Passive Optical Networks: Fundamental Deployment Considerations

Abstract

This paper provides a brief introduction to the subject of Passive Optical Networks (PONs) and discusses a number of issues that should be considered by a service provider or enterprise that is contemplating the deployment of PONs for distribution/access purposes. In addition to basic equipment costs, these include such issues as electrical power, heating/cooling and space demands (quantities and locations), traffic capacities and patterns, required cabling, equipment expected lifetimes and reliability, operations, and security. In general, careful analysis is needed to determine whether PONs or some other technology (e.g., Ethernet switches) should be deployed in any particular application.

POC

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NOTE

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PON Basics

In its basic configuration, a PON consists of an Optical Line Terminal (OLT) connected to multiple Optical Network Units (ONUs) via an Optical Distribution Network (ODN).[1] Traditionally, ODNs have been made up entirely of passive optical components (in particular, single-mode optical fibers and optical splitters) and the resulting PONs have utilized bidirectional transmission on each fiber (e.g., between the OLT and a splitter and between the splitter and each ONU).[2] In addition, the OLT-to-ONU traffic is typically carried in one or two continuous signals (e.g., one supporting data and voice services, one supporting video services) that are broadcast to all of the ONUs, while the ONU-to-OLT traffic is carried in Time Division Multiple Access (TDMA) burst signals. Both bidirectional transmission on the same fiber and the transmission of a second OLT-to-ONU signal (if applicable) are facilitated by the use of a different optical wavelength for each signal and the inclusion of basic Wavelength Division Multiplex (WDM) components in the OLT and ONUs. Finally, the available bandwidth in both the downstream and upstream directions is shared between all of the PON's ONUs and thus their associated users.

In almost all cases, the OLT is responsible for dynamically allocating the shared bandwidth based on policies, traffic-load information provided by the ONUs, and the traffic received from external equipment for delivery to particular ONUs/users. All of this (except for the OLT's connections to external equipment) is illustrated in **Figure 1** for the case of an Ethernet PON (EPON) with four users, three of whom subscribe to a video overlay service and one of whom does not transmit any upstream traffic in the time period illustrated. Note that in this figure, different colors are used to represent traffic to/from different ONUs, not different optical wavelengths. In most existing PONs the nominal wavelengths of the downstream data traffic, downstream video overlay and upstream signals are 1490, 1550 and 1310 nm, respectively.

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[1] The terms ONU and Optical Network Terminal (ONT) are often used interchangeably. However, some standards documents (e.g., ITU-T Recommendation G.987) define an ONT as an ONU that supports a single subscriber. Thus, ONU is a more general term and is therefore used throughout this paper. Also, the term OLT is used here to refer to the network-side equipment connected to a splitter in a single ODN, but in other contexts may instead refer to a larger set of equipment that terminates multiple ODNs. In this paper, this latter set of equipment is referred to as an OLT Network Element (NE). Thus, an OLT NE typically contains multiple OLTs.

[2] While the component that allows a single OLT to be connected to multiple ONUs is generally referred to as a "splitter," it is typically a bidirectional device that in the upstream direction couples the signals received on the fibers from multiple ONUs into the single fiber connected to the OLT. In addition, it may consist of a single integrated device (e.g., a 1×32 splitter) or several cascaded devices (e.g., a 1×8 splitter and eight 1×4 splitters). Finally, while it is possible for such devices to be designed to have asymmetrical loss and/or optical power split characteristics (e.g., a 1×16 splitter with 14 dB of loss from the OLT fiber to any particular ONU fiber but only 4 dB of loss from any particular ONU fiber to the OLT fiber, or a 1×2 splitter that directs 75% of the power received on the OLT fiber to one ONU fiber and (most of) the remaining 25% to the other ONU fiber), in practice the splitters used in PONs generally have symmetric loss and optical power split characteristics.

