FTTH Standards, Deployments and Research Issues

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Abstract

In this paper we investigate the current status of Fiber-to-the-Home Passive Optical Networks. We start by reviewing the driving forces behind the push for broadband from the customer and service provider sides. PONs are currently preferred for new FTTH deployments for a variety of reasons; we review their standards, new technologies and deployment plans in the United States, Japan and Korea. We then describe SUCCESS-HPON, a next-generation optical access architecture that allows a smooth transition from TDM to WDM-PON. We finalize by summarizing what we believe are the main open research issues in this area.

Keywords: FTTH, PON, WDM-PON.

1. Introduction

The driving forces for Fiber-to-the-Home/Curb/Node (FTTX) technologies in the telecom business can be better understood by briefly reviewing the history of broadband access. Traditionally, the two most common electronic communication services have been standard analog broadcast or cable TV and Plain Old Telephone Service (POTS). These two services were provided by separate infrastructures that coexisted peacefully for many years. The advent of the WWW created a marked increase in the demand of home data communication services. Starting about a decade or so ago, ILECs and MSOs started satisfying this demand in the form of Internet dial-up and DSL services the former, and HFC cable-modem services the latter, and thus started competing directly for customers.

The bandwidth offered by DSL and HFC networks has been enough for users' demands for now. However, the nature of the traffic that flows through the Internet is changing. New applications require higher bandwidths, support for constant-bit-rate (CBR) streaming media, symmetric data rates (e.g., for peer-to-peer file transfer), low delay for interactive applications and security. The Internet, originally designed to provide a best-effort service and make use of statistical multiplexing, will need many architectural upgrades in order to accommodate these new demands [1].

One of the main current Internet issues is the last-mile bottleneck. While data rates in LANs, MANs and WANs range in the 100 Mbit/s - 10 Gbit/s, in broadband access they range in the 100 Kbit/s to a few Mbit/s. This bottleneck prevents the development of high-bandwidth interactive consumer services.

ILECs, MSOs and others are all looking into ways to satisfy new broadband access demands. The Holy Grail is two-fold: First, have Fiber-to-the-Home (FTTH) connectivity to the customer premises; then, be able to provide voice, video and data, the so-called *triple-play*, over this single media. The ways to attain this Holy Grail are not at all clear, given intense competition, varying regulation and the uncertainty of customer take-rates [2]. New technologies, such as vDSL2 and WiMax, increase the array of possibilities, but also the uncertainty on the best way to proceed. It is clear, though, that none of these other technologies can provide the bandwidth that fiber does, making it the ideal medium for high-bandwidth applications and/or as the backhaul of wireless and DSL networks.

Several technologies can be used for FTTX. The most straightforward, but most expensive, is through a point-to-point (P2P) network with active components from the Central Office (CO) to the premises. Limited deployments have used this technology (e.g. in Japan), but its costs are high: P2P networks need a separate fiber for each user and/or maintenance of the active elements in the distribution network.

A good fraction of the installation and maintenance costs of access networks is due to active elements, when they are present. Because of this, Passive Optical Networks (PONs), those in which the distribution network has only passive elements, are currently viewed as the best alternative for FTTX. Most of the operating costs of the ILECs currently come from copper network maintenance; some argue that ILEC's operating costs can actually be reduced by aggressively deploying FTTH [3].

2. PONs

PONs have a tree topology in order to maximize their coverage with minimum network splits, thus reducing optical power loss. This is important, since a passive distribution network has no amplifiers or regenerators.

There are three standardized versions of PON: Ethernet PON (EPON), Broadband PON (BPON) and Gigabit PON (GPON). They all use two wavelengths, one for downstream and one for upstream data traffic. These wavelengths are time-shared among users, making them Time Division Multiplexed PONs (TDM-PONs). The total bandwidth available per user is thus limited by this time-sharing, especially if the connection is going to be used for CBR applications. A third wavelength can optionally be used for downstream analog video broadcasting (RF).

Wavelength Division Multiplexing (WDM) can be used in PONs to increase the overall throughput. The cost is, however, usually much higher due to the use of tunable and wavelength-sensitive optical components. WDM-PONs are regarded as the next step after TDM-PONs, and are currently mostly in research phase. Korea Telecom (KT) has, however, announced the launch of a 100Mbit/s WDM-PON in 2005. Table 1 compares some of the key characteristics of PONs.

	EPON	**BPON**	**GPON**	**WDM-PON**
Standard	IEEE 802.3ah	ITU G.983	ITU G.984	None
Framing	Ethernet	ATM	GFP/ATM	Protocol Independent
Maximum Bandwidth	1 Gbit/s	622 Mbit/s	2.488 Gbit/s	1-10 Gbit/s per channel
Users/PON	16	32	64	100's
Average Bandwidth per User	60 Mbit/s	20 Mbit/s	40 Mbit/s	1-10 Gbit/s
Video	RF / IP	RF	RF / IP	RF / IP
Estimated Cost	Lowest	Low	Medium	High

Table 1. PON Comparison.

2.1. BPON and GPON

In 1995, North American operators joined efforts in the FSAN committee to draft standards for PONs. The results of their efforts were later standardized by the ITU in the G.983 and G.984 recommendations.

