

IP vs. ATM: Choosing the Optimal Transport Protocol for GPON Deployments

Executive Summary

Telecom service providers have continually evolved their network architecture to add new services such as high-speed data and Voice over Internet Protocol (VoIP). Now they are looking to add video and entertainment services including Standard-Definition Television (SDTV), High-Definition TV (HDTV), IPTV and interactive gaming. These efforts have come in response to increased competition from cable and other competitors that have introduced triple-play bundles of video, voice and high-speed data services and have siphoned off Plain Old Telephone Service (POTS) customers. Service providers are also looking to capitalize on growing demand for video services.

Until recently, however, a major challenge to implementing many of these new broadband applications was insufficient bandwidth in the “last-mile” infrastructure from the central office to the customer premises. Today, last-mile architectures have matured. With deep-fiber networks offering the ultimate bandwidth access, Gigabit Passive Optical Network (GPON) applications have emerged as one of the most advanced and cost-effective ways to deliver high-bandwidth Fiber to the Premises (FTTP) solutions. Yet not all GPON implementations are created equal. This white paper explores how GPON implementations that carry Ethernet packets in their native IP format, rather than using the legacy Asynchronous Transfer Mode (ATM) format, offer higher efficiency and scalability, and thus ultimately provide greater revenue over the life of the network.

Telecom Service Providers Look to Add Bundled Services

Over the past decade, traditional telecom service providers have faced increased competition as cable and other competitors have rolled out triple-play bundles of video, high-speed Internet and voice services. Service providers have thus been adding their own bundled services for residential and business customers. They have also been looking to capitalize on growing demand for video and entertainment services to increase revenues, Average Revenue Per User (ARPU) and profitability. Indeed, as Figure 1 shows, video today comprises the single largest portion of household entertainment spending, with a year-over-year increase in spending per household for the past five years. The market for HDTV in particular is expected to explode over the next few years, growing from 21 percent of all TV sales in 2004 to 70 percent by 2010. Moreover, according to data compiled in 2007 by the Consumer Electronics Association, 30 percent of those customers are expected to purchase more than one HDTV. These customers will increasingly expect HDTV content for each of those sets. Service providers adding video capabilities are aiming to exceed the end-user experience available with cable services and are looking to implement IPTV, which enables interactive and personalized services. Other options for expansion include music and video games as well as new business services and services to multi-dwelling units.

By offering a wide selection of services on a single invoice, service providers can increase revenues and decrease churn. Due to the

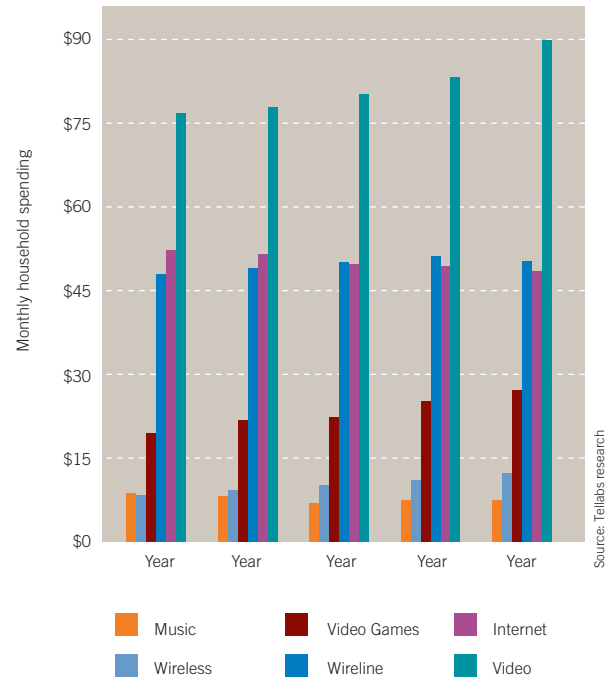


Figure 1. The market for entertainment services of all kinds has grown year-over-year for the past five years, with video representing the single largest portion of household entertainment spending.

broader range of available service offerings — specifically video — and more reliable service delivery, Tellabs has worked with service providers that have reduced churn rates to as low as 1.5 percent by offering bundled service packages.

