Fiber to the Home Architectures

The interest in deployments of fiber to the home (FTTH) is rising, particularly in Europe. Although initial FTTH deployments in Europe were mainly carried out by municipalities and utilities, large incumbent operators are starting to announce FTTH deployments. In the United States and Japan, FTTH deployments are mostly based on Passive Optical Network (PON) technology. Deployments in Europe constitute mostly point-to-point and ring-based topologies employing Ethernet technology, referred to as Ethernet FTTH (E-FTTH), along with a small number of small-scale PON FTTH deployments.

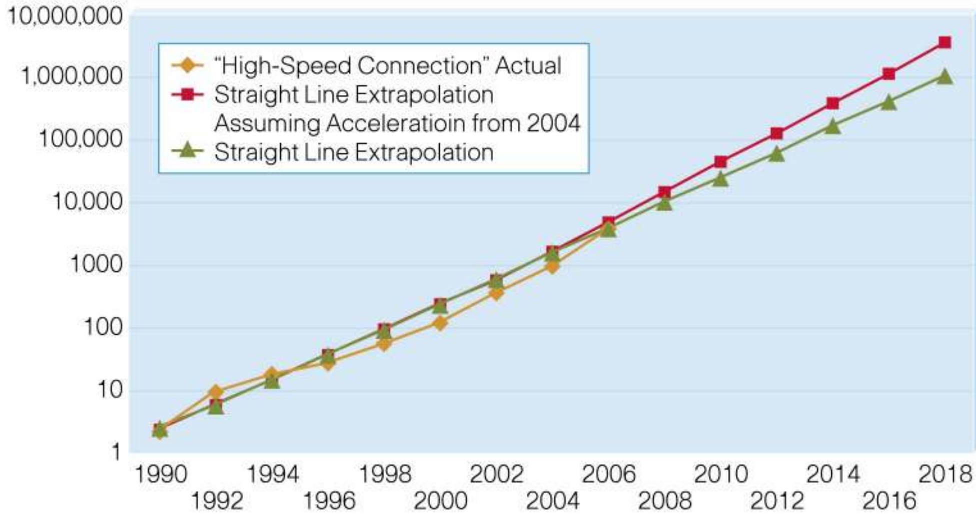
This white paper discusses the different access network architectures, explores the access protocols being deployed, and provides an overview of their respective characteristics. The rationale for PON FTTH deployments is becoming less compelling, which matches the service roll-out plans of most organizations investing in FTTH today.

Services and Bandwidth Requirements

Internet access speeds have been rising at a steep rate, both the speeds required by the applications and those delivered by the industry and the service providers. Bandwidth-intensive content and peer-to-peer applications consume the great majority of bandwidth in most broadband networks today. This race between application requirements and technical capabilities is much like what has occurred in the PC industry, where each increase in processor speed and memory is quickly absorbed by applications that are novel for the PC setting, such as image processing or video editing.

Nevertheless, new broadband deployments are commonly justified primarily by today's applications rather than anticipated demands. Streaming video content is considered by many as the ultimate bandwidth-hungry application. When one adds the bandwidth requirements of one high-definition TV stream, a few standard-definition TV streams, and Internet browsing, for instance, it may seem that 20 to 25 Mbps bandwidth is sufficient in the long term. But historical data and projections (see **Figure 1**) indicate long-term growth in bandwidth demand that is exponential. Indeed, some service providers are already offering 1 Gbps access to residential customers today, and there are already substantial deployments of 100 Mbps networks in some European countries. These high bandwidth data rates can only be provided on the basis of FTTH.

Figure 1. How Much Bandwidth (from FTTH Worldwide Market & Technology Forecast, 2006–2011; Heavy Reading Report, June 2006)



Certain applications are especially demanding of high bandwidth (sustained or bursty):

- Download of large video files for editing or post-processing
- Joint video editing or other forms of remote collaboration on huge files
- Telepresence, which includes concurrent video, voice, and application traffic
- Novel video applications like the TV Perso service, which allows subscribers to stream their user-generated content to potentially all Free subscribers in France

Most data applications have highly bursty traffic patterns and require high bitrates only for a relatively small fraction of time. They can easily be supported and may share common aggregation and backbone networks, which can be highly oversubscribed. In contrast, streaming applications like broadcast video, video on demand, or voice over IP (VoIP) require bandwidth to be reserved for the entire duration of the application. Another factor to consider is the increasingly symmetric nature of the traffic patterns. Peer-to-peer file sharing, e-mail, remote collaboration, VoIP, and others create inherently symmetric traffic streams in contrast to the highly asymmetric client-server type applications like video streaming or Web browsing.

