

3 Taxonomy of WDM-PON-based Access Network Technologies

There are a number of WDM-PON-based access architectures providing layer 2 (L2) connectivity between the central office (CO) housing the operator equipment (Optical Line Terminal, or OLT), and the demarcation point (Optical Network Unit, or ONU) located in the proximity of the end subscriber. Depending on the actual location of the ONU, there are several classes of fiber access networks, namely:

- FTTN / FTTLA (fiber-to-the-node, -neighborhood, or -last-amplifier): in this architecture, fiber is terminated in a street cabinet, with the drop section between the cabinet and customer premises typically implemented using either coaxial or twisted pair cabling. FTTN is often considered to be an interim step toward full FTTH.
- FTTC (fiber-to-the-curb, -closet, or -cabinet): this architecture is very similar to FTTN, with the only difference being the difference between the termination point (ONU) and customer premises. In FTTC, the ONU is typically located within 1,000 feet (300 m).
- FTTP (fiber-to-the-premises): this architecture covers typically both FTTH and FTTB architectures.
- FTTB (fiber-to-the-building, -business, or -basement): in this architecture, fiber is terminated at a selected location within the building, such as the basement in a multi-dwelling unit, with the drop section between the termination point (ONU) and customer premises typically implemented using either coaxial or twisted pair cabling.
- FTTH (fiber-to-the-home): in this architecture, fiber is terminated directly within the premises of a residential customer.
- FTTD (fiber-to-the-desktop): in this architecture, fiber extends all the way to the main computer room or fiber media converter near the user's desk.

The term CO represents any type of head-end, hub, central office, or other physical location housing the OLT. These optical access architectures can take different forms depending on:

- the number of physical fibers between the OLT and the ONU,
- the number of wavelengths used per direction between the OLT and the ONU,
- the number of wavelengths used simultaneously by a single ONU,
- the existence of a shared or dedicated channel per ONU,
- the type of employed scheduler (centralized or distributed), and
- the type of optical modulation.

The taxonomy of optical access architectures used in this document is presented in Table 1. Individual names of optical access architectures are used when a PHY channel represents a wavelength. Other PHY channels are possible (e.g., OFDM channel, CDM channel) but they are not reflected in Table 1.

Table 1: Taxonomy of optical access architectures

PHY channels per PON per direction {one / many}	PHY channels per ONU per direction {one / many}	PHY channel connectivity type {P2P / P2MP / mix}	Type / name of network
one	one	P2P	P2P link
		P2MP	EPON, 10G-EPON, GPON, XG-PON

many	one	P2P	WDM-PON ₁
		P2MP	SSD-WDM-PON ₁ / MSD-WDM-PON ₁
	many	P2P	WDM-PON _n
		P2MP	SSD-WDM-PON _n / MSD-WDM-PON _n
		mix	?

Figure 1 illustrates different types of PON architectures in which multiple wavelengths are used per PON. Note that each line connecting the OLT and ONU represents a pair of wavelength channels – one wavelength channel in the downstream direction and one wavelength channel in the upstream direction.

In some scenarios, an ONU may use at least one pair of wavelength channels (one downstream, one upstream), forming a WDM-PON. In other scenarios, an ONU shares more than one pair of wavelength channels with other ONUs using a TDM scheme, resulting in a hybrid PON. Depending on the order in which WDM sharing and TDM sharing is applied to these wavelength channels, hybrid PON can be further divided into SSD-WDM-PON and MSD-WDM-PON.

Figure 1: Various options for a WDM-PON

Commented [MH1]: Update the figure per comments from R07

Also, update the document to use terms C-OLT and C-ONU, as defined in SIEPON (copy definitions or reference them to SIEPON).

3.1 WDM-PON

A WDM-PON provides each ONU (and customer(s) connected to such an ONU) with at least one dedicated pair of wavelength channels (one downstream and one upstream), creating logical P2P data connections between the OLT and the ONU. This means that no multiple access techniques are required for the upstream direction as a dedicated upstream wavelength channel is continuously available to each ONU. Furthermore, each wavelength channel is transparent to data rate and MAC frame format, allowing each wavelength channel to run at a different data rate (e.g., 10 Mbps, 100 Mbps, 1000 Mbps, or higher) and/or a different MAC frame format (Ethernet, IP over glass), depending on customer demand and requirements.

3.2 Hybrid PON

A hybrid PON provides a group of ONUs (and customer(s) connected to such an ONU) with at least one pair of wavelength channels (one downstream and one upstream), shared among ONUs in a TDM or WDM fashion. In this way, P2MP connections between the OLT and specific group of ONUs are created. Depending on the way a group of ONUs shares the assigned wavelength channels, hybrid PON is further classified into Multiple Scheduling Domain WDM-PON (MSD-WDM-PON), Single Scheduling Domain (SSD-WDM-PON), and wavelength agile (WA)-PON. For simplicity, the difference between MSD-WDM-PON, SSD-WDM-PON, and WA-PON is explained only for the upstream direction.