The Need for More Bandwidth

Until recently, however, service providers were unable to offer many high-speed broadband services, particularly video, due in large part to bandwidth limitations in the last-mile infrastructure. These bandwidth demands, moreover, will only continue to grow. Figure 2 shows the bandwidth demands required for various video and entertainment services. For example, each HDTV stream requires from 9–14 Mbps with MPEG-4 compression and 19 Mbps with MPEG-2 compression, with the actual bandwidth requirements varying with the type of broadcast. For example, a basketball game in HDTV using MPEG-4 might require 14 Mbps while “talking heads” might require 9 Mbps. As cable companies move to improve the speed of their high-speed Internet service offerings from the current 10 Mbps per subscriber to as high as 30 Mbps with the upcoming network upgrade to Data Over Cable Service Interface Specification (DOCSIS) 3.0 later in 2008, telecom service providers will also need to provide comparable or higher bandwidth options



to remain competitive. To keep up with the growth in demand for increasingly higher bandwidth, service providers will need to offer at least 50 Mbps and as much as 100 Mbps to each subscriber over the next three to five years for a bundled data and IP video offering.

Service Demands per Home	Low BW (MPEG-4)	High BW (MPEG-2)
High Speed Data & VoIP	5–30 Mbps	5–30 Mbps
Gaming Stream	1–4 Mbps	1–4 Mbps
VoD Stream	2 Mbps	15 Mbps
PVR Stream (HDTV)	9–14 Mbps	19 Mbps
Real-time SDTV Stream	2 Mbps	4 Mbps
Real-time HDTV Stream	9–14 Mbps	19 Mbps

Figure 2. HDTV and high-speed Internet are driving the need for more bandwidth to each home.

Fiber is the ultimate carrier of bandwidth and the next major push for service providers who wish to offer broadband service bundles is fiber in the last mile. The business case for last mile fiber deployment is further strengthened by recent FCC rulings that clarify the rules of competition and level the playing field for broadband services provided by telecom service providers and cable MSOs. In particular, Incumbent Local Exchange Carriers (ILEC) are now exempt from unbundling, or making their networks available to competitors, if they build FTTP networks in greenfield locations. Furthermore, ILECs are now only obligated to make a 64 Kbps equivalent circuit for voice access available to competitors in overbuild applications.

GPON Meets Service Providers' Requirements

Today, Gigabit Passive Optical Network (GPON) — an all-fiber access architecture that links the Central Office (CO) or headend to the customer premises through a passive Optical Distribution

Network (ODN) — is coming to be seen as the technology of choice for FTTP. Infonetics predicts that the market for GPON gear will grow from \$740 million in 2006 to \$1.4 billion in 2009. With the right implementation, GPON is capable of delivering:

- High bandwidth
- Enhanced scalability and low costs
- Flexible deployment options
- A clear migration path through support for both legacy and future services

High Bandwidth

With downstream speeds of 2.5 Gbps and upstream speeds of 1.2 Gbps, GPON provides the necessary bandwidth to provide bundled services to customers.

Relatively Low Costs

While fiber offers comparable initial capital expenditure for Greenfield deployments compared to copper deployments, operational expenses are much lower. GPON technology allows the service provider to share the cost of running fiber from the CO to the premises among many users — usually up to 32 locations — resulting in lower costs than if the carrier were to deploy individual fibers to each location. The fiber is run from the CO to a centralized distribution point, from which fiber extends to each customer location. Passive optic splitters extend the fiber at the distribution point, guiding the laser light on the fiber to the appropriate locations. Because PONs do not require any power to the outside plant to power the splitters, the resulting overall operational cost and complexity is much lower. Finally, fiber is not subject to environmental impacts, such as oxidation, that affect copper and lead to high recurring maintenance expenses. Overall, while copper costs in the neighborhood of \$100 per line annually, operational costs for fiber are significantly lower, as shown in Figure 3.

