

## ***FTTH Explained: Delivering efficient customer bandwidth and enhanced services***

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### **Overview:**

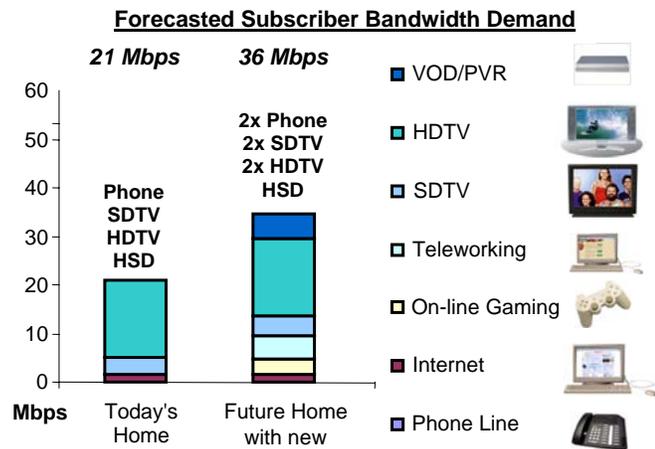
Telecommunication carriers worldwide have come to the realization that their aging copper access infrastructure is being taxed as residential and business customers utilize ever-increasing, symmetrical bandwidth-intensive applications. The telecommunications landscape has matured to a point that carriers seek to offer network convergence and enable the revolution of consumer media device interaction. These demands are being met by the deeper penetration of optical fiber in access networks and increasing deployment of fiber to the home (FTTH). As a result, FTTH is the fastest growing global broadband technology with significant deployments occurring in Asia, Europe and North America.

This tutorial provides details why carriers are deploying FTTH today, while detailing the architectures and protocols used in its deployment. Passive optical networks and point to point networks will be defined as well as the multiple supporting protocols and standards such as ATM and Ethernet and their resulting video capabilities. Considerable time will be spent comparing and contrasting the deployment of fiber to the home, building/multi-dwelling unit, curb and node; commonly referred to as a group as FTTx. Finally, the components and technologies used in the outside plant will be detailed.

### **Introduction:**

The twenty-first century heralded countless changes across our landscape; arguably none will be more important than the transformation of our telecommunications providers means to deliver consumers, both residential and business, telecommunication services. This phenomenon is being underpinned by two technologies; Internet Protocol commonly referred to as IP and optical fiber. Today, the technology is available to provide all classes of service, voice, video and data, over a common protocol; IP.

Carriers are quickly moving to maximize the number of services they offer to a single customer via a bundled offering. Technologies such as VoIP, IPTV and broadband are becoming commonplace across our society. As bundled services and technologies are deployed, carriers are realizing that their original networks, designed to efficiently deliver a single service, are stressed and in many cases incapable of offering the desired services. Figure 1 depicts forecasted subscriber service and bandwidth demand (note new compression schemes include MPEG-4 and Microsoft Windows 9/VC1). Today's networks are being designed to provide 20+Mbps while 3-5 years from now carriers will need 40+Mbps capability as multiple services are used in the home, HDTV becomes more prevalent and users demand faster internet connections. This is resulting in the largest investment in the access network since the turn of the century and the wiring of the western world for voice services.



Leading this investment wave is the deployment of single-mode optical fiber deeper into these access networks in order to curb the thirsty bandwidth requirements of their customers. Increasingly, carriers are finding that deploying the fiber all the way to the customer enables network future proofing, maximizes the symmetrical bandwidth throughput of a carrier's access network, provides for network reliability, reaps significantly reduced operating expenses and affords enhanced revenue opportunities. The industry refers to this technology as FTTH.

**Architectures:**

The deployment of optical fiber in an access network can be achieved in multiple ways. In fact, many access technologies are commonly referred to as FTTx when in fact they are simply combinations of optical fiber and twisted pair or coaxial cable networks. These technologies do not provide for the inherent capability of a FTTH network. Nonetheless it will be useful for us to discuss them later in this tutorial.

