WHITE PAPER

Upgrade Strategies for GPON2

The WDM-PON Solution

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Executive Summary

Passive optical networking (PON) provides the bandwidth that consumers and enterprises demand. That's why dozens of service providers worldwide – such as AT&T, British Telecom (BT) and Verizon Communications – are deploying or have launched PON technologies, including Gigabit (GPON), which supports peak downstream rates of 2.5 Gbps, roughly only 40 Mbps per subscriber.

The catch is that GPON won't meet the long-term bandwidth requirements of enterprises and consumers. That's one of reasons for growing service provider interest in Wave Division Multiplexing PON (WDM-PON), which is more efficient from both a bandwidth and financial perspective. WDM-PON provides a nearly future-proof solution because its initial per-subscriber capacity of 1 Gbps is more than enough to support the most bandwidth-intensive applications and services, such as high-definition video.

This white paper provides an overview of WDM-PON, including its features, deployment options and how it compares to technologies such as GPON and GPON/CWDM PON. It also discusses ADC's PONy Express™ platform, which uses Wave Division Multiplexing (WDM) to provide cost-effective access to business parks, campuses, and multi-dwelling unit/multi-tenant units over a shared network infrastructure, without sacrificing security or limiting bandwidth.

The PON (R)evolution

A passive optical network (PON) is a point-to-multipoint, fiber-to-the-premises (FTTP) network technology, where a single fiber serves 16 or more premises. The basic architecture features an Optical Line Termination (OLT) unit that resides in the service provider's central office or headend office and connects to multiple Optical Network Units (ONUs), each of which is located at or near the customer's premises.

The PON family of technologies currently includes:

- **Broadband (BPON)** – Based on the ITU-T G.983 standard, BPON offers asymmetrical service with 622 Mbps downstream transmission and 155 Mbps upstream transmission and support for up to 32 ONUs.
- **Gigabit (GPON)** – Based on the ITU-T G.984 standard, GPON offers asymmetrical service with 2.5 Gbps downstream transmission and 1.25 Gbps upstream and support for up to 64 ONUs.
- **Ethernet (EPON)** – Based on the IEEE 802.3ah standard, EPON supports downstream speeds of up to 1.2 Gbps and up to 16 ONUs.
- **Wave Division Multiplexing (WDM-PON)** – WDM-PON is capable of using ITU standard wavelengths, greatly simplifying the standardization process. Current systems support fully symmetrical speeds of up to 20 Gbps and up to 16 ONUs. Bandwidth is dedicated in up to 1.25 Gbps increments to each ONU. The technology has virtually unlimited scalability in terms of bandwidth and wavelengths. Future versions may have as many as 64 10 Gbps wavelengths.

The entire PON sector has been growing rapidly over the past few years. Between 2006 and 2007, worldwide equipment sales grew 56% to $1.74 billion, according to a March 2008 report by Infonetics, an independent analyst firm. The report also forecasts the WDM-PON segment growing at a 41% compound annual growth rate (CAGR) between 2007 and 2011.

WDM-PON is a response to growing consumer and enterprise adoption of bandwidth-intensive applications and services, such as high-definition TV (HDTV) and HD videoconferencing. Although WDM-PON's predecessors provide ample bandwidth, some service providers already are growing concerned about their ability to keep pace with customer requirements. That's why some service providers, such as Korea Telecom, have already begun deploying WDM-PON equipment.

WDM-PON gives service providers a graceful, long-term way to accommodate growing bandwidth requirements by maximizing the capacity of each fiber strand. Unlike Time Division Multiplexing (TDM)-based PON technologies, which use TDM techniques to divide the bandwidth among multiple users, WDM-PON uses multiple wavelengths along each strand, with each wavelength serving a single user. That architecture increases both the upstream and downstream bandwidth available to each user.

WDM-PON has inherent features that can provide a major competitive advantage for service providers that target the enterprise market. For example, TDM-PON technologies such as BPON and GPON send the same signal to all subscribers' ONUs, creating a security risk that must be mitigated by using encryption. WDM-PON avoids that security risk altogether by allowing the service provider to put each customer on a separate wavelength. That ability can be a plus in the eyes of security-minded enterprise CIOs and IT managers.