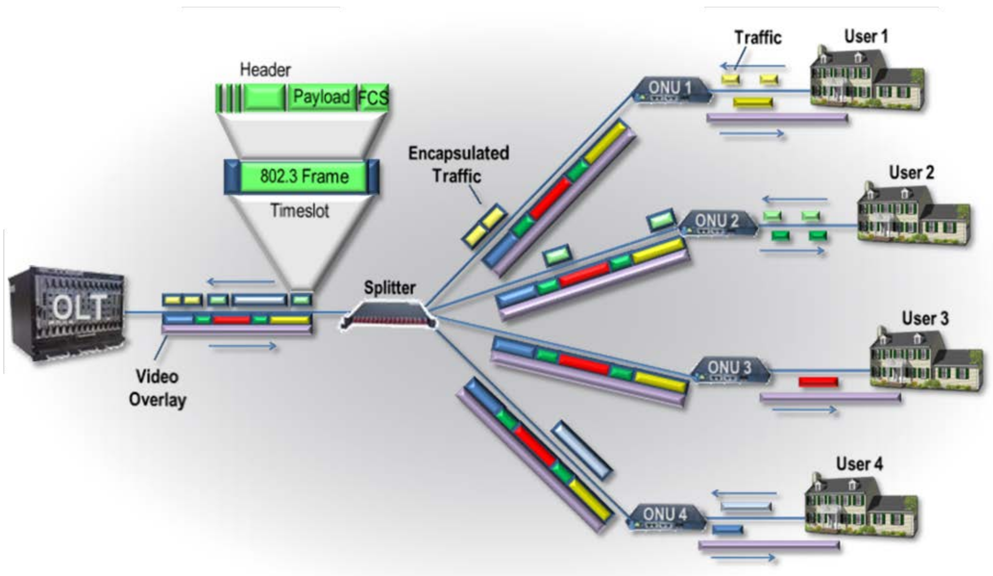

Figure 1. PON Example – EPON

As indicated in Table 1, PONs come in several varieties, utilizing different bit rates, data framing or encapsulation methods (e.g., Ethernet, ATM, GPON Encapsulation Method [GEM]), maximum split ratios, maximum fiber distances, etc. In addition, several varieties have been (or are being) standardized by ITU-T, while others have been (or are being) standardized by IEEE. Also, some PON systems may support advanced features such as dual homing and active range extension. Such features require additional facilities and/or equipment (e.g., fibers, splitters, transceivers, protection switching equipment, optical amplifiers) and may introduce active components into the ODN.

Table 1. PON Type Summary

PON Type	Typical Bit Rates		Framing	Typical Max. Split Ratio	Typical Max. Fiber Length	Primary Standards Documents
	Down	Up				
Broadband PON (BPON)	622 Mb/s	155 Mb/s	ATM	1×32	20 km	ITU-T G.983 series
Gigabit PON (GPON)	2.488 Gb/s	1.244 Gb/s	ATM and GEM	1×64	20 km	ITU-T G.984 series
10 Gigabit PON (XGPON)	10 Gb/s	2.488 Gb/s or 10 Gb/s	XGEM	1×64	20 or 40 km	ITU-T G.987 series
Ethernet PON (EPON)	1 Gb/s	1 Gb/s	Ethernet	1×16	20 km	IEEE 802.3 (clause 60)
10 Gigabit EPON (10G-EPON)	10 Gb/s	1 Gb/s or 10 Gb/s	Ethernet	1×32	20 km	IEEE 802.3av
Next Generation-PON2 (NG-PON2)	Not specified. As of mid-2012, several technologies were under consideration for standardization, with the Full Service Access Network group (FSAN) recommending Time and Wavelength Division Multiplexed (TWDM) PONs. In addition, several TWDM and WDM PON systems were available as proprietary systems. (A WDM PON utilizes multiple pairs of wavelengths, each dedicated to a single ONU, and advanced WDM components to support significantly higher overall bit rates. A TWDM PON then adds the TDMA technique used in traditional PONs to support multiple ONUs per pair of wavelengths.)					