Aggregation and backbone networks can be upgraded comparatively easily, and bandwidth increases can be accommodated without much additional investment. Investments into an access infrastructure, however, have to be considered as being very static. Therefore, network planners must take care to determine whether a seemingly cost-effective shared access technology will constitute a bottleneck for future bit-rate requirements.

FTTH Architectures

Cost Considerations

Constructing an FTTH network is very labor intensive and, therefore, costly. Experience tells us that the dominant part of an FTTH deployment goes into civil works, with a relatively small part related to the actual optical fiber cables. This implies that when civil works have to be carried out it does not really matter how much fiber is being deployed.

Furthermore, while the electronic elements in an FTTH network have a life cycle of few years, the fiber plant and the optical distribution network has a longer life cycle of at least 30 years. This longevity and the high cost of labor required in physical construction places strong demands on proper design of the fiber plant. Once it is in place, it is quite costly to change or update.

FTTH architectures that have been deployed can be classified in three broad categories:

- Ring architectures of Ethernet switches
- Star architectures of Ethernet switches
- Tree architectures using PON technologies

Ethernet-Based Architectures

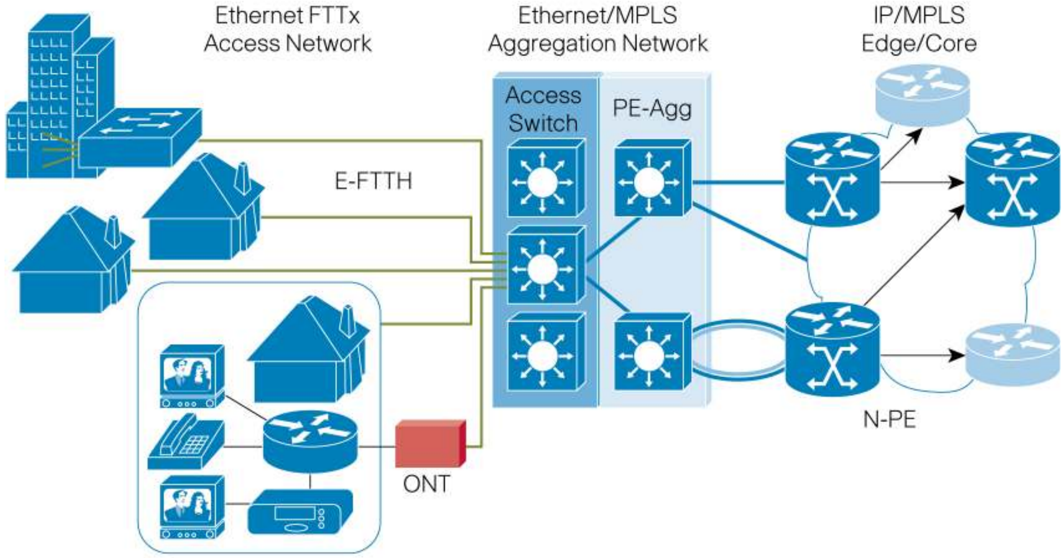
The requirements for rapid time to market and low cost per subscriber have favored network architectures based on Ethernet switching. Ethernet transmission and switching have become commodities in the enterprise networking market and have led to attractive costs, mature products, and rapid innovation cycles.

Initial Ethernet FTTH projects in Europe have been based on architectures where switches located in the basements of multi-dwelling units have been interconnected by Gigabit Ethernet in a ring structure.

Such a structure provides excellent resilience against fiber cuts and can be built cost-effectively, but it has the disadvantage of sharing a bandwidth over each access ring (1 Gbps) that is comparatively small in relation to long-term requirements, thus providing a challenge for scalability of the architecture.

More recently, primarily Ethernet star architectures have been used as shown in **Figure 2**. Star architectures provide dedicated fibers (typically single-mode single fiber with 100BASE-BX or 1000BASE-BX Ethernet transmission) from every endpoint to the point of presence (POP), where they are terminated on an Ethernet switch. Endpoints can be single family residences, apartments, or multi-dwelling units where a switch in the basement fans out to the apartments using any appropriate transmission media technology.