Another major advantage for the enterprise market is that WDM-PON is the only PON technology capable of providing the scalability and dedicated, symmetrical bandwidth that many business applications demand. As a result, service providers can use WDM-PON's capabilities as a powerful market-differentiator.

WDM-PON benefits service providers in other ways, too. For example, it's the only PON technology that lets service providers remotely pinpoint the location of a break on the distribution fibers. That translates into reduced overhead costs and faster troubleshooting and repair because unlike other PON technologies, WDM-PON doesn't require an expensive, time-consuming truck roll to track down the break.

Another example is WDM-PON's fundamental role as a Layer 1 transport technology. As a result, provisioning is plug-and-play, which reduces operational costs and accelerates time to market. It also maximizes the capability of existing resources, such as fiber, and assets such as switches and routers, without duplicating their functionality.

Upgrade Strategies for GPON

Recently, a great deal of industry discussion has focused on what the next technology is beyond GPON. Some of the options mentioned are a hybrid GPON/CWDM PON, 10G GPON or an active Ethernet solution over a GPON infrastructure. But each of these technologies has its drawbacks, to the point that none of them makes a lot of sense from a competitive or financial perspective. Ultimately, the only real upgrade path for GPON is WDM PON.

Hybrid GPON/CWDM PON Issues

The hybrid GPON/CWDM PON solution is based on fear, uncertainty and doubt (FUD)-style marketing from the GPON vendors, who have realized that their technology cannot handle the bandwidth demands of tomorrow's consumer and enterprise applications. GPON/CWDM PON is difficult to implement because of two key issues:

- GPON/CWDM PON requires the use of CWDM on the feeder fiber (Figure 1). At a minimum, implementing this solution means that all the subscribers who share the same feeder fiber will be taken out of service to provide this upgrade. There could be additional disruptions if other changes are required between the splitter and the OLT. If there are changes to the hardware in the ONU and the line cards in the OLT, this becomes even more of an issue.
- GPON/CWDM PON doesn't provide a long-term fix for the bandwidth problem. It provides only temporary relief. Instead of all 32 subscribers sharing the same feeder fiber, now there are eight subscribers sharing one of four channels. Furthermore, this will require a new splitter module in the outside plant, splitter cabinet. Because even the vendors backing GPON/CWDM PON believe that WDM-PON will eventually become a reality, service providers should be aware that if they implement this solution, they will have to install another splitter module for WDM-PON in the future. This requirement means that there could be as many as three different types of splitter modules in the cabinet. If there is not sufficient space for the modules, another cabinet is required.

10G GPON Issues

Availability is the key drawback for 10G GPON. It's a relatively nascent technology, with a lot of work left to be done before it can even be considered as an option. Some of 10G GPON's unresolved issues may be insurmountable. One example is the physics of doing a 1x32 split on a 10G feeder fiber. Even if that hurdle can be overcome, the next one is the 10G PON's relatively high cost, which is due to 10Gbps optical transceivers having to support a 20km range over 32 splits.

Other key drawbacks include the fact that the 10G GPON upgrade affects service and that 10G GPON will face the same interoperability issues as the existing BPON and GPON systems. Also, at 10Gbps on the feeder fiber, it is still only half the available aggregate bandwidth of WDM-PON today. By the time it is commercially available, WDM-PON will likely be up to 80Gbps (32x2.5Gbps) on the feeder fiber. With the rate of consumer bandwidth growth, TDM-based PONs will have to be upgraded an average of every five years.

