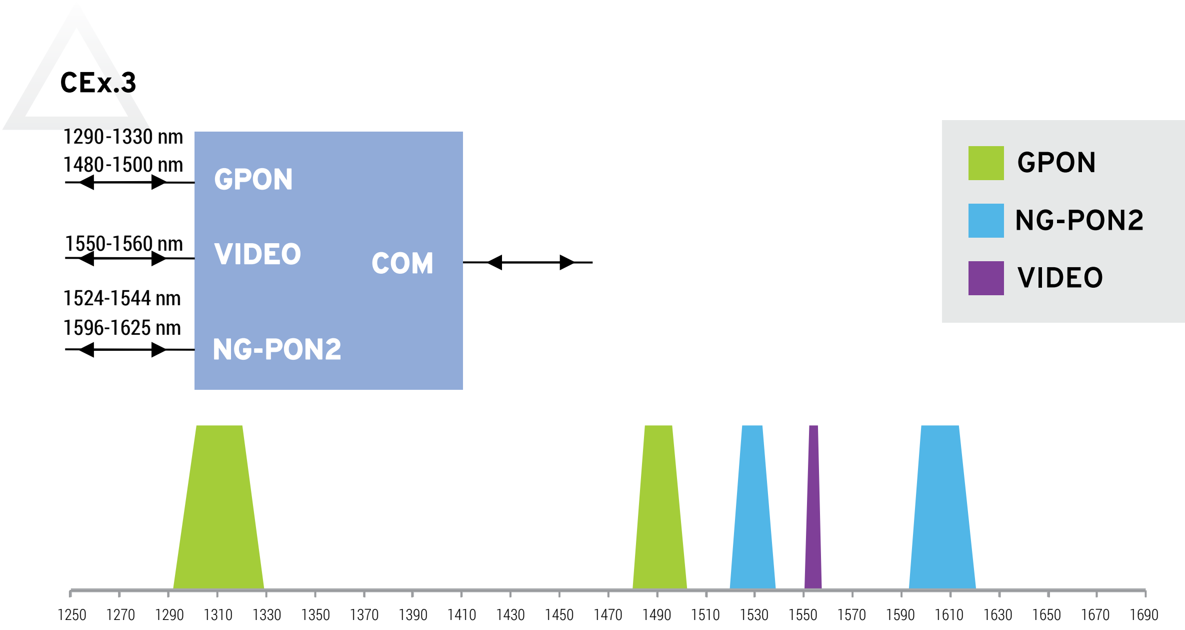
CEx.3
1290-1330 nm
1480-1500 nm
1550-1560 nm
1524-1544 nm
1596-1625 nm
GPON
VIDEO
NG-PON2
COM
GPON