Architecture Comparison on OpEx: PON, HFC, xDSL

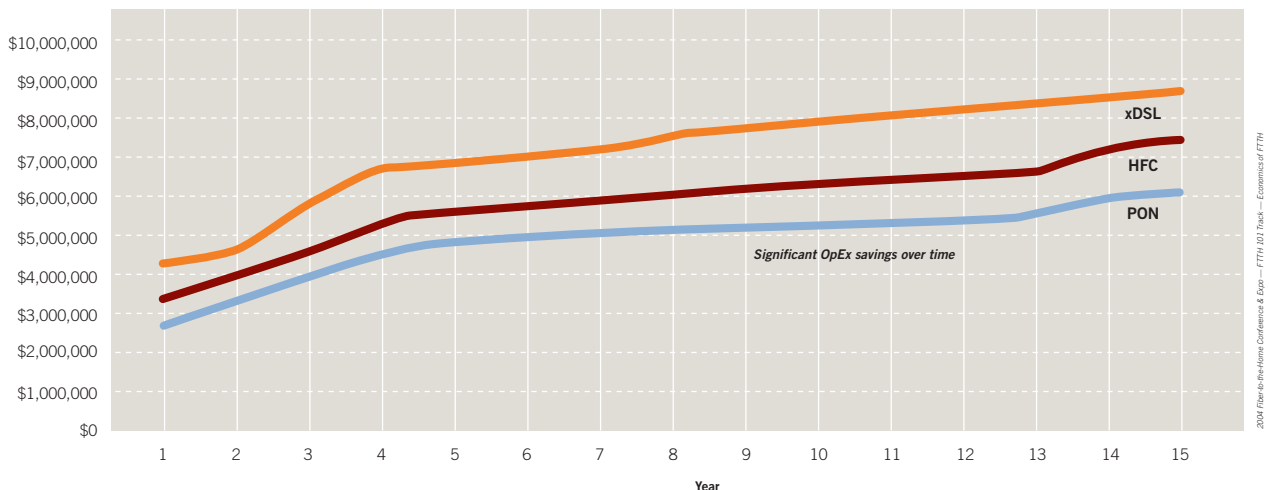


Figure 3. Operational costs for fiber are significantly lower than those for copper

Flexible Deployment Options

In some cases, it may not make sense to run fiber directly to the premises, but rather to use the existing copper infrastructure for the last mile with VDSL2 or ADSL2+ and then migrate over time to an all fiber network. The right Multiservice Access Platform (MSAP) can provide a clear and seamless path to FTTP while leveraging the existing copper infrastructure using VDSL2 and/or ADSL2+ technologies.

A Clear Migration Path

The correct GPON implementation can also offer a clear migration path for adding services without disrupting existing equipment or altering the transport layer in any way because it supports emerging and legacy services, including video, high-speed data, business services and services to multi-dwelling units.

Video: Standard Video, VoD and IPTV

GPON supports both Radio Frequency (RF) video overlay and IPTV, allowing service providers to maximize existing investments in headend equipment without impeding their migration to IPTV.

With RF video overlay, the broadcast video is carried as a separate wavelength outside the normal downstream data path to enable the complete group of broadcast video channels to be transported over composite RF signals at up to 870 MHz. Service providers can transport signals, including video, from a video headend over a GPON infrastructure by using Erbium-Doped Fiber Amplifiers (EDFA) with a Wavelength Division Multiplexer (WDM) to combine the video and other optical transport signals onto a single fiber.

Service providers can deliver two-way interactive digital services (e.g., Video on Demand (VoD)) over GPON using a two-way digital cable headend. The set-top box on the downstream end receives analog or digital video streams and can communicate upstream with the headend for interactive services. Optical Network Terminals (ONT) are available that allow service providers to add a fourth wavelength upstream using the latest standards for RF over Glass (RFoG).

Service providers can deliver IP video via GPON by using an IP video headend that injects IP into the network downstream to subscriber-premises ONTs. The IP video is carried in band with broadband services over the GPON infrastructure to homes that have an IP interface. Signal transport is initiated automatically when a viewer selects a channel, triggering a request for service back to the system CO.

High-Speed Data Services

High-speed data access via 100Base-T and 1000Base-T Ethernet connections at the ONT are critical for both residential and business users alike. Service providers can take advantage of this demand and market a much wider range of data services (including higher bandwidth data services) with GPON. This includes the ability to offer high-speed symmetrical services, something competitive high-speed infrastructures often struggle to provide.