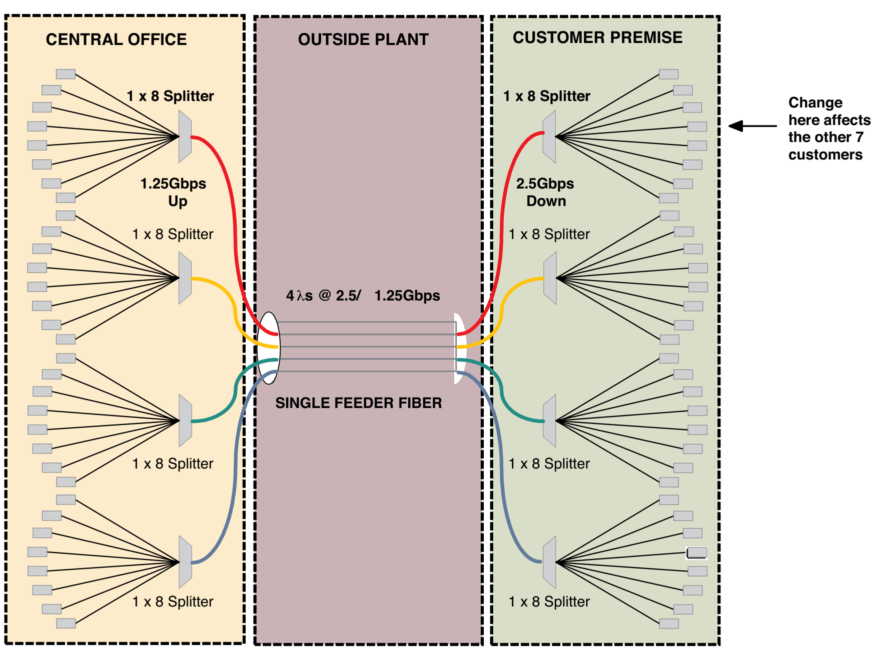

Fig. 1: Hybrid GPON/CWDM PON

Active Ethernet Issues

Active Ethernet (Figure 2) requires intelligence in order to penetrate deeper into the network to handle potential bandwidth contention issues on the feeder fiber. As a result, a switch is required where the passive splitter resides in a passive optical network – an additional infrastructure cost.

There are multiple reasons why most service providers cringe at the idea of putting active electronics in the outside plant:

- It requires environmentally hardened equipment, which increases the cost.
- It requires power to be provided to the outside plant cabinet.
- Splitter cabinets are not designed to house active Ethernet products; therefore, an active Ethernet solution will likely require another outside plant cabinet to be deployed at or near the existing splitter cabinet.
- Bi-directional WDM connections are required to operate over a single fiber. Otherwise, two feeder fibers and 48 distribution fibers are required for a 1x24 switch.

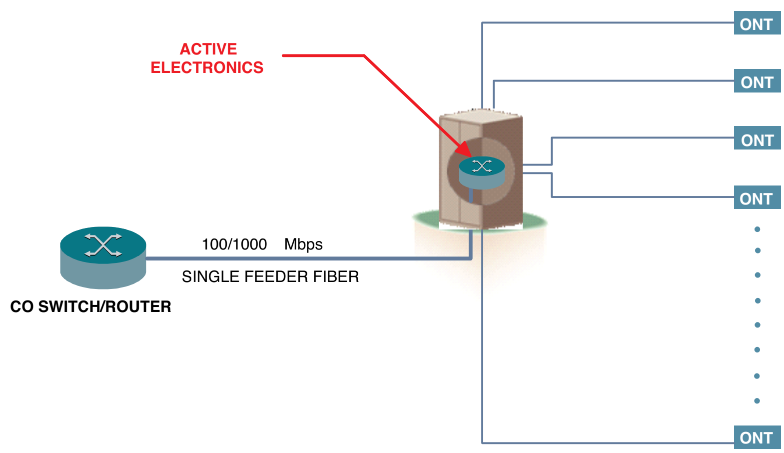

Fig. 2: Active Ethernet

WDM-PON

WDM-PON (Figure 3) is the only viable solution for upgrading GPON. It combines the best elements of private, point-to-point networks—security and dedicated bandwidth—with the best elements of traditional PON-low infrastructure costs due to shared fiber resources and passive components in the outside plant. In addition, WDM-PON uses "colorless" optics, which eliminates the inventory management issue associated with other DWDM/CWDM solutions and reduces provisioning to plug-n-play. WDM-PON also is available today, with Korea Telecom among the service providers that have already deployed it.