FTTH is simply the 100% deployment of optical fiber in the access network. It is commonly deployed in two specific configurations. In the first one fiber is dedicated to each user in the

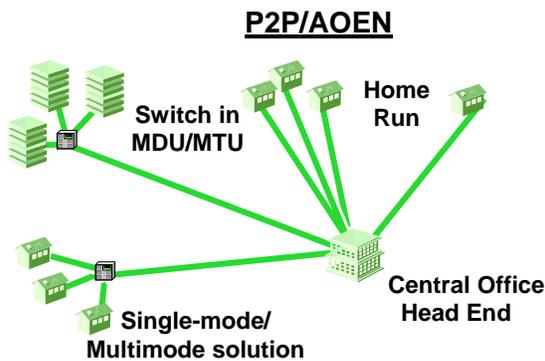


Figure 2

access network. This is referred to as a point-to-point (P2P) network. In the second, one fiber is shared (via a power splitter) amongst a set amount of users, typically 16-32, and is referred to as a passive optical network (PON). There are advantages and disadvantages to the deployment of P2P and PON networks based on financial, bandwidth and component considerations.

Point-to-point networks are characterized by the use of one fiber and laser per user. They are the simplest FTTH networks to design. P2P networks are sometimes

referred to as all optical Ethernet networks (AOEN). Figure 2 illustrates several examples of how P2P architectures might be deployed. Again, a dedicated fiber is terminated at the subscriber and active devices at the central office (CO) for a telecommunications provider or head end (HE) in the case of a CATV operator or a remote device in the field. The remote device or switch in the field is always an active device and must be powered. Single-mode or multi-mode fiber media can be used throughout the network. Characteristics of a P2P network include active electronics in the field, their inherent simplicity, are fiber rich and require no sharing of fiber or bandwidth for the subscriber.

Passive optical networks are characterized by the "splitting" of the optical fiber one or more times in the field, resulting in the sharing of the optical fiber amongst multiple users. The fiber in a PON is typically shared with 16-32 users. Hence the bandwidth of the fiber originating at the CO/HE is shared among a group of users. The splitting of the network is accomplished by an optical splitter. These splitters can split the fiber 2-32 times and, by their nature, introduce inherently high losses in the network. Therefore, their use is limited due to the power budget considerations of the

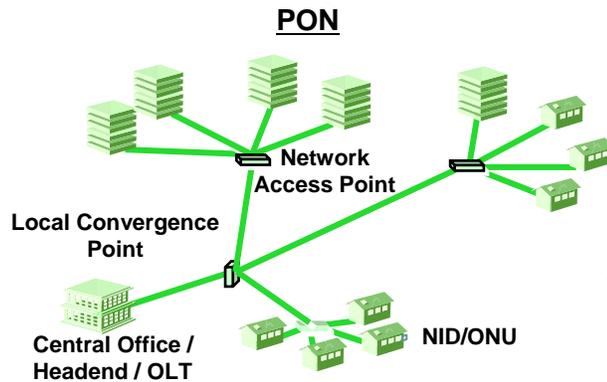


Figure 3

network. A PON will have less optical reach than a P2P network, which does not use splitters. Typically a PON is capable of reaching subscribers 20km from the original transmitter, which will cover 98% of the population. A PON is characterized by the use of no electronics in the field and is supported by a set of mature standards and is the most widely deployed FTTH architecture in the US. Figure 3 illustrates the multiple configurations of a PON. The individual components of a PON will be discussed in more detail in the OSP section of this tutorial.

Carriers deploying PON have additional architectural choices to sort through. Notably this is deciding between a centralized splitter versus a distributed/cascading splitter arrangement. Both are deployed for different reasons depending on the tradeoffs of their specific characteristics.