The underlying transmission technology for the first set of standards is ATM cell-based. Because of this, they were at first named ATM PON (APON). The name was later changed to Broadband PON (BPON) to emphasize that they were not limited to ATM traffic. The BPON standards specify from the physical layer all the way up to OAM. The maximum speeds are 622 Mbit/s downstream and 155 Mbit/s upstream. Many manufacturers, including AFC, Alcatel, Calix, Motorola and Terawave, currently produce BPON products.

Since the encapsulation of IP traffic in ATM cells creates a high overhead, or *cell-tax*, and in an effort to make a more flexible standard, GPON was developed. In GPON, the encapsulation is done using the Generic Framing Protocol, a flexible method for both bursty and CBR traffic. The GPON standards are in development, having the physical and transmission layers already well defined. Since the OAM and other higher-layers have not been defined yet in the standards, operators are reluctant to deploy them for now. Flexlight and Optical Solutions are some of the current manufacturers of GPON equipment.

Deployments. Most of the North American operators have been involved in the development of the BPON and GPON standards. In their announced current and future FTTX deployments, they plan to use equipment based on these standards, because of their flexibility to support CBR applications and to adapt to their previous TDM-based infrastructure (e.g., T1 lines).

Verizon, SBC and Bellsouth issued a joint request for FTTX proposals in late 2003. Bellsouth has opted for FTTC deployments with Gigabit Ethernet (GigE) feeder links instead of PONs; SBC has decided to go for B/GPON FTTH in new housing complexes, while deploying GigE FTTN+DSL in existing units. Verizon has decided to go for B/GPON FTTH in all cases. SBC expects to have 1M B/GPON FTTH and 17M FTTC+DSL customers by 2007. Verizon had 1M customers passed by the start of 2005, and expects to have 3M by year's end, but the take-rate is not public.

In Japan, NTT had been deploying BPON for some years and it actually had about 100k customers by 2004. However, NTT intends to shift its customers to EPON for reasons explained below.

2.2. EPON

A separate PON standardization effort was started based on the IEEE Ethernet protocol. The idea here was to make use of the huge base of low-cost Ethernet designs to allow for simpler, less expensive technology to be used in PONs. The downside is that Ethernet is mostly engineered for bursty data and not for CBR or TDM services. EPON was developed and formalized in the IEEE 802.3ah standards. The scope of these standards is limited to the physical transmission layer and thus the interoperability of the higher layers is not guaranteed. The maximum rate for EPON is nominally 1.25 Gbit/s, but due to the use of 8B/10B coding, it is effectively 1 Gbit/s.

Deployments. Companies such as Alloptic, Centillium, Passavé and Teknovus produce EPON products, mostly for the Asian market. In Japan, both NTT and KDDI needed, due to intense competition, to deploy Gigabit FTTH services and could not wait for the GPON standards to be fully developed. In addition, providing broadcast video or POTS services is not a top priority for them due to regulation issues. Thus, they decided to shift to EPON for new and old customers. NTT has currently about 1M FTTX subscribers (including PON and P2P), which are going to be progressively switched to EPON.

2.3. WDM-PONs

WDM-PONs, as we mentioned above, use expensive components and, unlike long-haul networks, their cost is shared by only a few tens of users per network. However, they can provide Gbit/s rates to each user, which TDM-PONs cannot. The issue is how to do this in a cost-efficient manner.

Deployments. In Korea, current vDSL systems provide 54 Mbit/s. The Korean government has a residential Internet connectivity rating system. In order to attain higher home connectivity ratings, KT has decided to go for 100 Mbit/s guaranteed per user with WDM-PONs, with a service scheduled to start later in 2005. The details of their architecture are not public.

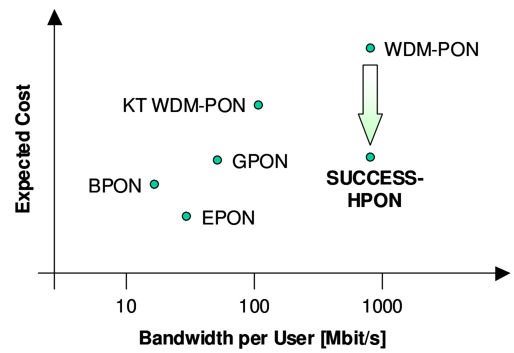

Figure 1. Relative costs and bandwidths of PONs.

2.4. Hybrid TDM/WDM-PONs

The deployment of TDM-PONs has started. It is expected that by 2009 the number of users will be more than 10M worldwide [4]. Given this installed base and the increasing bandwidth demands, the issue will be how to migrate to WDM-PONs in a flexible and cost-efficient manner. Some Hybrid TDM/WDM-PONs have been proposed, including Samsung's Hybrid PON [5] and Stanford's SUCCESS-DWA [6] and SUCCESS-HPON [7]. In this paper we will discuss the latter.