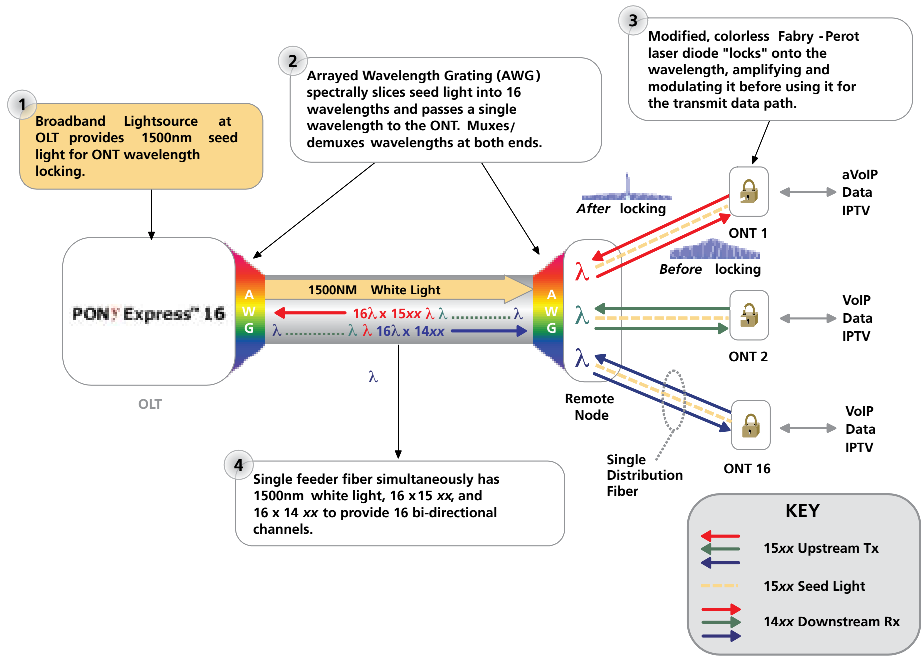

Fig. 3: WDM-PON Network: Downstream Wavelength Locking & Colorless Optics

WDM-POM's detractors argue that the technology is too expensive, not standardized, too large for high density applications or an inefficient use of bandwidth. Although there is some merit to these points with existing systems today, the future potential of the technology easily overcomes these concerns.

Current WDM-PON systems are more expensive than GPON, but they also provide 16 times more bandwidth today. Detractors should keep in mind that the cost of a GPON ONU is more than a WDM-PON ONU. The primary cost in a WDM-PON is light source that is required to provide the seed light necessary for wavelength locking, a key component of the "colorless" optics scheme. Significant cost reductions are occurring and will continue as the technology becomes more widespread. With some of the future plans for reducing the size of the WDM-PON systems, it is anticipated that equipment costs could be as low as $500 per subscriber (including all equipment costs from end-to-end) in volume deployments.

Standardization is a critical issue in GPON and 10G GPON, and even with it, there still isn't universal interoperability between vendors. However, WDM-PON is a transport platform that delivers exactly what is put into it. Therefore, there are no interoperability issues at either end of the WDM-PON network. This flexibility, coupled with the point-to-point nature of the technology, allows it to support multiple services and multiple bit-rates in the native format.

Today, although these systems are Ethernet-only because the prevailing thought is that IP over Ethernet will be ubiquitous, adding TDM interfaces is relatively simple and non-service affecting for existing customers. In addition, if the wavelength plan should ever change due to further standardization, WDM-PON systems that employ "colorless" optics technology would only be minimally impacted as the change would only affect the Arrayed Wavelength Grating (AWG), a device that determines the wavelength plan, rather than the ONUs or OLT line cards. That's because the AWG is also responsible for multiplexing/demultiplexing the wavelengths into and out of the feeder fiber.

Figure 4 illustrates some of the benefits of WDM-PON technology.