A centralized split provides for a “central” location for all the PON splitters; typically located in a passive, field rated cabinet (see Figure 4 for example). Carriers looking to maximize port efficiency in the CO/HE and use of 1x32 splitters in order to maximize the shared capacity of the fiber plant will be drawn to a central split configuration. This results in minimizing the number of

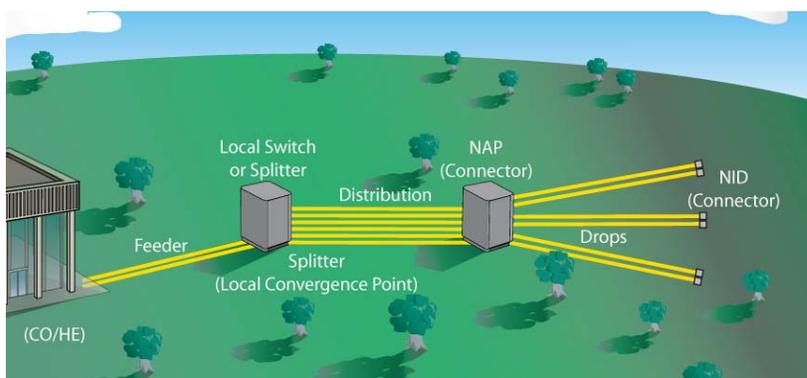


Figure 4 – Centralized Split

transmitters used in the CO/HE and optical splitters and fiber in the field. Centralized split architecture also provides for a better overall loss measurement for the PON thereby increasing network reliability. A single 1x32 splitter has less loss than 1x2 and 1x16 or 1x4 and 1x8 cascaded splitters or any combination of 1x16, 1x8, 1x4 and 1x2 splitters in the network.

This improves optical reach and the reduction of optical components is directly proportional to increased reliability of the network via the reduction in points of failure. In addition, centralized split has been shown to minimize capital expenditure of splitters initially in the network, facilitating a “pay-as-you-grow” approach due to the higher splitter output port efficiency at low to medium take rates. Centralized split also provides for simplification of network troubleshooting and fault location that directly translate into labor savings.

A distributed/cascaded split configuration results in pushing splitters deeper into the network (see Figure 5 for an example).

As the splitters are not centralized the requirement for field cabinets is reduced or removed as splitters are commonly incorporated into modified enclosures or even back in the CO/HE. The sharing of a CO/HE transmitter among 32 users is still achieved through the distribution of multiple splitters along the optical path. For example a 1x4 followed by a 1x8, at different locations in the network, results in bandwidth sharing amongst 32 users.

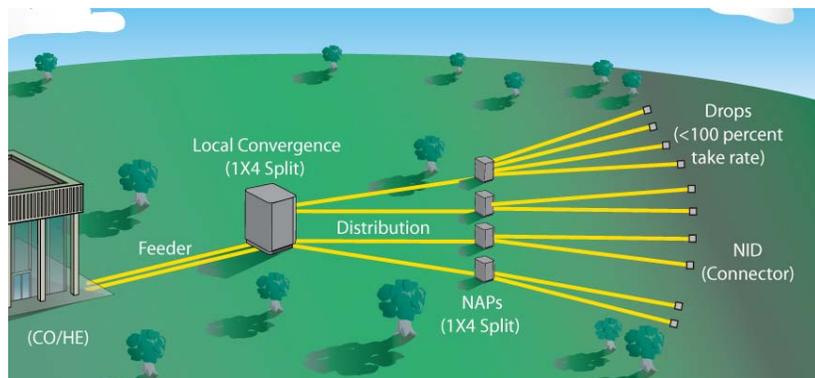


Figure 5 – Distributed Split

The deep positioning of splitters can result in the “stranding” of splitter assets as the carrier awaits new subscribers on the network or take-rates are low. Network testing and

fault location can be more difficult with a distributed/cascade split configuration as it is difficult for test equipment to see through an array of splitters along the optical loop. Network reliability can be affected due to increased optical components.

**Protocols and Standards:**

Transmission standards utilized in FTTH networks are based on ATM and Ethernet technologies. Carriers are extremely familiar with both technologies which support a variety of services. Today, the majority of P2P networks utilize Ethernet technology and are governed under IEEE 803.2ah standards. P2P networks are simply an extension of legacy Ethernet used in metropolitan and enterprise spaces and extended into the access network. Bandwidth rates are only limited to the transmitter type at the CO/HE and the home. The majority of municipally owned and shared FTTH networks and early FTTH deployments in Japan utilized P2P networks.