Business Services

GPON implementations are available that are capable of supporting both existing and legacy business services. These include Digital Loop Carrier (DLC) services/circuits such as DDS, ISDN, coin/payphone, 2-wire and 4-wire special services, 2-wire and 4-wire transmit only services, and many others. Implementations are available that allow service providers to:

- Provide these services over a DLC architecture while supporting GPON in the same chassis
- Provide these services over GPON
- Support both sets of services with a plan for GPON migration when the portion of the network supporting DLC services warrants a full GPON upgrade

Multi-Dwelling Units

To deliver high-speed broadband services to Multi-Dwelling Units (MDU) such as apartments and high-rise buildings, service providers can run GPON into the telephone room and then run individual links via wiring in risers within the building (often copper and/or CAT-5 Ethernet). Typical services interfaces for MDU and MTU applications include ADSL2+, VDSL2 and native Ethernet carried over the existing wiring.

Choosing the Optimal GPON Implementation

GPON provides a smooth upgrade path from legacy to next-generation services, in part through its support for legacy traffic in its native format (e.g., ATM and TDM) and native IP traffic. However, because GPON equipment vendors have the option of transporting traffic in ATM or in native IP, service providers need to consider the transport protocol that the GPON equipment vendor chooses since this has significant implications for efficiency, performance and scalability.

GPON Encapsulation Mode (GEM) is the method that maps the service layers (TDM, ATM, IP) onto the PON physical layer. This flexibility to carry several protocol formats allows both legacy ATM access platforms and next-generation IP/Ethernet access platforms to support the latest GPON technology. But, the choice of underlying technology (IP vs. ATM) has a significant impact on efficiency, scalability and ultimately, service delivery. If the access platform utilizes ATM as the core transport and switching technology, the ability to deliver bandwidth and generate revenue will be greatly diminished. The following discussion explains why service providers are best served through GPON implementations that use native IP, rather than ATM.

An In-Depth Look at Why IP is More Efficient than ATM

ATM was the first transport protocol able to reliably carry multi-QoS broadband services over older service technologies, including T1, G.SHDSL and ADSL. Designed specifically to offer granular QoS over relatively low-speed, low-bandwidth links, ATM was challenged by the adoption of high-speed Ethernet technology beginning in the mid 1990s.

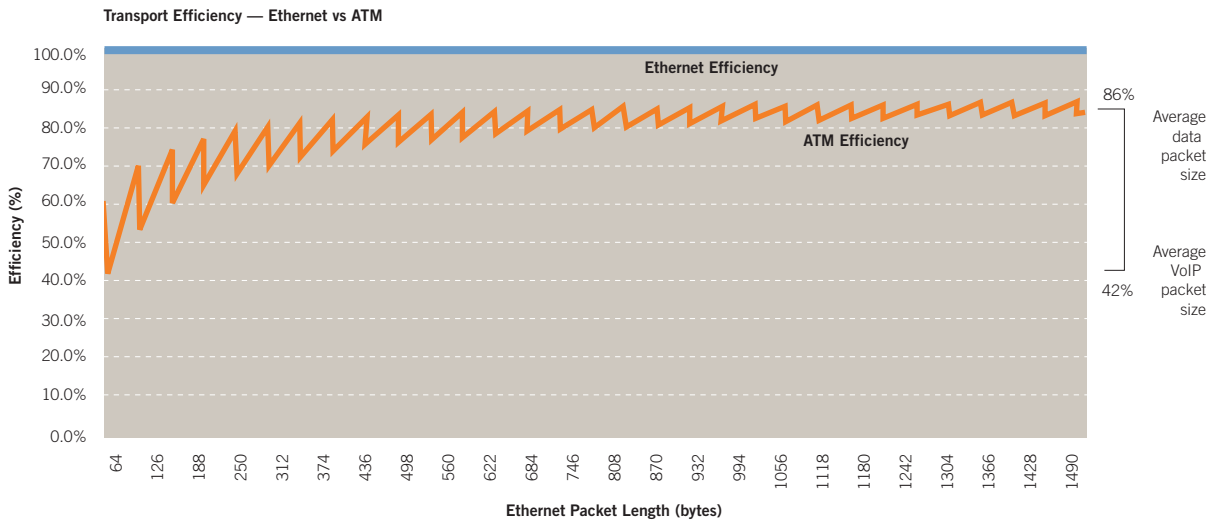


Figure 4. GPON using native IP offers efficiency greater than 98 percent while efficiency drops to 40–80 percent using ATM.