Figure 2. Ethernet FTTH Architecture with Star Topology



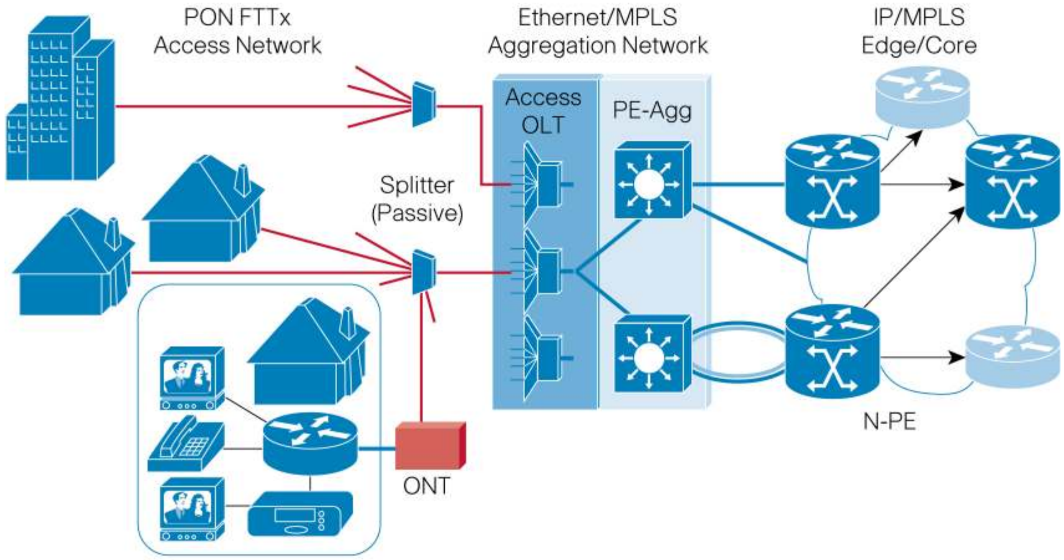
Passive Optical Network (PON) Architectures

PON architectures for FTTH deployments are characterized by passive optical splitters to distribute the fiber to each customer using splitting ratios ranging up to 1:64 or even 1:128.

The physical PON FTTH architecture typically supports the Ethernet protocol. In some cases, an additional downstream wavelength is overlaid in order to distribute traditional analog and digital TV services to each user without the need for IP set-top boxes.

Figure 3 illustrates a typical PON network that employs an Optical Line Termination (OLT) device that feeds a variety of optical network terminations (ONTs) or optical network units (ONUs). ONTs are usually dedicated to an individual end user. An ONU typically is located in a basement or even on a curbside and shared by a limited number of users. Voice, data, and video services are distributed over appropriate transmission media within the customer premises from the ONU or ONT.

Figure 3. Passive Optical Network (PON) Architecture



Currently there are three different standards for PON, summarized in Table 1. The bandwidth figures are indicating the aggregate bit-rate in upstream and downstream directions. This bit-rate has to be shared by 16, 32, 64, or 128 customers, depending on the deployment scenario.

Table 1. Passive Optical Network (PON) Flavors

	BPON	EPON	GPON
Standard	ITU-T G.983	IEEE 802.3ah	ITU-T G.984
Bandwidth	Downstream up to 622 Mbps Upstream 155 Mbps	Symmetric up to 1.25 Gbps	Downstream up to 2.5 Gbps Upstream up to 1.25 Gbps
Downstream wavelength	1490 and 1550 nm	1550 nm	1490 and 1550 nm
Upstream wavelength	1310 nm	1310 nm	1310 nm
Transmission	ATM	Ethernet	Ethernet, (ATM, TDM)

BPON can be considered a legacy technology that is still being deployed by few U.S. service providers but is quickly being superseded by the other technologies and architectures. Whereas EPON has been designed for lowest cost using Gigabit Ethernet technology, GPON was designed for higher downstream bitrates, lower overhead, and the possibility to carry ATM and TDM. These ATM/TDM capabilities, however, are hardly used in typical service provider deployments. Instead, GPON is predominantly used as an Ethernet transport platform for residential services.

Benefits and Issues of PON-Based Architectures

There are some benefits for service providers that deploy PON architectures instead of deploying point-to-point fibers, although some of these reasons are becoming less compelling in many markets.