Passive optical networks provide for a wide array of technology and protocol choices for the carrier. The Full-Service Access Network (FSAN) initiative oversees the development of PONs. Comprised of 20+ global carriers, the FSAN works with leading vendors in order to agree on common technology platforms for delivering converged services. The FSAN, not a standards organization, submits recommendations for adoption to the International Telecommunications Union (ITU). Figure 6 provides a complete breakdown of the PON protocols and the respective capabilities.

	<b>BPON</b>	<b>EPON</b>	<b>GPON</b>
<i>Standard</i>	ITU-T G.983	IEEE803.2ah	ITU-T G.984
<i>Bandwidth</i>	Downstream up to 622Mbps Upstream 155Mbps	Up to symmetric 1.25Gbps	Downstream up to 2.5Gbps Upstream up to 2.5 Gbps
<i>Downstream λ (nm)</i>	1490 and 1550	1550	1490 and 1550
<i>Upstream λ (nm)</i>	1310	1310	1310
<i>Transmission</i>	ATM	Ethernet	ATM, Ethernet, TDM

Figure 6 – xPON Protocols

Earlier PON deployments utilized ATM PON (APON) which evolved into Broadband PON (BPON). Broadband PON is governed by ITU G.983. The A/BPON protocol is characterized by having two downstream wavelengths and one upstream wavelength. The 1550nm and 1490nm wavelengths are used for downstream traffic with the 1490nm channel typically an IP channel for voice and data service. The 1550nm channel will be used for an RF or IP video overlay. Providing 622Mbps shared electronics are able to dynamically provide 20-30Mbps per subscriber. Time Division Multiple Access (TDMA), recommended by FSAN, is used for all down/upstream traffic.

An alternative to A/BPON networks is Ethernet PON (EPON), governed by IEEE 803.2ah. EPON only uses two wavelengths and exclusively uses IP. The 1550nm wavelength is used for downstream traffic and 1310nm is used for upstream traffic. Capable of 1.25Gbps in shared bandwidth, EPON under “best effort” conditions provides for 100Mbps but typically provides for bandwidth of 30-40 Mbps. GigaEthernet PON (GePON) can increase shared bandwidth to 2.5Gbps.

Broadband PON has evolved into Gigabit PON (GPON) in order to address bandwidth and protocol limitations. Capable of up to 2.5Gbps shared bandwidth among 32 users; GPON utilizes the same wavelength plan of BPON. It is governed under ITU standard G.984 and provides for protocol flexibility across ATM, Ethernet and TDM platforms.

**FTTH Outside Plant Components:**

A wide array of outside plant components are used to build FTTH networks. The earliest FTTH networks borrowed from the designs of metro and long-haul networks and became simple extensions of these networks. Soon it became clear to the industry though that if FTTH was to

become ubiquitous specialized products and installation methodologies would have to be introduced. Innovation would be required to tackle the high cost of access networks, address deployment velocity and improve network reliability.

All FTTH networks inherently are designed to deliver an optical fiber to the subscriber. Their design though is highly dependent on the unique nature of the access environment; hence product and design flexibility is critical. At their core FTTH networks contain an optical line terminal (OLT), optical cable and an optical network terminal (ONT). Various other specialized components are added to address the unique nature of the access network.

The OLT is typically located at the CO/HE but can also be located in a remote terminal in the field. The OLT houses the laser transmitters dedicated to each user in a P2P network or shared across several users in a PON. The OLT is also the aggregation point of voice from the public switch telephone network (PSTN), data from a router and video via its multiple forms.

The optical fiber carries the signal to the user and is divided into three sections, feeder cable (terminated at the CO/HE), distribution cable (fanning out across the access network and connect to the feeder cable “feeds”) and drop cable used to physically connect the users to the FTTH network. As a medium, optical fiber’s bandwidth is only limited by the transmitters of the OLT and hence future proofs the access network due to its tremendous bandwidth capacity.

The ONT receives the signal from the OLT and converts it into usable electronic signals that a user’s telephone, computer, TV or any other number of devices can receive. The ONT also serves to communicate IP traffic back to the OLT such that voice conversations can occur, web pages can be requested and TV channels can be changed. Typically the ONT is connected to a battery back-up device providing a limited time period (typically 8-hours standby) of life line services.