Today, the industry has moved from ATM to high-speed, high-density technology that uses native IP/Ethernet packets in the physical layer. A typical VoIP flow requires approximately 100 kbps of bandwidth at the Ethernet layer. When ATM is used to carry this service, the required bandwidth at the ATM layer is approximately 220 kbps. The result is 2.2 times the bandwidth required by choosing ATM technology on your GPON platform.

Native IP/Ethernet is the transport of choice for newer service technologies including ADSL2+ and VDSL2. Coupled with carrier-class QoS, IP becomes superior to ATM for modern high-bandwidth, high-density applications, leveraging the scalability and flexibility of IP and the reliability instilled with QoS mechanisms. In contrast, ATM efficiency varies with the length of the Ethernet packet. For services that utilize smaller packets, such as VoIP, efficiency is in the mid to upper 40 percent range. As Ethernet datagrams get larger for video, ATM becomes more efficient — in the range of 70–80 percent. However, this efficiency rate remains far lower than native Ethernet mapping over the same transport medium. Figure 4 illustrates the differences in efficiency between ATM and IP.

As a result, compared with ATM, IP over GPON offers:

- Better bandwidth utilization
- High transport efficiency, which means service providers can deliver more bandwidth to subscribers on a given infrastructure
- Greater scalability

ATM Encapsulation Wastes Bandwidth

ATM's low efficiency relative to IP is the result of the many layers of encapsulation required to convert ATM to Ethernet, which wastes

considerable bandwidth within the platform. As Figure 5 illustrates, converting ATM to Ethernet requires the following encapsulation layers:

- **RFC-2684 (Multiprotocol Encapsulation over ATM Adaptation Layer 5)** — The first step in the encapsulation process, outlined in RFC-2684, adds a header to the front (LLC/SNAP) and a Frame Check Sequence (FCS) to the back of the Ethernet frame. Thus, to an initial Ethernet frame of 68 bytes, the header and the frame check add 20 bytes of overhead. The efficiency is immediately reduced to 77 percent.
- **Common Part Convergence Sub-layer (CPCS)-PDU layer** — This second layer of encapsulation adds CPCS padding to the front of the frame so that it fits exactly into the ATM cell and a redundancy check to the back. Thus, to the 88 byte frame length created in the previous step, this step adds 56 more bytes of encapsulation for another drop in efficiency to 61.1%.
- **ATM Segmentation and Reassembly layer** — In this third layer of encapsulation, the Ethernet packet is segmented into multiple ATM cells. It takes many ATM cells to carry a single Ethernet packet. Each ATM cell is a total of 53 bytes in length with 48 bytes in the payload and 5 bytes in the header — which means that 5 bytes of bandwidth are wasted for each 48-byte segment for efficiency rate in this layer of 90.6 percent. At this point, the overall Ethernet — ATM cell efficiency for this 68-byte Ethernet packet is 42.8%.
- Added to this encapsulation, the mechanism that provides the steering logic necessary to deliver the ATM cells from one line card to another requires a fourth layer of overhead, which some vendors call a “packet.” A serial transport on the backplane typically runs at 2.48 Mbps carrying the packets between line cards. This steering logic adds 11 bytes to the 53 byte ATM cell to create a “protocol agnostic” 64 byte packet, further reducing the 42.8% efficiency in the above example to 35.4% overall transport efficiency through the ATM platform.

