Advances in Optical Access Networks

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Abstract: EPON standard (IEEE 802.3ah) only covers physical and data link layers; the rest is considered out-of-scope. This article explores several interesting research problems brought forward by EPON architecture, but left out by the standard.

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1. Welcome to the First Mile

For incumbent telecommunications operators, the access portion of the network always remained the "last mile", unambiguously reflecting its peripheral location in the grand scheme of all telecom things. The last mile was a virtual telecom backyard, unattended, always hidden from views, and not worthy showing to a houseguest or a traveling Wall Street analyst, for that matter. It is not surprising that the last mile has never received proper attention or sufficient investment.

This dereliction and unsatisfied subscriber's demand for new services attracted a new breed of players - companies traditionally involved in data communications. These companies envision a global networking environment with multiple services, such as telephony, video, data and many different flavors of each service, are carried in the digitized format over a single network by a single protocol. For these companies the access network becomes just the first mile in the datacom expansion into the telecom world. Understandably, the networking community has renamed this network segment to the *first mile*, to symbolize its priority and importance.

2. PONdemic is coming!

PONs have been considered for the subscriber access network for quite some time, even before the Internet spurred bandwidth demand. One of the first papers describing telephony PON was published by British Telecom researchers in 1988 [1]. Several alternative architectures for PON-based access networks have been standardized by several standards bodies, one of the main differentiating factors being the choice of the bearer protocol. Currently, standardized specifications exist for ATM-based PON (APON and BPON), Gigabit-capable PON utilizing Generic Framing Procedure (GPON), and Ethernet PON (EPON).

2.1 APON/BPON

In 1995, several major network operators formed Full Service Access Network (FSAN) initiative with a goal of creating a unified specification for broadband access networks. FSAN members developed a specification for ATM-based PON. In 1997, based on FSAN proposal, the ITU-T adopted Recommendation G.983.1, which specified APON architecture with a symmetrical 155 Mbps upstream and downstream bit rates. This specification was amended in 2001 to allow asymmetrical 155 Mbps upstream and 622 Mbps downstream transmissions, as well as symmetrical 622 Mbps transmission. This architecture is commonly referred to as Broadband PON (BPON).

2.2 GPON

In presence of ever-growing traffic volume, FSAN group has realized the need for architecture capable of higher bit-rate and improved efficiency for data traffic. However, the physical layer specification adopted for BPON made it quite difficult to achieve upstream bit rates above 622 Mbps. ATM-based PON also is inefficient for IP traffic. To overcome these limitations, in 2001, FSAN started a new effort to specify a PON system operating at bit rates exceeding 1 Gbps. The group has directed its attention to Generic Framing Procedure as a means to improve efficiency, while allowing a mix of variable-size frames and ATM cells. Based on FSAN recommendations, in 2003-2004, ITU-T has approved the new *Gigabit-capable PON* (GPON) series of specifications.

2.3 How EPON is different

Among the existing PON specifications, EPON is the only access network architecture that traces its ancestry not to public communications, but to private enterprise data networks. EPON is standardized by IEEE 802.3 work group – a group that reigns the LAN world, but has not ventured much beyond it. Ethernet in the First Mile was its first such attempt – a reconnaissance mission into yet unknown territory. It is not surprising that a great many things were done differently then they are traditionally done in the telecom world.

Both BPON and GPON architectures were conceived by the FSAN group, which is driven by major incumbent telecommunications operators. Most of the operators are heavily invested in providing legacy TDM services. Accordingly, both BPON and GPON are optimized for TDM traffic, and rely on framing structures with a very strict timing and synchronization requirements. Table 1 compares the bounds on physical layer overhead in BPON, GPON, and EPON. Very tight bounds in BPON and GPON require high-speed laser drivers. Also, to adjust the receiver gain within the allotted interval, BPON and GPON must reduce the dynamic range of the signal. They do so by adjusting ONU's power output, so that the levels of signals received at the OLT from different ONUs are approximately equal.

Table 1: Components of physical layer overhead.

	Laser on/off	**AGC**	**CDR**
BPON	≈ 154 ns		
GPON	≈ 13 ns	44 ns	
EPON	512 ns	≤ 400 ns	≤ 400 ns

In EPON, the main emphasis was placed on preserving the architectural model of Ethernet. No explicit framing structure exists in EPON; the Ethernet frames are transmitted in bursts with a standard inter-packet gap between the frames. The burst sizes as well as physical layer overhead are large in EPON. For example, the maximum AGC interval is set to 400 ns, which provides enough time to OLT to adjust gain without ONUs performing power-leveling operation. As a result, ONUs do not need any protocol and circuitry to adjust the laser power. Also, the laser on and off times are capped at 512 ns, a significantly higher bound than in GPON. The relaxed physical overhead values are just a few in a row of many cost-reducing steps taken by EPON. The IEEE 802.3ah task force believes that keeping the complexity and cost low and not over-specifying the standard will enable EPON to enjoy the same success and proliferation in access environment as its predecessors had in corporate LANs.