Access Fiber Saving

Fiber saving between the optical splitters and the central office or POP locations is the most relevant aspect for PON FTTH deployments. If a service provider has existing spare fibers or duct space available between the POP and some street cabinet, then this may prevent the need for digging up the streets. However, experience shows that the availability of this fiber infrastructure is often overestimated, which eventually leads to digging in more cases than initially anticipated.

Furthermore, in cases where aerial cabling is used, there is also a natural restriction in the dimension of the fiber cables on poles, which is one of the reasons for EPON deployments in Japan. In a scenario with no existing infrastructure or deployment to new neighborhoods, fiber saving is usually irrelevant because the marginal cost of additional fibers is negligible when trenches need to be dug, or when right-of-way solutions like sewer pipes can be used.

Port Saving in the Aggregation Central Office or POP

The fact that there is a dedicated optical interface per customer in a point-to-point scenario may imply that this architecture is inherently more expensive than an architecture sharing ports among a larger number of customers. Experience with a large number of projects, however, has shown that dedicated Ethernet ports are price competitive given the higher cost of PON ports. Ethernet ports are very inexpensive due to the huge numbers shipped in enterprise and service provider networks, whereas GPON ports are technology-specific and are shipped in significantly smaller quantities.

Assuming a 100 percent take rate of an FTTH offering, the point-of-presence (POP) for the Passive Optical Network (PON) architecture would have less active equipment compared to Ethernet FTTH. However, if one considers realistic take rates, as discussed below, the difference disappears. This is due to the fact that already the first customer on a PON requires an optical line termination (OLT) port, and thus, the number of OLT ports cannot be reduced based on a lower take rate.

The management of a large number of fibers appears to be very difficult without the availability of novel optical distribution frames that allow deployments of several thousands of fibers entering the point-of-presence from the outside plant. **Figure 4** shows a typical optical distribution frame currently being deployed across Europe in FTTH deployments using point-to-point architectures. Such a frame can accommodate more than 2000 fiber terminations in a rack.

Figure 4. High-Density Optical Distribution Frame

(source: Huber & Suhner)

Broadcast Video Overlay

As a PON structure is inherently a broadcast medium, some service providers find it appealing to use this capability for broadcast video distribution, which also allows maintaining the coaxial cabling at the customer site for analog/digital television.

Adding a second fiber in a point-to-point Ethernet FTTH scenario, however, has become very common, and service providers are now deploying hybrid architectures that use point-to-point structures for all the interactive services, including IPTV, and an additional PON overlay structure for the broadcast video distribution. This PON structure can then be optimized for a significantly larger number of subscribers compared to the use of PON for the interactive services.

More recently, architectures have been deployed that use a single dedicated fiber for both Ethernet transmission and broadcast video overlay using a wavelength division multiplexing scheme similar to the implementation in a PON.

Issues with Deploying PON Architectures

There are a number of major issues facing service providers that deploy PON architectures.

Shared Bandwidth

Bandwidth on the PON fiber tree is shared among as many customers as possible in order to benefit from potential cost savings on a per-subscriber basis.

As GPON technology provides 2.5 Gbps of aggregate downstream capacity, it does not seem to provide for longer term service growth and future subscriber demands given exponential growth in bandwidth demand. Furthermore, some proportion of the bandwidth has to be reserved for streaming services, reducing the bandwidth that can be shared statistically.

Encryption

As every PON effectively constitutes a shared medium, encryption is needed on all data streams.

GPON encryption is downstream only, and the use of the Advance Encryption Standard (AES) increases the privacy protection of end customers, and enhances the ability of service providers to prevent theft-of-service.

The fact that no encryption is applied in the upstream direction is based on the assumption that the directionality of upstream optical transmission will prevent any eavesdropping among endpoints on the same side of the splitter. However, studies have shown [1] that due to imperfections in the optical fiber plant (e.g., dirty optical connectors, bad splices,…), reflection of the unencrypted upstream signals toward the ONTs can deliver optical power levels high enough to be received by the other ONTs. As the key exchange is also unencrypted, the downstream code can be easily decrypted by an attacker.

Businesses with very strong privacy requirements, like financial institutions, usually strongly reject being connected to such a shared media structure.