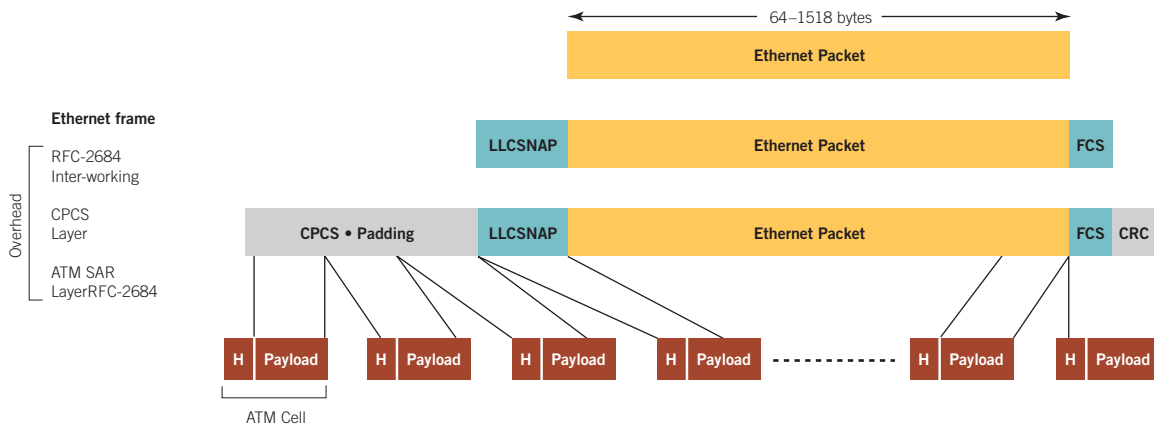


Figure 5. ATM encapsulation buries the IP/Ethernet protocol in three layers of overhead.

This system overhead, combined with additional inefficiencies due to the fact that ATM has not been updated in nearly 10 years, means that each subscriber can end up with as little as 14 Mbps, which is just 17 percent of the available bandwidth on a native IP/Ethernet GPON port. Thus, an amount of bandwidth that was once adequate ends up carrying a much smaller Ethernet payload — and the Ethernet payload is the portion of bandwidth carrying revenue-generating traffic.

IP Offers Efficient Bandwidth Utilization and Full Linear Scalability

In contrast, a solution that uses native IP with a nonblocking architecture provides enough bandwidth to enable the packets delivered to the platform to egress to the subscriber with no bottlenecks. Thus, with an all IP/Ethernet platform, a four port GPON module can effectively deliver 10 Gbps of Ethernet services for subscriber revenue generation. As a result, IP over GPON offers full linear scalability.

High Efficiency Means Greater Revenue

Service providers find themselves with a continual need to profitably increase bandwidth. Residential and business customers constantly expect more bandwidth, and as the cost per megabit for services declines, service providers must increase service/bandwidth offerings to achieve the same or better ARPU. For example, monthly cost per megabit of residential service is decreasing from \$25 in 2002 to an expected \$1 in 2010. Since the sweet spot for residential customers is \$50 per month, service providers will need to offer 50 Mbps at \$1 per megabit by 2010. Thus, GPON's ability to deliver scalable bandwidth will have a large impact on the revenue that can be generated for each card — and on long-term revenue overall.

When GPON is deployed on a ATM-based platform, once the system hits a certain percent of chassis capacity, it reaches its maximum serving capacity and the bandwidth delivered per user begins to decline as new subscribers are turned up, as shown in Figure 6.

In short, increasing system density over time will result in a decreased service offering per subscriber. Ultimately, system level Average Revenue Per User (ARPU) decreases with time and churn increases. In contrast, an IP platform with nonblocking architecture delivers the required bandwidth until it reaches capacity. The only limit to capacity is the number of network interfaces the service provider installs.

Tellabs Delivers on These Requirements

Tellabs is a leader in providing deep fiber solutions in North America with nearly two million PON ONTs shipped to date, and has provided commercially available VDSL2 solutions since 2005. As Figure 7 illustrates, these solutions offer a flexible migration path from digital copper to GPON fiber through support for:

- FTTP
- Fiber to the Node (FTTN) with ADSL2+ and VDSL2
- Fiber to the Curb (FTTC) with ADSL2+ and VDSL2

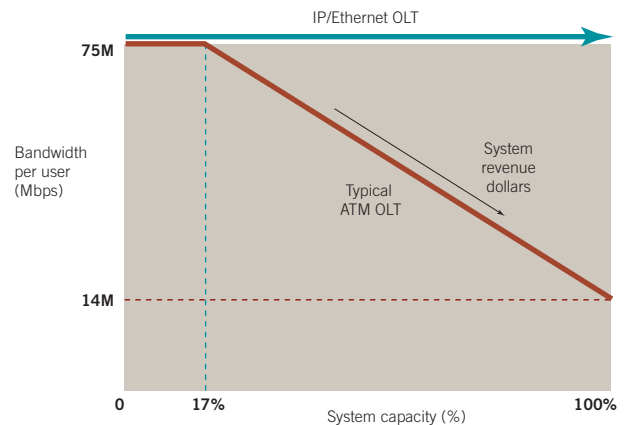


Figure 6. With ATM on GPON, increasing system density reduces the services telecom companies can offer each subscriber; IP offers no such limitations.