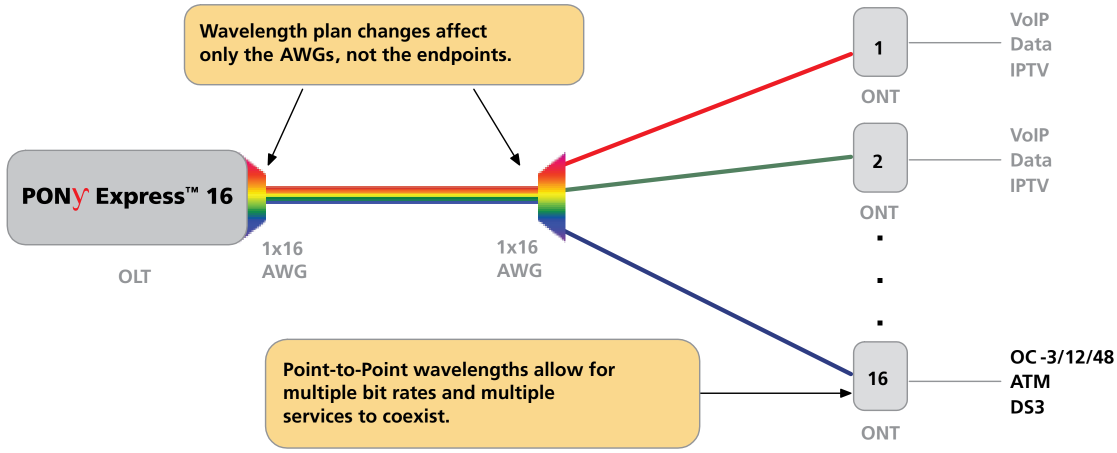

Fig. 4: WDM-PON Network: Future Proof

As for the density issue, WDM-PON technology can be drastically reduced in size. Although some vendors argue that a high-density blade is the best solution, this architecture severely limits the flexibility of the system. Service providers that are considering WDM-PON recognize this limitation and are more interested in keeping the flexibility and reducing the form factor through the use of small form pluggable optics (SFPs).

The WDM-PON ONT and the line card in the OLT can both be reduced to an SFP. With this approach, an SFP would be placedinto the customer premise equipment and the central office/headend core switch/router. Once done, the OLT would be reduced to a wavelength splitter and a light source in a 1RU rack-mounted chassis. Because AWGs can potentially go to 128 wavelengths today, it is possible to have 128 dedicated connections per 1-2RUs of rack space. With most high-density GPON OLTs being about 8RUs for roughly 1,000 subscribers, the density is comparable (WDM-PON density would be 128 x 8 = 1024). Additionally, the split ratios on a WDM-PON are not limited as with GPON, due to the point-to-point nature of the network. Using the aforementioned example, 1,024 subscribers would require only eight feeder fibers, while GPON will likely require 32 feeder fibers (assuming a 1:32 split ratio). Figure 5 illustrates these advantages.