Given that upstream transmissions from individual ONUs sharing assigned wavelength channels in a TDM fashion may collide, some sort of scheduling is required in the upstream direction. In the downstream direction, the medium is continuously available for transmission, since the OLT is the only device allowed to transmit data towards ONUs. Over the years, various medium access protocols have been designed, with various generations of EPON and GPON representing the most popular P2MP medium access protocols for optical access.

3.2.1 MSD-WDM-PON

In a MSD-WDM-PON upstream and downstream wavelength channels are assigned (dynamically or statically) to a group of ONUs.

In the upstream direction, the OLT then grants access to the assigned wavelength channel to a specific ONU, allowing the ONU to transmit its queued data. The duration of such access to the upstream wavelength channel granted to the given ONU depends on the operation of a Dynamic Bandwidth Allocation (DBA) mechanism. No other ONU is allowed to transmit during the same window of time. On a MSD-WDM-PON each ONU transmits on one and only one upstream wavelength at a time, as illustrated in Figure 2.

The OLT is the only device with access to the downstream wavelength channel and transmits data without needing arbitration.

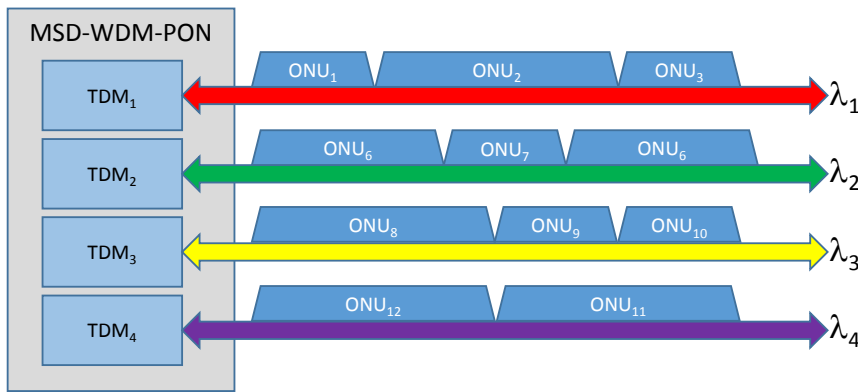


Figure 2: Upstream channel in MSD-WDM-PON

3.2.2 SSD-WDM-PON

In an SSD-WDM-PON all upstream and downstream wavelength channels are accessible to all ONUs connected to the given OLT.

In the upstream direction, the OLT grants access to all available wavelength channels to a specific ONU, allowing it to transmit its queued data. The duration of such access to all upstream wavelength channels granted to the given ONU depends on the operation of a DBA protocol. No other ONU is allowed to transmit during the same window of time. On an SSD-WDM-PON each ONU transmits on all upstream wavelength channels at a time as illustrated in Figure 3.

The OLT is the only device with the access to the downstream wavelength channel and transmits data without further arbitration on all available downstream wavelength channels.

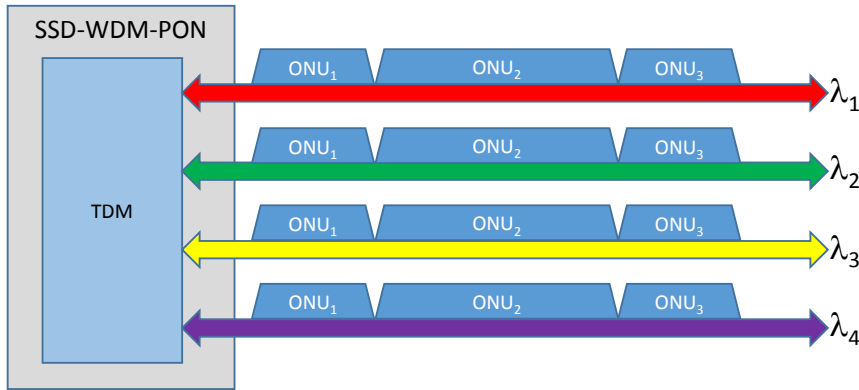


Figure 3: Upstream channel in SSD-WDM-PON

3.2.3 WA-PON

In a WA-PON more than one upstream and downstream wavelength channel is assigned (dynamically or statically) to a group of ONUs connected to the given OLT. The allocation of downstream and upstream wavelength channels to the given ONU may change over time dynamically, under the control of the OLT. The OLT may change the number of downstream and/or upstream wavelength channels assigned to the given ONU. Their placement in the available wavelength grid depends on the configuration selected by the operator, capacity planning, and other factors.

In the upstream direction, the OLT grants access to the assigned wavelength channels to a specific ONU, allowing it to transmit its queued data. The duration of such access to the assigned upstream wavelength channels granted to the given ONU depends on the operation of a DBA mechanism. No other ONU is allowed to transmit on the same wavelength channels during the same window of time. Effectively, in WA-PON, each ONU transmits on its allocated upstream wavelengths simultaneously with other ONUs as shown in Figure 4.

The OLT is the only device with access to the assigned downstream wavelength channels and transmits data to a group of ONUs without needing arbitration.