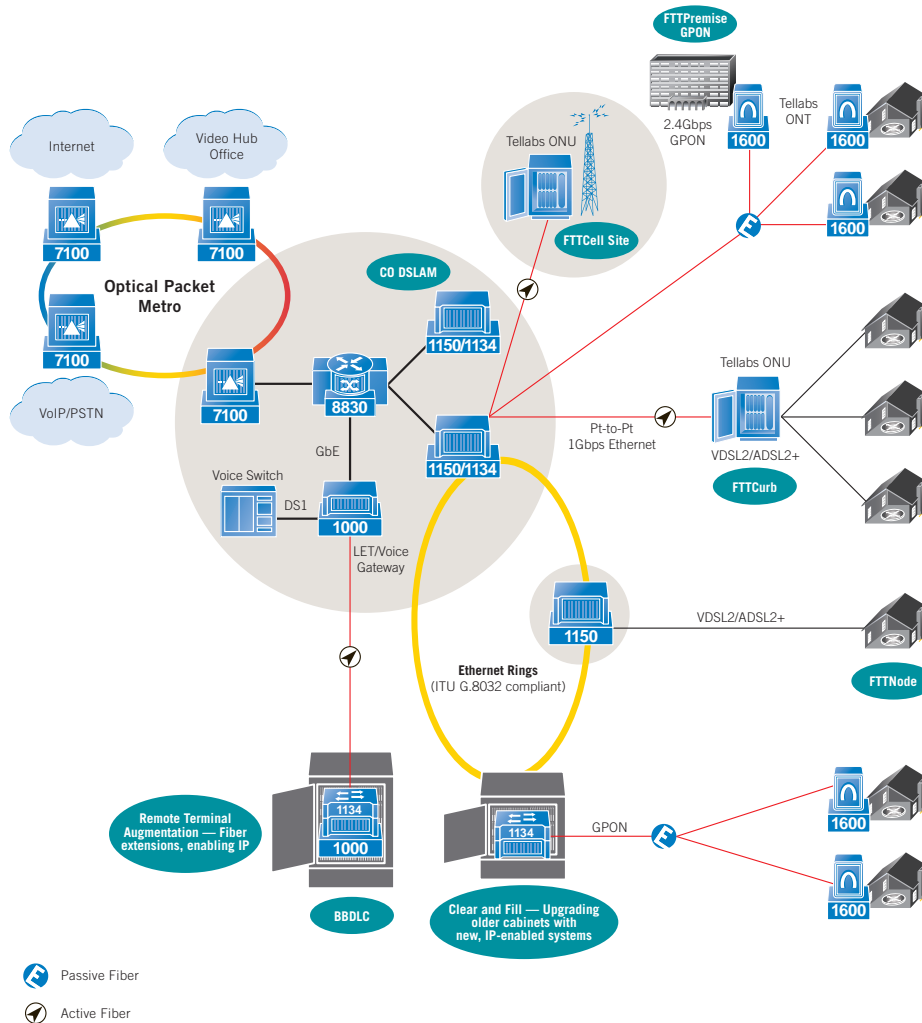


Figure 7. Tellabs access solutions offer the flexibility to deploy a full range of services.

The Tellabs deep fiber solutions also offer a full complement of high-speed data and existing as well as existing and legacy business services including:

- Symmetrical data
- Radio Frequency over Glass (RFoG)
- Digital Loop Carrier (DLC) services such as:
 - Digital Data Services (DDS)
 - Integrated Services Digital Network
 - Coin/payphone
 - 2-wire and 4-wire special services
 - 2-wire and 4-wire transmit only services

Tellabs fiber access solutions allow service providers to support both broadband DLC architectures and the latest in all-fiber GPON

technology concurrently. The integrated architecture supports cost-effective migration from a copper-to-optical outside plant infrastructure in a controlled manner.

Industry-leading Tellabs technology helps enable service providers to succeed through a suite of product and professional services solutions that includes MSAPs, GPON ONTs and voice gateways.