High Operating Bit Rate

Due to the shared medium nature of PONs, every endpoint (ONT/OLT) has to operate at the aggregate bit-rate. Even if a customer has only paid for a 100 Mbps service, each subscriber ONT on that PON tree has to operate at 2.5 Gbps (GPON). Operating electronics and optics at 25 times the required bit-rate has cost implications, particularly where volumes are not very high.

High Optical Power Requirements

Every 1:2 power split causes a degradation of the power budget by 3.4 dB. Consequently, a 1:64 split degrades the power budget by 20.4 dB (equivalent to a power ratio of 110). Therefore, in this model all the optical transmitters in a PON architecture need to provide 110 times more optical power compared to an Ethernet FTTH point-to-point solution given the same distances to overcome. This is also the case for upstream transmission as the splitter attenuation is symmetric.

Local Loop Unbundling

Local Loop Unbundling (LLU) is a type of regulatory situation in some regions that exists for deployments of copper based networks today that opens up the access of the physical copper loops so that subscribers can choose alternate service providers. This approach has dramatically improved penetration of DSL services and reduced prices for broadband access services to subscribers.

PON networks do not easily support LLU regulations because there is only a single fiber connecting a number of customers which, consequently, cannot be distinguished on a physical level but only on a logical level (see **Figure 5**). As a result, PON architectures would only support wholesale bit stream types of offerings by the service provider rather than direct subscriber access through local loop unbundling. Most of the newer FTTH deployments in Europe explicitly are built with LLU regulations in mind, which opens up new business opportunities even if not currently mandated by regulators.

Flexibility of the allocation of customers to PON optical splitters can theoretically be achieved by combining the splitter with an optical distribution frame in a field cabinet, as shown in **Figure 6**. This option seems appealing when the take rate of customers is not easily predictable, such as in overbuild scenarios and when regulators enforce LLU requirements. In this latter case, the field cabinet accommodates a splitter per service provider to be served and its associated feeder fiber towards the POP. However, such flexibility comes at the cost of building and maintaining the optical distribution frame in the field, an operating expense. Every customer change would require a field technician to patch fibers in field cabinets.

Figure 5. PON Splitter Architecture Limits LLU

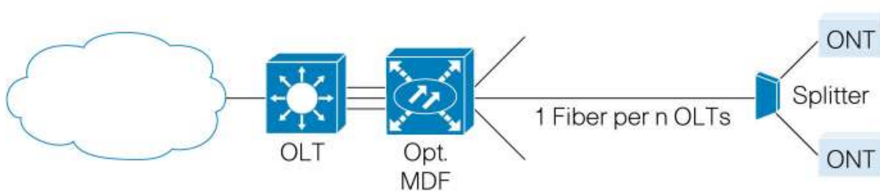
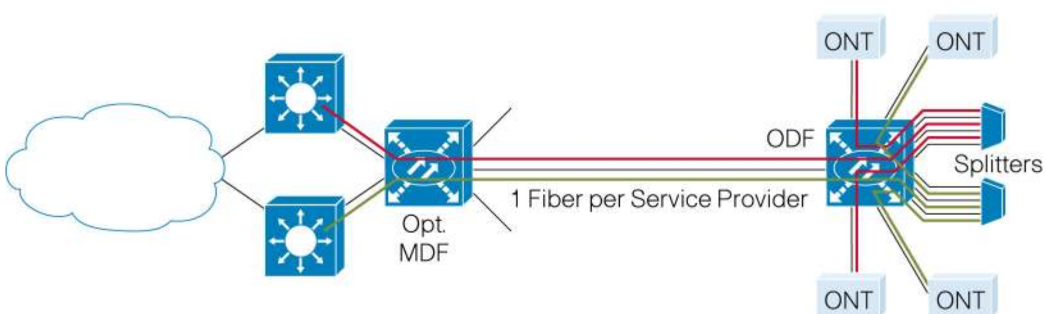


Figure 6. Fiber Plant with Optical Distribution Frame to Allow LLU



Subscriber Reach

Typical FTTH deployments involve connecting fiber to all potential customers in a neighborhood at the same time. In the case of PON, all those fibers are then connected to splitters and backhauled on feeder fibers to the central office/POP. Only after the deployment of all the fibers can customers subscribe for the FTTH service.