While the available numbers varied, it was clear that as of mid-2012 most of the PON systems that had been or were being deployed in the U.S. were GPON systems, while EPON systems were more popular internationally. Also varying were the predictions for when 10G-EPON, XGPON and/or higher-capacity proprietary PON systems would replace EPON and GPON systems as the primary PON technologies being deployed, but in general this was not expected to occur before 2014.

Deployment Scenarios

Most PON systems have been deployed by telecommunications service providers, who in turn have primarily marketed the resulting services to residential customers and small/medium businesses, or in some cases have used them in mobile backhaul applications. In addition, most PON systems have been deployed as outside plant networks (i.e., with the OLTs and splitters connected via kilometers of overhead or buried optical fibers, and supporting ONUs at multiple locations). On the other hand, there has been considerable variation in where PON ONUs have been deployed relative to the end users. Three of the ONU location options are illustrated in **Figure 2**, which shows an ONU deployed at a single-family residence (Fiber To The Premises or Home, FTTP or FTTH), at an apartment building or small business (Fiber To The Building, FTTB), and in a curb-side pedestal serving several single-family residences (Fiber To The Curb, FTTC). Also, in the FTTP/FTTH and FTTB cases the ONUs may be located either inside or outside the homes or buildings, and in the FTTC case the ONU is likely to be connected to each residence via a Digital Subscriber Line (DSL) service, and thus would need to also perform the functions of a DSL Access Multiplexer (DSLAM).

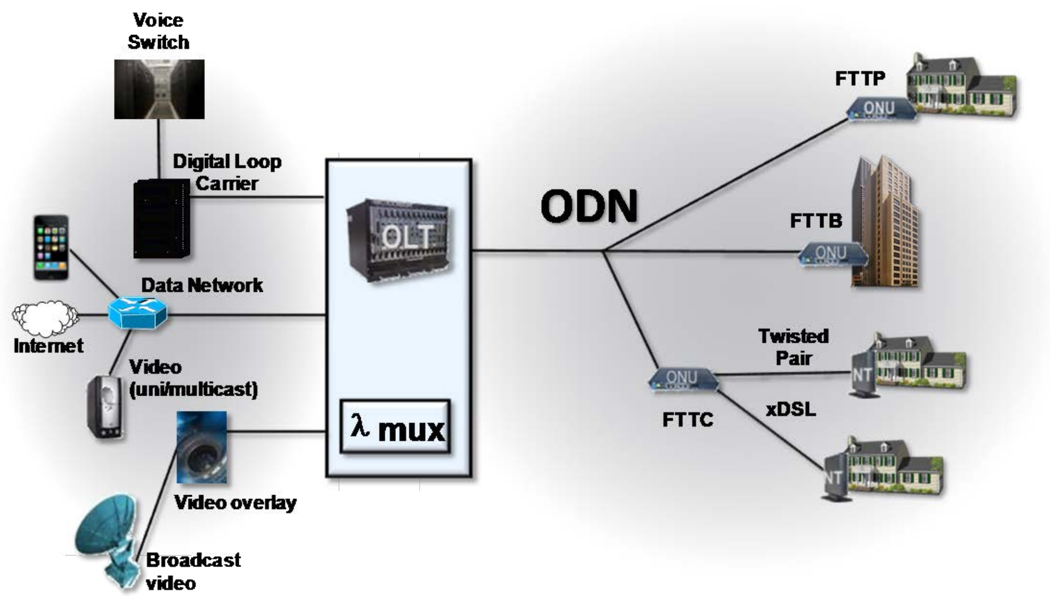

Figure 2. PON Services and Architecture Example

In addition to the types of PONs described and illustrated above, there has been growing interest in the use of PONs inside buildings. In such applications the splitter, the ONUs and possibly the OLT are located in the same (typically large) building, with fiber extending to ONUs serving individual desks, offices/apartments or groups of offices/apartments.