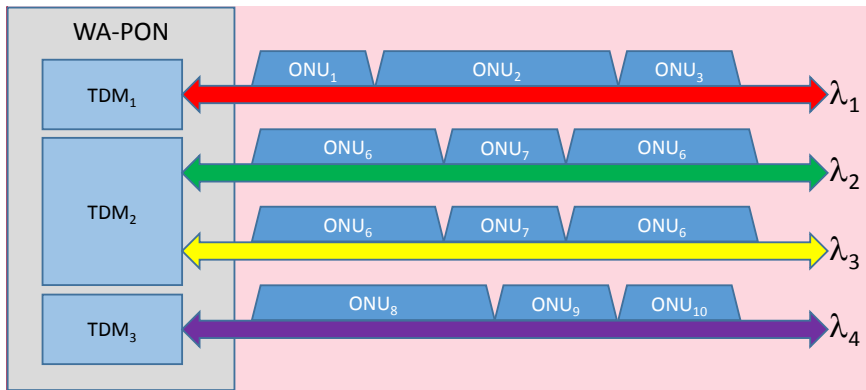


Figure 4: Upstream channel in WA-PON

In order to meet the full flexibility of a wavelength agile PON, a WA-PON ONU needs to support full tuneability of its receivers and transmitters, allowing such an ONU to receive and transmit on different wavelengths selected by the OLT.

3.3 Different ODN Topologies

Generally, an access network is designed to provide *point-to-multipoint (P2MP) connectivity*: a device in the central office can communicate with multiple subscribers, but the subscribers are prevented from communicating directly with each other. In PON, all transmissions are performed between the OLT and ONUs located at or near the customer premises.

There are several PON-based ODN topologies that offer point-to-multipoint connectivity suitable for the access network. These include *passive tree*, also known as *trunk-and-branch* (see Figure 5.a), *passive bus* (Figure 5.b), or *passive ring* (Figure 5.c). In all the cases, the topology is passive. Instead of active (powered) devices, all junction points are built using 1×2 or 2×2 optical tap couplers, or 1×N optical splitters.

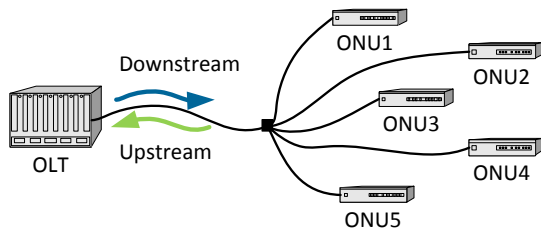
In a tree topology, a single trunk fiber is connected to a 1×N splitter that fans out the signal to a number of (typically, 16 or 32) branches. Various branches may in turn be connected to another splitter that fans out to yet more branches. Two very common ODN configurations use a 1×32 splitter or a 1×4 splitter followed by four 1×8 splitters. In this topology, the upstream and downstream optical signals propagate in opposite directions in the same fiber.

A bus topology is similar to the tree topology in that the upstream and downstream optical signals propagate in the opposite directions in the same fiber. However, instead of using a 1×N splitter, the bus topology employs 1×2 tap couplers that divert a small portion of the signal away from the main bus toward an ONU. The couplers may have a fixed or progressive tapping ratio. The couplers with fixed ratio divert a constant fraction of power away from the main bus. The ONUs that are attached to the PON bus nearer to the OLT gets higher power than the ONUs that are attached at the far end of the bus. To alleviate this problem, the tap couplers with progressive ratio may be used. In this case, the taps nearer the OLT diverts a smaller fraction of power than the taps farther away, resulting in approximately equal portion of power reaching every ONU.

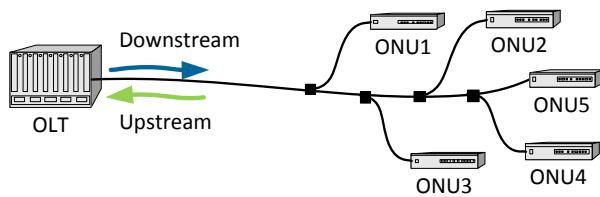
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A ring topology utilizes 2×2 couplers to connect ONUs to a fiber ring. The fiber ring can be constructed with co-propagating or contra-propagating downstream and upstream signals. It is also possible to construct a ring with two downstream and two upstream channels, with one downstream/upstream pair propagating clockwise and another propagating counter-clockwise.

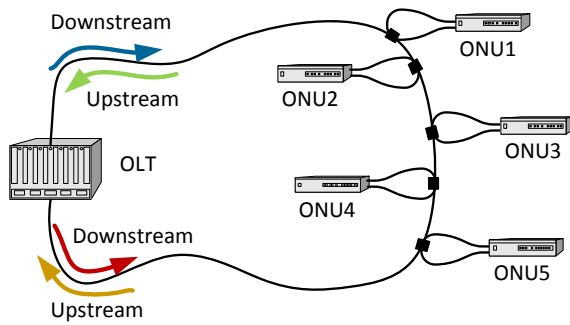
An added advantage of the ring topology compared to the bus or the tree is that the OLT receives its own transmission signal can detect the ring fiber failure almost instantaneously, instead of relying on ONU protocol timeout.



(a) Tree topology (using 1xN splitter)



(b) Bus topology (using 1x2 tap couplers)



(c) Ring topology (using 2x2 tap couplers)

Figure 5: Passive ODN topologies