NG-PON2
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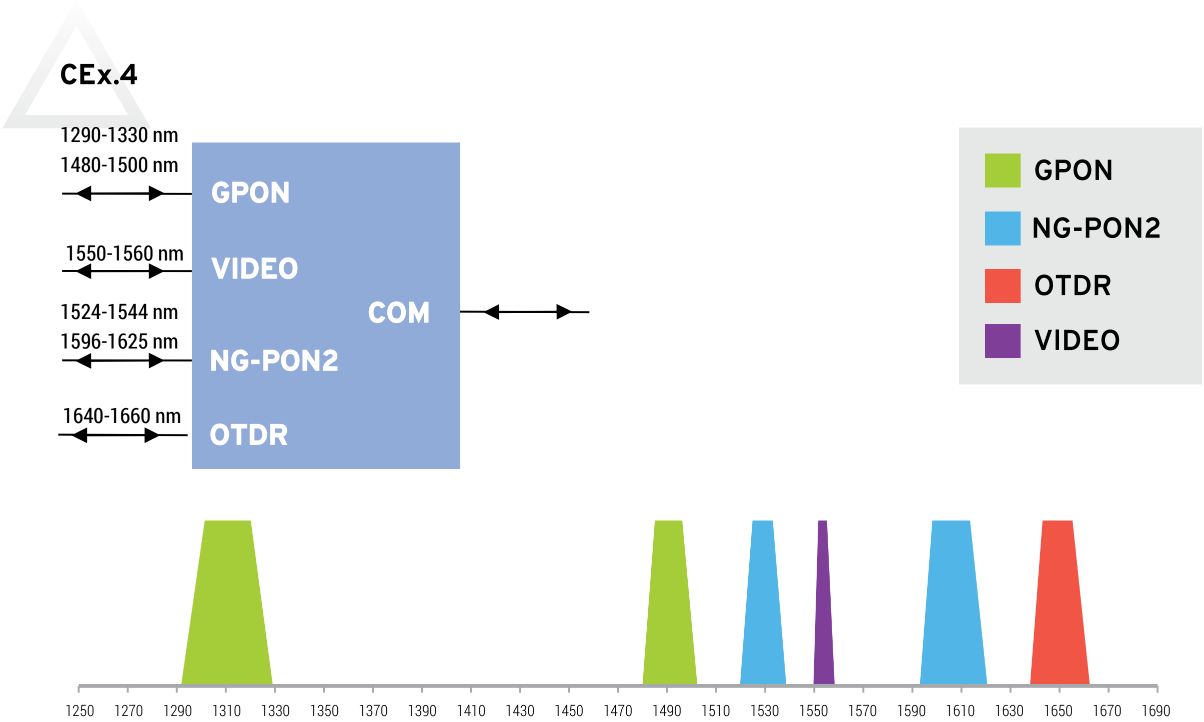
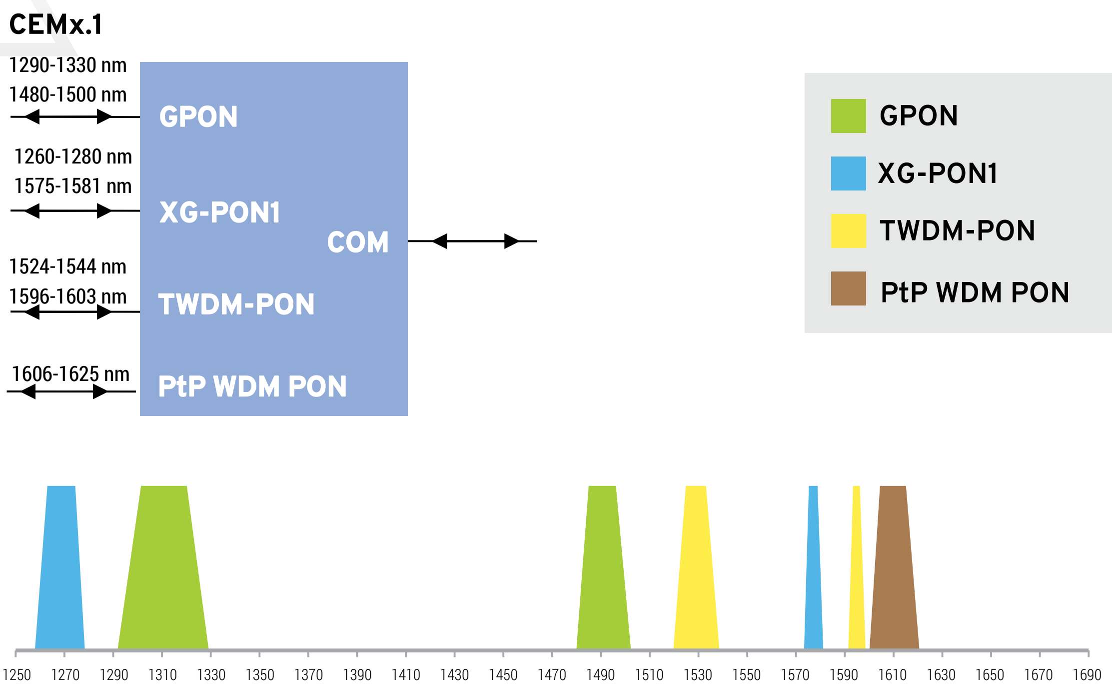