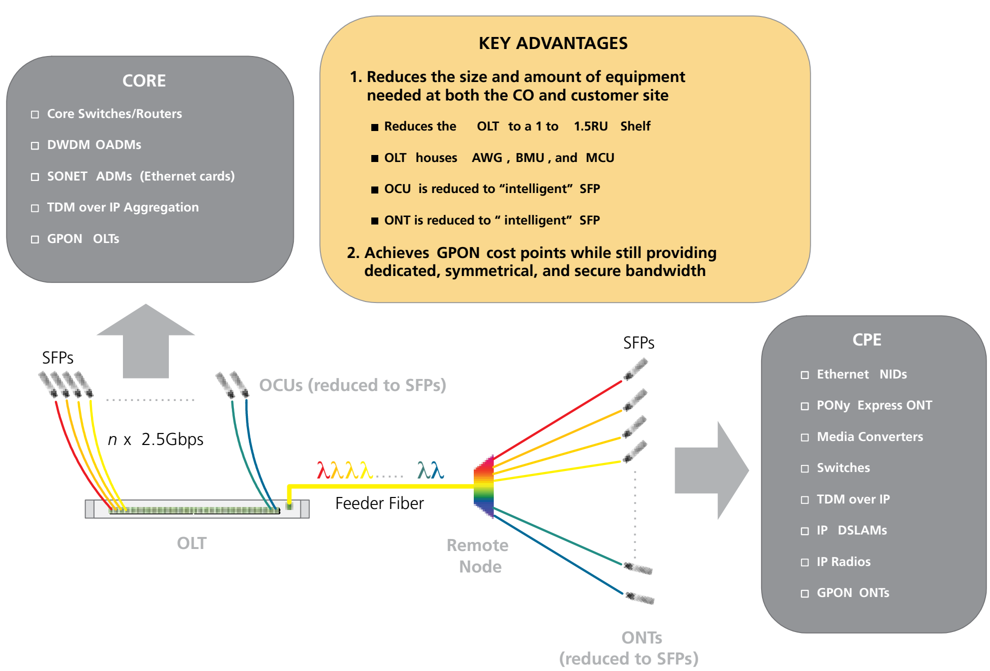

Fig. 5: WDM-PON Using SFPs to Increase Density-to-Size Ratio

Finally, some vendors claim that WDM-PON is an inefficient use of bandwidth because it is assumed that end users won't use all the available bandwidth. This argument has little merit because WDM-PON requires the same or less physical resources than GPON. (Specifically, the same or less fiber count on the feeder fiber and distribution fibers, and the same size splitter module in the outside plant cabinet.) Therefore, whether they use it or not doesn't matter. Because each connection is dedicated, the service provider can simply rate limit their service at the central office/headend office, and when they do, they don't have to worry about how it will affect service to their other customers. As a result, service providers should be able to simplify their back-office processes and turn up service much more rapidly for each customer.

Migrating from GPON to WDM-PON

One of the key advantages of WDM-PON is that it provides the simplest upgrade path for GPON, with the least amount of service impact. WDM-PON uses an AWG to multiplex and demultiplex wavelengths between the feeder fiber and the distribution fibers instead of a traditional Planar Lightwave Circuit (PLC) splitter. In a WDM-PON system that uses "colorless" optics, the AWG is also responsible for spectrally slicing a seed light, generally provided from the OLT, into the individual wavelengths that are passed to the ONTs. The AWG can be packaged in the same form factor as existing PLC splitters. This enables service providers to insert a module inside an existing GPON splitter cabinet to support WDM-PON. Figure 6 illustrates this design.

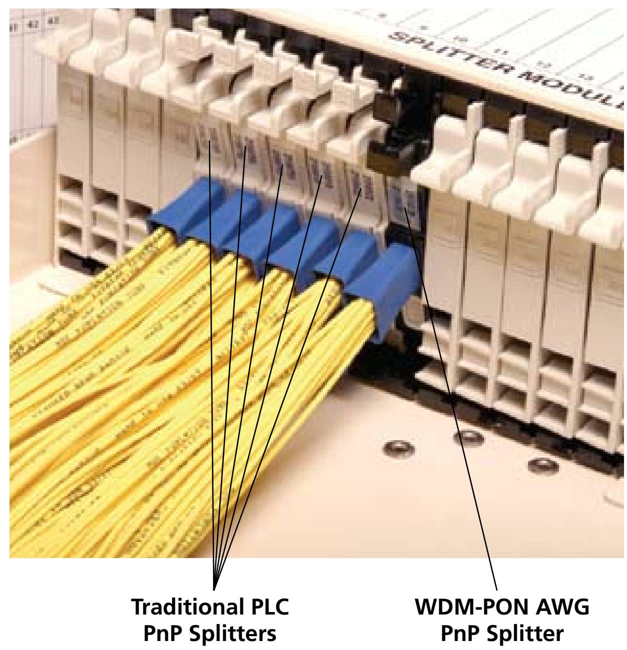

Fig. 6: Splitter Cabinet with PLC and AWG

Because most service providers have deployed excess and spare fibers running to the splitter cabinet, a new feeder fiber is used to connect to the AWG. Once done, the service provider can upgrade a customer simply by swinging over the distribution fiber from the PLC splitter to an available port on the AWG and changing the ONT to a WDM-PON ONT. This last step is necessary in order to provide the wavelength locking for a system that uses "colorless" optics; however, in time, the existing ONT may be reused with the addition of a simple, WDM-PON SFP. With this technique, customers can be upgraded on an as-needed basis without affecting other subscribers on the same PON – a major advantage over technologies with disruptive upgrades, such as GPON/CWDM PON.