Service providers rarely reach a take rate that approaches 100 percent in residential service deployments. Usually, take rates are closer to 30 percent, which means that the PON structure is not well utilized and the per-subscriber cost of OLT equipment is increased considerably. One solution is the use of remote optical distribution frames, as discussed in the context of LLU. However, this equipment adds considerable cost that is usually not compensated by the improvement in PON utilization.

Troubleshooting and Maintenance

Passive optical splitters cannot transmit any failure indication to the network operation center. Therefore, any problem in the fiber plant between the splitter and the subscriber ONT is virtually impossible to locate even when using Optical Time Domain Reflectometry (OTDR) technology because fiber path discontinuities behind the splitter cannot be determined uniquely. This makes troubleshooting and isolation of fiber network issues very complex in a PON architecture which leads to increased operations cost.

Resilience

A corrupt ONT that happens to transmit continuous light into the fiber tree will take down the entire communication for all subscribers on that PON, and it is very difficult to track down the corrupt device. Even if such a failure can be prevented with a certain degree by some protection circuitry, this issue can be exploited by an attacker who can jam the entire communication on the tree just by transmitting continuous light into it.

This constitutes a typical Denial of Service (DoS) attack which has become a real problem in the Internet infrastructure and which can now easily be extended to the broadband access network in the case of PON.

Technology Migration

The variety of PON standards, starting with APON in 1995, that have evolved to BPON, EPON, and GPON is an indication for the dynamic growth of bandwidth requirements by subscribers and an attempt to meet these needs with yet another PON technology.

Service providers today already recognize the limitations of today's PONs, and standardization organizations (ITU-T and IEEE) are already working on the next generation PON standards. It is not clear today which path will be taken for a standard to allow 10 Gbps aggregate bitrate – whether it will be a TDMA system running at 10 Gbps or multiple GPON systems sharing the same infrastructure using CWDM.

At some point in the future, the deployed PON equipment will have to be upgraded to new technology with higher bandwidth capabilities. There is no co-existence of any existing PON standards on the same tree. For the migration from one PON technology to another one there are two options:

- Take an entire tree out of service, replace all the endpoints, and then place the structure back into service. As ONTs are usually located at subscriber residences without immediate access for the service provider, this migration process can represent a logistical and labor-intensive challenge.
- Use a wavelength division multiplexing (WDM) overlay to implement the new PON technology on the same fiber plant but on different wavelengths. As current PON receivers are not wavelength-selective, this requires wavelength filters to be inserted at all the endpoints before the migration begins.

While standardization discussions for TDMA-based PONs are ongoing, a new architecture starts to mature: DWDM PONs. This architecture provides point-to-point connectivity over a shared fiber tree by using Dense Wavelength Division Multiplexing (DWDM). Since these optical paths are technology neutral there are no inherent limits on the bitrates per customer. This technology is clearly targeted by today's FTTH providers who are currently deploying TDMA-based PON systems. In an interview at NXTcomm in June 2007, Verizon's CTO Mark Wegleitner said:

"We are looking beyond GPON with a three- to five-year timeframe. The next step will be a move to wavelength-division multiplexing (WDM), a technology that would give each customer its own wavelength to its home, which translates to about 1 Gbps for each individual household. WDM is ahead of us."

It can be said that WDM-PON combines the best of both worlds: being future-proof and flexible while allowing the service providers to deploy this technology in a sparse-fiber environment.

Benefits of Ethernet FTTH Architecture

The Ethernet FTTH network architecture solution has many business and operational benefits that should be taken into consideration when deploying residential and business services.

Virtually Unlimited Granular Bandwidth

A direct fiber can provide virtually unlimited bandwidth, which offers the ultimate flexibility for future service deployments as bandwidth needs increase.

Ethernet FTTH enables a service provider to guarantee bandwidth for each subscriber and to create bandwidth profiles in the network on a per-customer basis. Each residential or business user can be provided with any amount of bidirectional symmetric bandwidth that they desire at any time.

Long Reach

Typical deployments of Ethernet FTTH access networks use inexpensive single-fiber 100BASE-BX or 1000BASE-BX technology with a specified maximum reach of 10 km. To support longer distances, there are optical modules available on the market that allow for a higher optical budget, and also duplex fibers with Ethernet optical transceivers that may be inserted into any Ethernet line card interface. Very sparsely populated areas can be covered employing individual types of Ethernet FTTH optics without affecting other customers on the same Ethernet switch.