The Tellabs® 1150 Multiservice Access Platform (MSAP) is a feature-rich, native end-to-end IP/Ethernet delivery platform that offers the packet-based high-bandwidth technology required for today's in-demand telecommunications services. Flexible applications — FTTN, FTTC and FTTP as well as support for traditional DLC-based services — help providers chart migration paths maximized for competitive customer rollouts and manageable CapEx/OpEx impact.



The Tellabs® 1150 MSAP is a high-density access platform designed to help service providers stay ahead of the technology curve and support competitive offerings to consumer and business customers. Focused on deep fiber solutions service delivery, the Tellabs 1150 MSAP features an IP/Ethernet architecture that supports optimized, scalable service delivery:

- Native IP/Ethernet architecture
- IP transport, including Ethernet rings
- Residential and business high-speed services
- Symmetrical and asymmetrical services
- Transparent LAN Service (TLS)
- RF return compliant with RFoG standards
- Transparent LAN Service (TLS)
- Integrated DLC special circuits
- Unified Element Management System (EMS)

Designed to support high-capacity FTTP, FTTN and FTTC deployments via a powerful nonblocking architecture, the Tellabs 1150 MSAP is a forward-looking access solution that can be deployed at cost parity to traditional copper networks. The Tellabs 1150 MSAP leverages the practically limitless capacity of fiber optic cable to help support extremely high-speed broadband networks over very short copper connections.

The Tellabs® 1134 Multiservice Access Platform (MSAP) offers a medium-density, full-service option — for smaller MSAP deep-fiber applications — that supports full-service GigE FTTC, GPON FTTP or FTTN applications supporting broadband, narrowband and legacy copper services. The Tellabs 1134 MSAP is designed to be deployed in existing cabinets to enable a flexible, remote MSAP that supports multi-shelf GigE aggregation/transport to the CO and migration to FTTN, GPON FTTP, GigE FTTC and future Ethernet rings.

The Tellabs® 1600 Series of GPON ONTs enables the delivery of integrated, high-speed services to both residential and business customers at a reasonable cost. Single-family Unit (SFU) ONTs provide interfaces for POTS, Gigabit Ethernet and both Multimedia over Coax Alliance (MOCA) and RF video. SIP-ready, the SFU ONTs are easily migrated to a softswitch environment. Business ONTs are available in several integrated, rack-mount units, as well as a modular

chassis-based model. Each business ONT supports multiple densities of POTS, GigE, VDSL2 and T1 services. The modular, chassis-based unit also supports an extensive list of special circuits.

The Tellabs® 1000 Multiservice Access Platform (MSAP) Voice Gateway (VGW) performs SIP to TDM conversions in all-IP networks, providing a cost-effective transition to VoIP. Offering standard VoIP for voice, the VGW broadens competitive service offerings, enabling service providers to offer bundled IP services. The Tellabs 1000 MSAP can also aggregate multiple exchanges via the IP network via aggregation to a single Tellabs 1000 MSAP VGW to replace multiple legacy voice switches. This gateway utilizes SIP for Bearer setup and teardown, with signaling passed transparently via FRC 2933 messages. In addition to support for Class 5 interfaces (GR-303, TR-08, Mode I and Mode II), the Tellabs 1000 VGW also supports INA interfaces for special service circuits.

The Tellabs® Panorama™ Integrated Network Manager (INM) offers unified management support for the entire suite of Tellabs access products. The Tellabs Panorama INM enables service providers to monitor and provision various elements in their network from a centralized system, increasing efficiency and saving OpEx while providing quicker service turn up and time to revenue.

Summary/Conclusion

As customers continue to demand new bandwidth-rich services, service providers are increasingly looking to fiber-oriented solutions like GPON/FTTP, FTTC or FTTN with ADSL2+ or VDSL2 to provide the necessary bandwidth at the last mile. Using a solution that currently offers or incorporates a migration plan to IP/Ethernet service delivery allows service providers to maximize their usage of this bandwidth to provide more services to larger numbers of subscribers — and thereby increase the revenue they can derive from the system. Tellabs offers the full range of services and solutions, including MSAPs, ONTs, voice gateways and network management systems, that allow service providers to implement a feature-rich, native end-to-end IP/Ethernet delivery platform that offers the packet-based high-bandwidth technology and flexibility required for today's in-demand telecommunications services. Tellabs solutions also provide the bandwidth and flexibility to support service providers well into the future.

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