Although some vendors argue the same thing can be done with a hybrid CWDM PON or active Ethernet, both lack the key attributes that make WDM-PON so attractive. In the case of the hybrid GPON/CWDM PON, service providers must perform wavelength management, stock different colored optics and likely change out their existing ONTs, all of which complicates the implementation of the technology and increases implementation costs. Furthermore, there is still some wavelength sharing, which makes the technology unsuitable for secure applications or future high-bandwidth services – limiting the service provider's ability to target government agencies and some enterprises.

In the case of active Ethernet, putting active electronics in the field has presented maintenance issues and is generally much more costly. Also, it is unlikely that this solution could be implemented in the same cabinet as the existing GPON service.

One last key topic to consider is the evolution of networks to all IP. Most service providers agree that an all-IP network is ultimately where the market is headed. GPON is based on TDM technology, which is fine for today, but in the future, the industry's preferred approach will be a single IP over Ethernet residential gateway to the house. This may be in the form of a set-top box or customer premise switch. When this industry shift occurs, the underlying technology of GPON will be obsolete. This is also a concern with 10G GPON. With this in mind, the only viable option for upgrading GPONs is WDM-PON.

ADC's WDM-PON Solution: PONy Express

ADC's PONy Express solution is the industry's first transport platform to use a PON architecture to break the access bottleneck. Using Wave Division Multiplexing (WDM), the PONy Express 16 provides cost-effective access to business parks, campuses, and multi-dwelling unit/multi-tenant units over a shared network infrastructure, without sacrificing security or limiting bandwidth. PONy Express simultaneously provides up to 16 customers with 1Gbps dedicated, symmetrical bandwidth.

Each PONy Express ONU is "colorless," a design that eliminates the sparing/inventory issue that plagues traditional DWDM systems and provides "plug-and-play" system provisioning. The PONy Express 16 is integrated into other ADC products, such as the OmniReach® FTTX Fiber Distribution Hubs, providing a compelling solution unique to the industry.

The PONy Express' key features include:

- Support for point-to-point and point-to-multipoint architectures
- Up to 1 Gbps of dedicated, symmetrical bandwidth per subscriber
- A single fiber for up and downstream traffic
- Colorless optics on the ONUs and the OLT line cards

The PONy Express' key benefits include:

- Allowing service providers to leverage their existing infrastructure, thereby reducing capex
- Recovering fiber infrastructure, including freeing up 31 fibers' worth of capacity
- Enabling multiple services and bit rates to exist simultaneously without complex traffic management
- Allowing service and bit rate upgrades without infrastructure changes
- Reduced inventory costs by using colorless ONUs and OLT line cards
- Plug-and-play simplicity, which reduces time to market and eliminates wavelength management issues
- Use of existing ADC fiber distribution products to support the passive WDM-PnP splitter module
- Coexists with GPON to enable residential and business services to be served from the same cabinet
- Simplifies the migration path from GPON to higher bandwidth support for services such as IP HDTV

The main benefits of WDM-PON technology are:

- Delivery of different bit rates and protocols over the same PON
- An end-to-end solution with colorless DWDM ONUs, which translates into low inventory costs
- Delivery of mixed services enabled by independent wavelength links
- Guaranteed network security through dedicated wavelengths
- Point-to-point wavelengths are easily upgradeable without service interruption to other users

Conclusion

When service providers consider the evolution of their GPON networks, they must consider the following factors:

- How easy is it to implement each technology?
- How future-proof is each technology?
- How cost-effective is each technology?

WDM-PON is the only technology that addresses all three of these issues in ways that improve the service provider's competitive and financial positions. For example, by co-existing with GPON, service providers can leverage existing assets to upgrade customers one at a time without affecting the service of other subscribers on the network. As networks evolve to all IP, service providers can service subscribers who are early adopters of IP-based, residential gateways while still leveraging the service provider's existing network infrastructure. On a per Mbps basis, WDM-PON is the most cost-effective technology available today. On a per subscriber basis, WDM-PON can even compete with the costs of GPON today, while offering 16 to 32x more bandwidth on the feeder fiber. In conclusion, WDM-PON represents the easiest, most future-proof, and cost effective strategy for upgrading GPON networks.

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