Deployment Considerations

For either outside plant or in-building applications, one of the primary alternatives to deploying PONs is to deploy an Ethernet switch-based network in which several layers of Ethernet switches (e.g., distribution switches, access switches) are used to connect multiple end users and a network edge router. In comparisons against such switch-based networks, PON equipment suppliers often claim dramatic power savings (e.g., 80%) for their customers, as well as significantly lower equipment, infrastructure and operating costs, and reduced space requirements. Note however, that in evaluating such claims (or performing an independent analysis) it is important to consider all of the relevant issues and differences.

In some applications, PONs have several clear advantages over Ethernet switch-based networks. These include the following:

- In a PON there is no need for electrical power, a controlled environment, or even significant space at an intermediate location. This can be a major advantage in an application where the use of an Ethernet access switch would require running electrical power to a location that would not otherwise need it, the construction of a Controlled Environmental Vault (CEV) or other structure, and/or the installation of heating/cooling equipment (e.g., in a telecommunications equipment closet).

- A PON has the ability to support a broadcast video service that is independent from its voice and data services using only a single additional transmitter, basic WDM equipment at the OLT and ONUs, and an additional receiver at each ONU (or rather at each ONU supporting one or more users who subscribe to the service).

- In a switch-based network the cost of powering the access switches is typically borne by the service provider. Conversely, in an FTTP/FTTH or FTTB network the cost of powering the ONUs is generally borne by the users. This shift can result in major savings for the service provider.

As indicated above, the preceding are clear advantages (of PONs relative to switch-based networks) in some applications. On the other hand, they may be irrelevant in other applications. For example, if a company is considering using PONs to provide access between its data center and employee offices, it is likely to bear the costs associated with powering either the access switches or the ONUs. In addition, in such a case there may be no need for any new structures, or for broadcast video services.

In addition to the issues discussed above, general capital equipment costs and per-user capacity considerations, other issues that should be taken into account in evaluating PONs and switch-based networks include:

- Overall power usage – While the use of PONs can eliminate electrical power demands at intermediate locations in the network, it may increase in the demands at the network endpoints. Thus, a careful and complete analysis is needed in order to determine how “green” the various options are for any particular application.

- Data traffic patterns – In a PON, data traffic between two ONUs has to be sent across the PON twice, from the source ONU to the OLT and then from the OLT to the destination ONU. On the other hand, in a switch-based network such traffic can often be switched at an access switch (i.e., much closer to the users). Whether or not this is important in a particular application depends on the overall load on the network and whether a significant portion of that load is ONU-to-ONU/intra-switch traffic.

- Cabling – Currently, many buildings in which PONs could conceivably be deployed are already equipped with multimode fibers and/or Cat. 5 or 6 Ethernet cables. In those cases, a change to PONs, which are specified to utilize single-mode fiber, could result in significant (re)cabling costs. On the other hand, the installation of single-mode fiber is likely to facilitate both immediate and future upgrades to higher bit rates, particularly if the fiber is extended to very close to the user. In addition, while the applicable standards for both PONs and Ethernet switches define interfaces that support bidirectional transmissions over the same fiber, Ethernet switches are much more likely (than PONs) to be equipped with interfaces that use separate fibers for each direction of transmission. As a result, the use of PONs may significantly reduce the number of fibers needed in the network.

- Traffic protection – Although the relevant standards define several architectures in which redundant equipment and fibers can be used to provide protection against failures in various portions of a PON (e.g., between redundant OLTs and a splitter, see **Figure 3**), implementation of those architectures may require the use of proprietary communications between OLT NEs.