CEx.4
1290-1330 nm
1480-1500 nm
1550-1560 nm
1524-1544 nm
1596-1625 nm
1640-1660 nm
GPON
VIDEO
NG-PON2
OTDR
COM
GPON
NG-PON2
OTDR
VIDEO
1250 1270 1290 1310 1330 1350 1370 1390 1410 1430 1450 1470 1490 1510 1530 1550 1570 1590 1610 1630 1650 1670 1690

Tab. 3. CEx multiplexer parameters (according to ITU-T G.984.5 recommendation):

Multiplexer	Protocol/service	Range	IL_{max}*
CEx.1	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	XG-PON1	1260-1280 nm 1575-1581 nm	<1.1 dB
	NG-PON2	1524-1544 nm 1596-1625 nm	<1.0 dB
CEx.2	GPON	1280-1330 nm 1480-1500 nm	<0.8 dB
	XG-PON1	1260-1280 nm 1575-1581 nm	<1.1 dB
	NG-PON2	1524-1544 nm 1596-1625 nm	<1.2 dB
	OTDR	1640-1660 nm	<1.4 dB
CEx.3	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	VIDEO	1550-1560 nm	<0.8 dB
	NG-PON2	1524-1544 nm 1596-1625 nm	<1.0 dB
CEx.4	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	VIDEO	1550-1560 nm	<1.0 dB
	NG-PON2	1524-1544 nm 1596-1625 nm	<1.1 dB
	OTDR	1640-1660 nm	<1.3 dB