As discussed, P2P networks are characterized by their simplicity. A P2P network minimizes the amount of components in the field and has all the items described above as well as enclosures used to connect the multiple cables deployed in the field. PON networks more efficiently utilize the optical fiber in the field and the transmitters of the OLT. Therefore their design is more complex as compared to P2P.

Beyond the OLT, optical cable and ONT, the PON includes many specialized components that serve to address the cost, deployment and reliability concerns of earlier FTTH deployments (see Figure 7). The most important of these is the optical splitter. Depending on the split architecture chosen, splitters can take the form of 1x -32, -16, -8, -4 and -2 and can be located almost anywhere in the access network. As discussed many carriers choose the centralized split

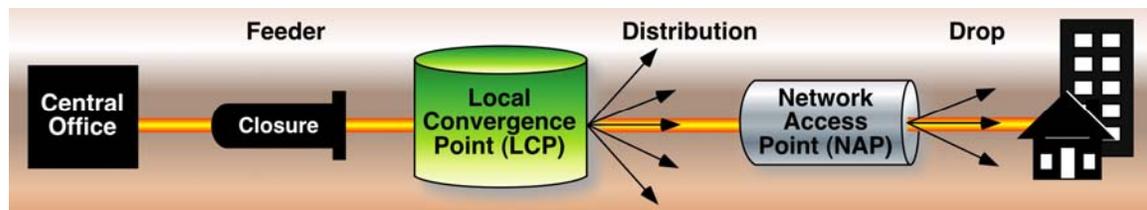


Figure 7 – Typical PON Components

architecture due to its inherent efficiencies. The aggregation of splitters is typically located in a cabinet called a local convergence point (LCP). This is where feeder cable ends and distribution cable begins (from here each customer has a dedicated fiber). The distribution cable then snakes its way into the neighborhoods and buildings of the access network. When a distribution cable nears a user a network access point (NAP) is used to access a small number of optical fibers in the cable. From this point drop cables, usually containing 1-4 fibers, are used to connect to the subscriber’s ONT.

A recent standardized innovation in the drop cable and NAP is the use of environmentally hardened connectors. Legacy networks connected all the optical fibers of all access components with an optical splice, either mechanical or fusion. While typically introducing little optical loss into the network, the splice also introduced high cost into the network deployed due to the time involved to achieve one splice and the technician skill level and equipment deployment requirement. Connectors eliminate these costs; greatly improving deployment velocity while introducing little loss into a network due to the short loop lengths inherent of access networks. FTTH network connectors are standardized technology governed by Telcordia GR-3120.

**FTTx Explained:**

The industry today has earmarked the “general” penetration of fiber into the access network as “FTTx”. This has created some confusion though as FTTx covers several different architectures and protocols. In fact, some of today’s digital subscriber loop (DSL) and hybrid fiber coax (HFC) networks qualify as FTTx networks due to their use of fiber in the access, as does a PON. Hence, it is best when referring to a deep fiber penetration network to refer to its actual architecture. The most common architectures are FTTHome (FTTH), FTTBilding (FTTB), FTTCurb (FTTC) and FTNode (FTTN). Each of these has a different physical architecture as depicted in Figure 8.