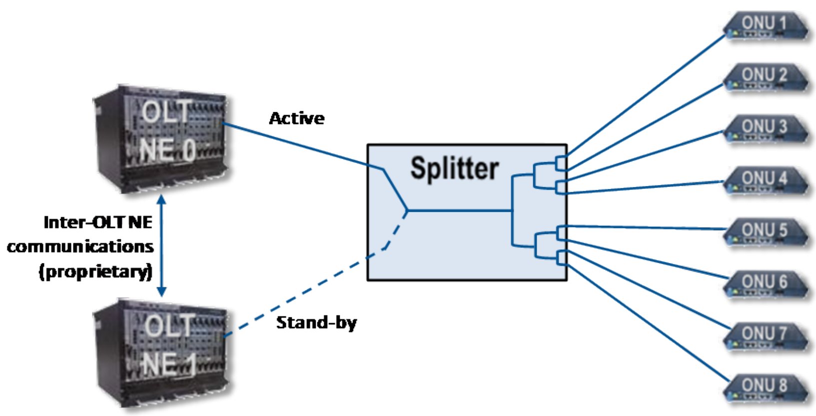

Figure 3. PON Type B Redundancy Example Utilizing Distinct OLT NEs

- Equipment expected lifetime and reliability – In many cases, Ethernet switches are designed as enterprise-class equipment while PON OLTs and ONUs are designed as carrier-class equipment with generally higher expected lifetime and reliability (e.g., Mean Time Between Failures [MTBF]) numbers. On the other hand, some equipment suppliers offer products that can be equipped and deployed as NEs in either PONs or Ethernet switch-based networks, and in such cases the expected lifetime and reliability numbers may be practically independent of the type of network in which they are deployed. In addition, given the pace of change in communications technologies, it is possible that even the highest capacity products that are currently available may become obsolete well before the end of their expected lifetimes. In that case, a difference in the expected lifetimes of two candidate products (or types of products) may have minimal impact.

- Data networking functionality – In an Ethernet switch-based network it is possible that the switches support data networking functions beyond those needed to simply transport traffic between users and a network edge router (or other local users). In comparing a PON to a switch-based network it is important to determine if the OLT and ONUs support equivalent data networking capabilities, or if the deployment of a PON would make it necessary for other equipment (e.g., user equipment, the network edge router) to perform those functions (and what impact, if any, that would have on the other equipment).

- Operations – In general, PONs are specified and designed such that an OLT and its associated ONUs can be managed as a single entity (through the OLT), and also to support significant test and diagnostic capabilities. As a result of these and other factors (e.g., generally higher reliability numbers), PON equipment suppliers often claim significant operational cost savings for service providers that deploy PONs instead of switch-based networks. The applicability of such claims needs to be evaluated in light of the specifics of any particular potential deployment.

- Security of data transmissions – In most PONs (i.e., all except WDM PONs), downstream traffic is broadcast by the OLT and received by all of its associated ONUs. It is then the responsibility of each ONU to ignore the traffic intended for the other ONUs. To ensure that an eavesdropper with an ONU on the PON cannot monitor the traffic intended for other ONUs, additional security is needed. In the types of PONs specified by IEEE (i.e., EPON and 10G-EPON) it is assumed that the necessary security will be provided via various higher layer protocols supported by external (e.g., end user) equipment. This approach is consistent with that used in other Ethernet-based networks. In contrast, the ITU-T BPON, GPON and XGPON standards all include mechanisms for providing security at the PON protocol layer, independent of any higher layer security that may or may not be provided.

- Vulnerability to attacks – In general, a PON is relatively vulnerable to a physical layer denial-of-service attack by a malicious user who modifies an ONU or replaces it with equipment to transmit an interfering signal during time intervals assigned to other ONUs for their upstream bursts. A service provider with a switch-based network that is subjected to an equivalent attack could simply (and presumably remotely) disable the access switch port via which the interfering equipment is connected to the network, while in the PON case it would be necessary to physically disconnect the interfering equipment or the fiber via which it is connected. On the other hand, the lack of powered equipment at intermediate (and possibly remote) locations may make PONs less susceptible than switch-based networks to eavesdropping attacks.

Conclusions

Evaluating the possible technologies and architectures available for use in any particular distribution and access network application can be a complex and challenging task. While capital equipment costs are likely to be a major consideration, a number of other factors need to be considered (e.g., electrical power, heating/cooling and space demands, traffic capacities and patterns, required cabling, equipment expected lifetimes and reliability, operations, security). Although their capabilities and characteristics make PONs the clear choice in certain distribution and access applications, other applications can call for the use of other technologies.