2.4.1. SUCCESS-HPON

The Stanford University aCCESS - Hybrid TDM / WDM-PON [7], or SUCCESS-HPON, architecture provides a smooth migration path from TDM to WDM-PONs. Figure 1 illustrates the place of SUCCESS-HPON among other PONs: it provides bandwidths comparable to regular WDM-PON, but at lower costs. This is achieved by (1) eliminating the need for lasers at the customer's premises and (2) sharing tunable components at the CO.

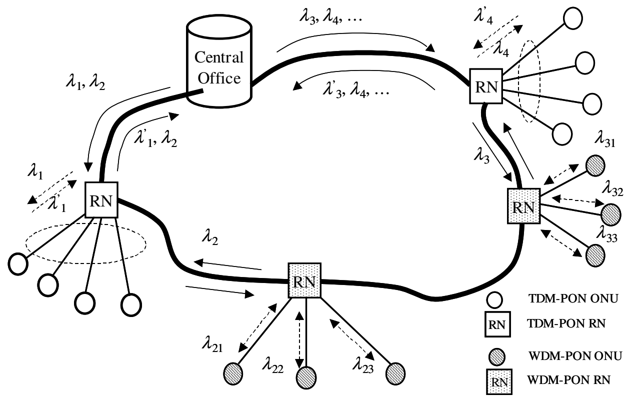

Figure 2. SUCCESS-HPON Architecture.

In SUCCESS-HPON (Figure 2), the need for fixed or tunable lasers at the customer's WDM Optical Network Units (ONUs) is eliminated by sending a continuous wave (CW) from the CO in which to modulate the upstream data. Avoiding the need of lasers, especially tunable ones, makes the ONUs considerably less expensive. There are several options for modulating the CWs at the ONUs. We propose to use Semiconductor Optical Amplifiers (SOAs), under the assumption that their potential integration with the electronics will decrease costs further.

Tunable lasers and receivers at the CO are shared by all the network users for both downstream and upstream data traffic. This allows decreasing the total amount of components needed. This approach is scalable, since the number of components can be gradually increased as new customers join the network. Sharing these components is not easy; in order to do so effectively, innovative scheduling algorithms were developed [8].

3. Open Research Issues

In FTTX PONs, issues similar to those that arise in other networks, such as QoS, fairness, security and reliability, are present. Beyond these issues, however, there are some that are particular to access networks.

TDM-PONs. The EPON standards specify only the network's physical layer; the algorithms and protocols used to assign bandwidth to the users, ensuring fairness and QoS, are left open to the implementer. Considerable work has gone into developing Dynamic Bandwidth Allocation algorithms for this. A separate issue is how to provide open access for multiple ISPs to share the same fiber infrastructure when the local legislation requires it.

Large-scale IP Video Networks. As discussed above, some service providers plan to deploy large-scale IP video networks to provide HDTV and VoD services. Even though this has been done in limited-size trials, the concept of a national IP video network is new and challenging. Some have suggested that the ideal situation is a combination of analog and IP video [9] (this also depends on legislation and copyright issues). Some of the technical difficulties lie in the deployment of scalable multicasting protocols, mapping multicast groups to conventional video channels and the development of inexpensive integrated set-top boxes.

Integrated ONU / Wireless Base Station / Home Gateway / DSLAM. The integration of various components provides an opportunity to develop combined scheduling algorithms and MAC protocols that take into account multiple interfaces and users to optimize performance. Research on architectures, protocols and algorithms for such an integrated unit will be very valuable.

Hybrid TDM/WDM-PON Architectures. To provide a smooth transition from TDM to WDM, the proposed network architectures will most likely need to efficiently share expensive tunable components. In the case of SUCCESS-HPON, by sharing the most expensive components, the overall cost of the network decreased; however, this increased the computational complexity of the system. This tradeoff between number of components and computational complexity is an issue of further research.

WDM-PON. Research that lowers the cost of devices that are passive and WDM functional (e.g., athermal AWGs) and that facilitates the integration of optics with electronics (e.g., SOAs in an ONU) is very important. As in the case of Hybrid TDM/WDM PONs, how to select which devices to share and how to share them with fast scheduling algorithms is also a matter of further research.

4. Concluding Remarks

There are many possible approaches for FTTX, in terms of technologies used, fiber reach and services provided; each country also has a particular legislation that affects the best local choices. This variety of approaches and the uncertainty of customer take-rates make it difficult for U.S. service providers to promptly commit to invest in large-scale deployments, slowing down FTTX penetration. However, it is acknowledged that given the bandwidth limitations of DSL and wireless solutions, fiber optic access will probably become commonplace, even if it takes longer than expected.

Once the bandwidth demands exceed the capacity of TDM-PONs, there will be a need to move to WDM-PONs. We have discussed the proposed SUCCESS-HPON architecture, which provides a smooth transition path from TDM to WDM-PON in a scalable and cost-efficient manner.

There are still many open research issues in both TDM and WDM-PONs, ranging from devices and systems integration to scheduling algorithms and communication protocols. These issues, added to the increasing residential bandwidth demands and competition among service providers, create a fertile ground for further research work with an industry impact.

Acknowledgements

The authors would like to thank STMicroelectronics, Stanford's SNRC F/M/A program and OIDA's PTAP program for their support.

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