Flexible Growth

Only customers that have a subscription with their service provider occupy ports on the Ethernet FTTH access switch. In this case, as the customer base is growing, additional Ethernet line cards and customers can be added with a very fine granularity. In the PON architecture, instead, the first customer connected to a tree requires a more expensive OLT port and the associated cost per subscriber is only improved by adding customers to the same PON tree.

Technological Neutrality

Although current Ethernet FTTH deployments use Ethernet technology to connect the customers, this may not hold true for the next 30 to 40 years to come. But single-mode fiber is a medium that will be able to support any still-to-be-invented transmission scheme. Furthermore, in some special cases, fiber-based technologies like SONET/SDH or Fiber Channel are used to connect business customers. These technologies can easily be deployed over the same fiber plant as Ethernet FTTH and in many cases from the same Ethernet aggregation platform.

Bandwidth Migration

As the single-mode fiber is technology and bit-rate neutral, it is easy to upgrade any customer to some higher bit rate without affecting other customers. This means, for example, that a customer who has Fast Ethernet today can be upgraded to Gigabit Ethernet next year just by moving the customer's fiber to another switch port and by replacing only the Ethernet device on the customer's premises. All the other customers in the Ethernet FTTH access networks will be unaffected by this change.

Local Loop Unbundling

Physical local loop unbundling regulations are easily supported with the separate fiber per customer design of Ethernet FTTH architectures but are difficult to support in PON architecture due to the shared medium nature of the PON tree. The LLU aspect has been a major criterion for some of the new FTTH players in Europe as they are building networks where the subscriber access network fiber infrastructure must be made available to multiple service providers.

Security

On a physical level the dedicated fiber is the most secure medium today, particularly compared with any shared medium. In addition, Ethernet switches in service provider environments are purpose built to provide physical port level and logical customer separation capabilities with many robust security features that prevent virtually all infringements.

Customer Premise Equipment

Ethernet FTTH architectures employ simple customer premise equipment (CPE) devices that have sufficient intelligence to provide access network connectivity and the full range of services for each subscriber. These Ethernet CPE devices are usually deployed inside customer residences or apartments and are quite inexpensive.

In the PON architecture, the CPE device (ONT) is an integral part of the PON architecture because it cooperates in the operation of the shared medium. Beside the functions of the simple Ethernet CPE (integrated router/switch, VoIP support, management capabilities), the PON device must also support:

- The PON Media Access Control protocol
- Burst-mode lasers to ensure that the ONT only transmits at certain time slots allocated by the OLT
- High optical power (e.g., up to 20.4 dB higher than Ethernet optics)
- Decryption
- Very high speed

These additional functions make a PON ONT device inherently more expensive than an Ethernet FTTH CPE device deployed in a point-to-point scenario.

As GPON in particular is not a mature architecture, interoperability among OLTs and third-party ONT devices is desirable but not yet settled. This is similar to the situation that existed with ADSL technology during the early years of deployment.

Due to the security issues discussed above, it is typical for service providers to own and deploy the PON ONTs themselves rather than allowing subscribers to purchase cheap devices at a retail store, which might compromise the integrity of the access network.

Unless outdoor deployment is required, Ethernet FTTH CPE devices can be inexpensive off-the-shelf devices. Moreover, these do not create security issues as any undesired behavior can be detected quickly, and then the port on the access switch can be switched off. Service providers may still choose to own and deploy the Ethernet CPE to ensure consistent service characteristics across their networks, but they are not forced to do so by the technology employed.

The functionality of CPE devices in residential environments tends to follow the pace of consumer equipment development cycles. If a PON ONT includes similar functionality, it will require the service provider to deploy new ONTs at the same pace. To avoid the labor costs related to the replacement of CPEs, it may prove more effective to separate Ethernet CPE and PON ONT and allow the customer or service provider to easily replace the CPE. Although such a model also exists for Ethernet FTTH deployments, it is not mandated by the technology. Instead, with growing penetration of this technology a large variety of CPEs will become available that customers can purchase and connect at their own discretion.

Operational Expense

For businesses considering FTTH deployments, the ongoing operational expenses play a significant role, along with the civil construction costs, whereas the capital expense associated with the electronic equipment and fiber, and their associated installation costs account for a smaller portion of the project costs. Though there is little data available that would allow a direct comparison between the architectures, there is evidence that the operational cost for an Ethernet FTTH deployment is less than that for PON FTTH architectures. Table 2 provides a summary of the most important aspects.