* - Without connectors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1480-1500 nm
GPON
1260-1280 nm
1575-1581 nm
XG-PON1
COM
1524-1544 nm
1596-1603 nm
TWDM-PON
1606-1625 nm
PtP WDM PON
GPON
XG-PON1
TWDM-PON
PtP WDM PON
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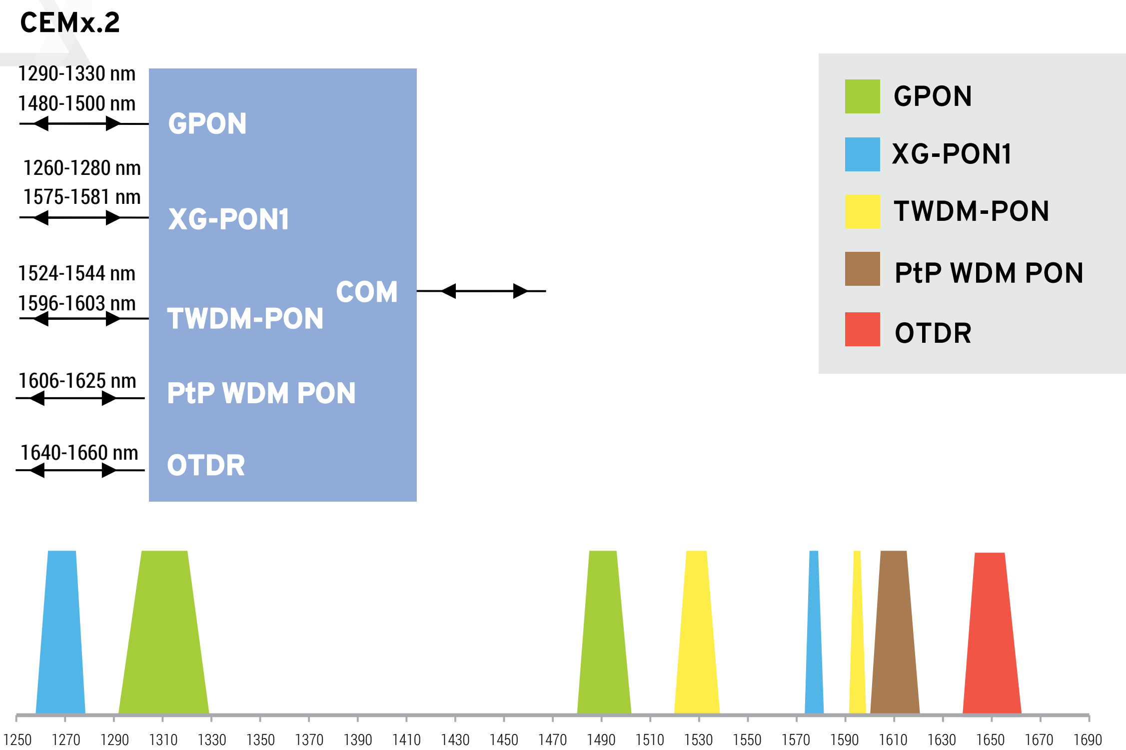
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1480-1500 nm
GPON
1260-1280 nm
1575-1581 nm
XG-PON1
1524-1544 nm
1596-1603 nm
COM
TWDM-PON
1606-1625 nm
PtP WDM PON
1640-1660 nm
OTDR
GPON
XG-PON1
TWDM-PON
PtP WDM PON
OTDR
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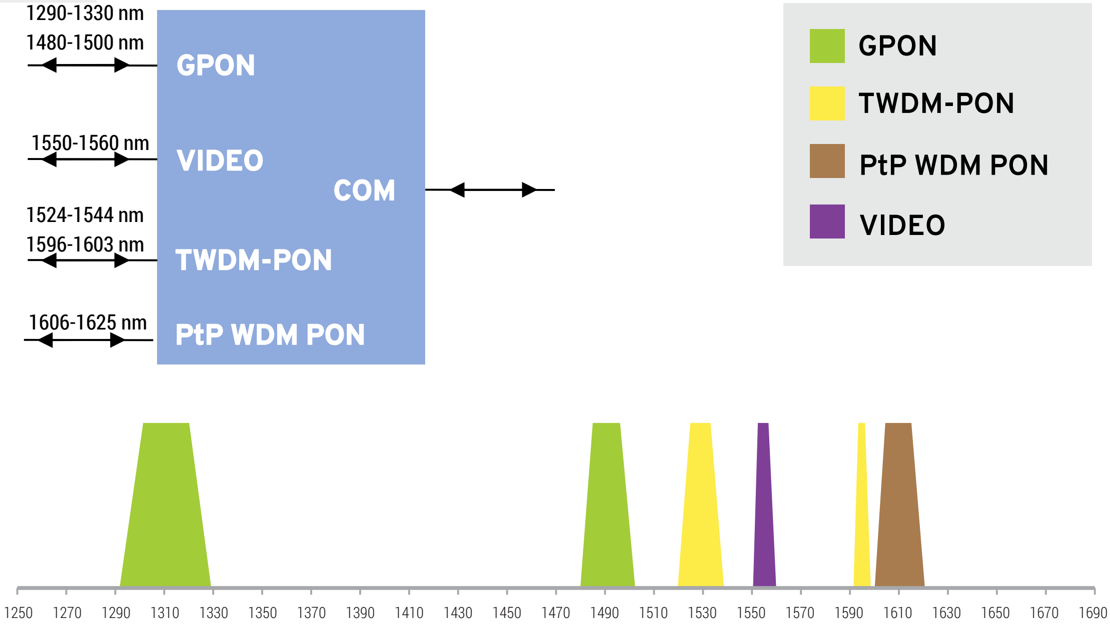
CEMx.3