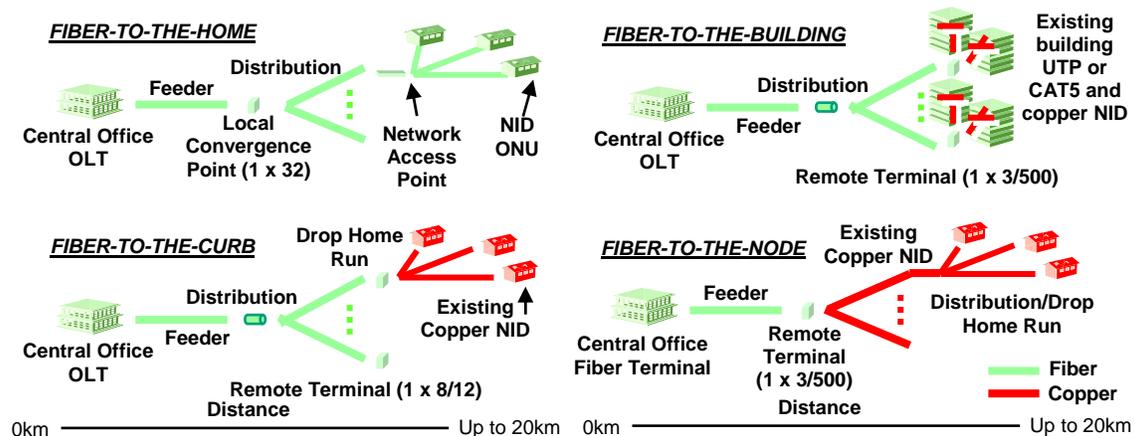


Figure 8 – FTTx Architectures

As we have discussed extensively, FTTH pushes fiber all the way to individual residential dwellings. FTTH is completely absent copper in the outside plant and typically provides for 30-100Mbps service, but due to the inherent characteristics of optical fiber can provide literally infinite bandwidth. FTTB typically uses the P2P architecture in the outside plant providing a dedicated fiber to each building or block of buildings. The fiber is terminated at a remote terminal (RT) which is an active device requiring powering and security typically located in the basement, communications room or utility closet. If the building is outfitted with CAT5 cable to each dwelling unit an Ethernet Local Area Network is installed providing shared bandwidth of 10 or 100Mbps. If twisted pair is only available the RT is a DSLAM and is installed to provide requirement bandwidth services offering up to 50Mbps; today’s FTTB applications are providing ~10Mbps.

FTTC typically pushes fiber 500-1000 feet from the subscriber terminating at an RT and will serve 8-12 subscribers. FTTN is similar in architecture to FTTC except that the RT is positioned much further from the subscribers; up to 5000 feet and will serve 3-500 subscribers. Both utilize existing twisted pair outside plant to connect to the customer. Bandwidth is dictated by two factors; DSL technology and copper loop length. VDSL and VDSL2 works best at longer loop lengths and is predominantly used for FTTN while ADSL2, 2+ and 2++ are being used in today’s FTTC systems. Signals over copper significantly degrade over long distances directly affecting the bandwidth capability. In the most extreme conditions (4-5 km) some customers may not even be able to be served by DSL. If copper conditions warrant in some cases the carrier will use both twisted pairs

to boost the bandwidth throughput. Both architectures have afforded ~20Mbps service in the laboratory. Due to shorter copper loop lengths in a FTTC network the operator has improved scalability from a bandwidth perspective. Large scale deployments of both FTTC and FTTN are planned in the future.

Fiber penetration directly correlates to the bandwidth throughput of each defined architecture and therefore the service capability for the operator. As discussed earlier, the bandwidth requirements of each carrier differ but all are growing. The carrier must take this into account as it deliberates over the desired architecture to deploy. Fiber penetration is also an indicator on the capital expenditures (CapEx) and operating expenditures (OpEx) expected. Deep fiber will result in a higher CapEx for existing neighborhoods, but is actually near cost parity with all architectures for new builds. Deep fiber will deliver the maximum amount of OpEx savings comparably. FTTH enables the delivery of savings due to reductions in cost for network, central office and outside plant operations as well as customer service. Network reliability dramatically increases as well with FTTH ensuring a steady stream of revenue and enhanced customer satisfaction.

### **Summary:**

Carriers from Boston to Berlin, and Seoul to Sydney are faced with an access network dilemma on how to upgrade an access network considerably taxed by the need to provide more bandwidth to residential and business consumers. Universally, carriers are choosing to place fiber deeper in the access network to overcome the limitations of copper, but are faced with a myriad of architecture choices. Today, many are investigating the deployment of FTTH, whether it is PON or P2P, centralized split versus distributed, while still many more are in the midst of rehabilitating significant portions of their access network with FTTH.

FTTH is being chosen due to its intrinsic ability as a medium to maximize bandwidth to the residence, that future proofs one's network, provides for enhanced network reliability, increased customer satisfaction, expanded service capability and improved network OpEx. This tutorial defined the architectures and protocols used in the deployment of FTTH and the components and required technologies used in the outside plant. There were comparisons and contrasts to the deployment of the family of FTTx architectures addressing how FTTH is used today to efficiently and effectively address carrier bandwidth, deployment and service concerns.