Table 2. Operational Expense-Related Issues of Architectures

Issue	Point-to-Point	PON
Resource planning in access	Simple: dedicated fiber	Complex: shared medium, subscribers mutually dependent
Engineering rules	Simple: dedicated fiber	Complex: needs to work for all numbers of customers per PON tree
Fiber troubleshooting	Simple: failure uniquely located through reflection measurements	Complex: location of failure behind splitter difficult to identify
Encryption key management	Not needed	Required
Bandwidth efficiency	Optimal: no restriction	Restricted: control protocol overhead (guard times)
Bandwidth/technology upgrade	Simple: can be done on a per-customer basis	Complex: replacement of all active equipment at once or wavelength overlay
Customer turnover	Switch over to other service provider with optical distribution frame (LLU) or configuration change (wholesale)	Configuration change (wholesale)
Connecting a new subscriber	Patch at optical distribution frame and configuration of switch, compensated by capital savings	Configuration of OLT
Outage after cable break	Longer in the feeder part (more fibers to splice), shorter in the drop part (easier diagnostics)	Shorter in the feeder part (fewer fibers to splice), longer in the drop part (difficult diagnostics)

One of these not previously discussed is the impact of cable breaks due to construction work. From an Ethernet FTTH perspective, the worst case is represented by a break of a large cable with several hundred fibers in the feeder part of the access network. Compared to a cable carrying PON traffic, which typically requires fewer fibers, it will take longer to have this cable repaired. This, however, is not different from the situation in today's copper networks, which are also built in a star topology. These types of outages occur very rarely because service providers understand how to protect these valuable assets. Furthermore, this problem can be mitigated by distributing traffic over a larger number of smaller cables, which can be spread over a wider area so that the cut of a single cable affects a relatively small number of customers. Fiber ribbon technology also helps to mitigate this problem as those cables allow splicing of an entire ribbon (i.e. 24 fibers) at once, reducing repair times considerably.

In addition, it has to be considered which proportion of the fiber plant constitutes the feeder part and which one is related to the drop part. In most deployments the drop part is spread over a very wide area, which means that the probability of a cable cut there is significantly larger than in the feeder part. From a topology perspective, in this part of the access network there is no difference between the architectures. Troubleshooting in this area, though, is more difficult in a PON architecture because measurements using OTDR are much more complex in a PON.

Summary

Fiber-based access networks are being deployed today based on different architectures and technologies. Mature standards for these technologies and availability of the necessary equipment allow for a low-risk deployment of service provider networks. Their success creates considerable dynamics in the industry. It can be expected that competitive pressure from these networks will cause the incumbent service providers to invest more in fiber-based access networks.

In North America, incumbent service providers (most notably Verizon) are deploying PON technologies, primarily due to their existing infrastructure, consolidation, potential reduction of many POPs, and projected high take rate for multiple services from subscribers. In Japan, EPON is currently the most deployed architecture, mainly because virtually all the deployment in Japan is aerial, which restricts the size of the cables that can be deployed.

Elsewhere in the world, particularly in Europe, deployments are mainly based on Ethernet FTTH in point-to-point topologies and Ethernet ring deployments. At this point, PON architectures have made little headway in Europe because most European FTTH projects have been driven by municipalities, utilities, and housing companies. Key factors in many Ethernet FTTH deployments are the flexibility of the business model and the ability to support future services.

Fiber deployment to residences is a huge investment that should last for the next 30 to 40 years. Although every deployment scheme for FTTH has its own merits, there is a high risk that short-term savings in the fiber infrastructure from PON FTTH deployments will significantly impact the future use of the expensive fiber infrastructure without major follow-on investments.

Point-to-point fiber deployment should clearly be the preferred solution due to its obvious advantages. Tree-shaped fiber topologies should only be used where there are compelling reasons to save fiber or some real estate for fiber management in the POPs. Looking ahead DWDM PONs appear to be the most attractive way of utilizing a tree-shaped fiber topology instead of TDMA-based mechanisms.

Overall, the discussion is no longer about whether FTTH will happen, but only about when and at what pace.

References

[1] David Gutierrez, Jinwoo Cho, and Leonid G. Kazovsky, **"TDM-PON Security Issues: Upstream Encryption is Needed,"** *Proceedings of IEEE/OSA OFC 2007, Mar. 2007.*

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