1290-1330 nm
1480-1500 nm
GPON
1550-1560 nm
VIDEO
COM
1524-1544 nm
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TWDM-PON
1606-1625 nm
PtP WDM PON
GPON
TWDM-PON
PtP WDM PON
VIDEO
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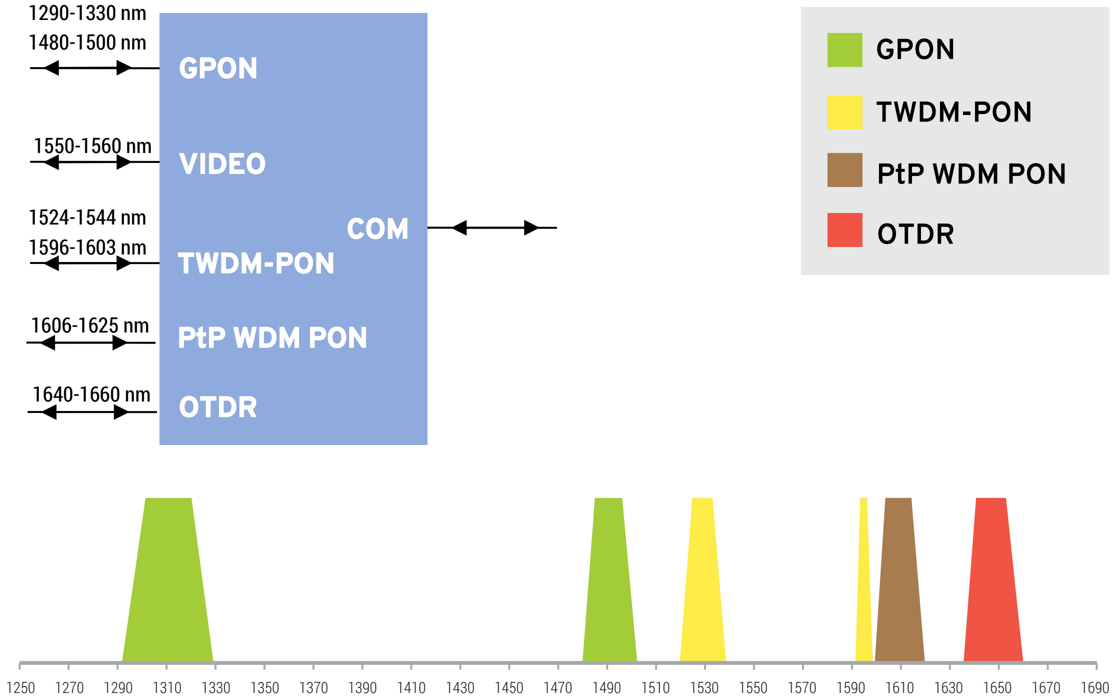
CEMx.4


1290-1330 nm
1480-1500 nm
GPON
1550-1560 nm
VIDEO
1524-1544 nm
1596-1603 nm
COM
TWDM-PON
1606-1625 nm
PtP WDM PON
1640-1660 nm
OTDR
GPON
TWDM-PON
PtP WDM PON
OTDR
1250 1270 1290 1310 1330 1350 1370 1390 1410 1430 1450 1470 1490 1510 1530 1550 1570 1590 1610 1630 1650 1670 1690

Tab. 4. CEMx multiplexer parameters (according to ITU-T G.984.5 recommendation):

Multiplexer	Protocol/service	Range	IL_{max}*
CEMx.1	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	XG-PON1	1260-1280 nm 1575-1581 nm	<1.1 dB
	TWDM-PON	1524-1544 nm 1596-1603 nm	<1.2 dB
	PtP WDM PON	1606-1625 nm	<1.3 dB
CEMx.2	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	XG-PON1	1260-1280 nm 1575-1581 nm	<1.1 dB
	TWDM-PON	1524-1544 nm 1596-1603 nm	<1.4 dB
	PtP WDM PON	1606-1625 nm	<1.3 dB
	OTDR	1640-1660 nm	<1.6 dB
CEMx.3	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	VIDEO	1550-1560 nm	<1.2 dB
	TWDM-PON	1524-1544 nm 1596-1603 nm	<1.1 dB
	PtP WDM PON	1606-1625 nm	<0.9 dB
CEMx.4	GPON	1290-1330 nm 1480-1500 nm	<0.8 dB
	VIDEO	1550-1560 nm	<1.2 dB
	TWDM-PON	1524-1544 nm 1596-1603 nm	<1.3 dB
	PtP WDM PON	1606-1625 nm	<0.9 dB
	OTDR	1640-1660 nm	<1.5 dB

* - Without connectors