3. What's cooking?

Owing to the ample capacity available in FTTH systems, high-quality, new broadband services are emerging. For example, in Japan, KDDI is offering high-speed Internet connections, high-grade IP telephony, DVD-grade multi-channel broadcasting and video on demand (VOD) in their FTTH service called "*Hikari Plus*." In this service, a subscriber can view 30 channel broadcasting TV programs supported by the IP multicast technology and more than 2,000 VOD programs, such as Hollywood movies. On-line karaoke service is also available. Due to the stable, low latency and low bit error ratio characteristics of optical fiber transmission, the quality of this IP telephony is as good as that of the existing PSTN. In fact, high-grade video telephony can also be easily expected using FTTH systems in the near future. Another example of a novel service in Japan is the distribution of new DVD-contents to in-home DVD recorders through FTTH systems, which has been field-tested by Poweredcom, Toshiba and Tokyo Electric Power Company.

Advent of gigabit-capable optical access networks accelerates the growth of broadband services, and EPON systems are being considered a key piece of infrastructure for future full-fledged FTTH services. For example, In Japan, NTT has recently announced that they will increase the number of their FTTH customers to 30 million by 2010 by using the gigabit EPON technologies, and many other telecom carriers, such as KDDI, Softbank BB and K-Opticom, and CATV operators will also provide their FTTH services by using the gigabit E-PON technologies.

4. The road ahead

The Ethernet in the First Mile task force has completed its charter in June 2004, culminating in ratification of IEEE 802.3ah Standard. Unlike other standards bodies, IEEE 802.3 only specifies a small portion of a communications system (only physical and data link layers); the rest is considered out-of-scope. Active academic and industrial research is fueled by a number of interesting challenges brought forward by EPON architecture, but left out by the standard.

3.1 Open access

An increasing number of access networks are now being built by *neutral* access networks operators (NANO), such as municipalities, or utilities providers. These NANOs intend to attract multiple service providers (SP), which would provide multiple and different services. Some SPs may provide only voice-based services, while others may specialize in video and conferencing.

Such open access networks should be designed to serve individual and non-cooperative users and *independent and non-cooperative service providers*. It is likely, that in the future, such SPs will also provide aggregate billing for rendered services, and they will forward a fraction of the payment to NANOs. As such, NANOs are faced with contradictory and may be even mutually-exclusive requirements: (1) SLA should be provided per user in order to ensure acceptable services, and (2) SLA should be given to SPs because SPs pay to NANO for access. Add to this a possibility of users simultaneously accessing multiple SPs and dynamic user migration, and we have a very rich and involved research problem.

3.2 Global fairness

Many existing DBA algorithms for EPON assume that total bandwidth available in EPON is 1 Gbps and is constant. However, it is highly unlikely that the CO's uplink capacity will be sufficient to serve each EPON with full 1 Gbps. Figure 1 illustrates a more realistic setup – a number of OLTs will be connected through a switch to a single 10 Gbps uplink. This configuration immediately raises several questions. Can the OLT DBA handle variable bandwidth available to it? The issue of ensuring fairness across all users in the same EPON was addressed in [2]. But can the switch enforce fairness among subscribers served by different EPONs?

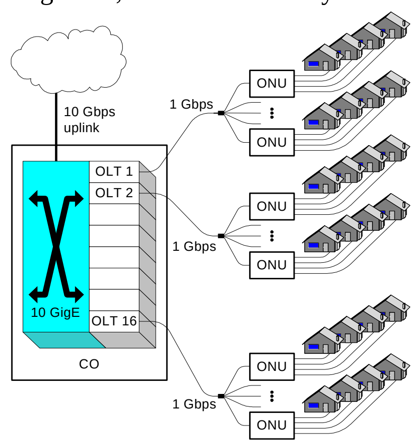

Figure 1: Bandwidth aggregation in access network.

3.3 Upgrading EPON

By the amount of bandwidth it makes available to subscribers, EPON is a giant leap compared to currently mass-deployed technologies. But if EPON is successful and more bandwidth-intensive services become available to and demanded by users, this capacity will unavoidably get exhausted. For example, one gigabit capacity will not be large enough to accommodate more than 100 HDTV broadcasting channels. It is, therefore, crucial for the success of EPON technology to provide a smooth path for future upgrades. There are several possible upgrade scenarios.

In a *wavelength-upgrade* scenario, some of the EPON ONUs will migrate to new wavelengths for both upstream and downstream traffic. While the data rate on each wavelength will remain the same, there will be fewer ONUs to share that bandwidth capacity. This procedure can be repeated again in the future and eventually will lead to a WDM PON system where each subscriber is allocated its individual wavelengths.

With the finalizing of the 10 Gbps Ethernet standard by the IEEE, *rate upgrade* appears as an attractive solution. To allow incremental upgrade cost, only a subset of ONUs may be upgraded to operate at higher rates. Thus, the rate-upgrade scenario will call for a mixed-rate EPON where some ONUs operate at 1 Gbps, and some at 10 Gbps.

In a *spatial-upgrade* scenario, some ONUs migrate to a new PON (i.e., some branches are re-connected to another trunk). Thus, a 1×32 EPON may become two 1×16 EPONs, and so on, eventually leading to a point-to-point architecture with an independent fiber running to each subscriber.

3.4 Protection

In some critical deployments, access network may require fast protection switching. To achieve this, a certain path redundancy should be added to a PON by providing several alternative, diversely routed paths. Dissimilar access environments, such as campus, MDU, or single-residence, may require different protection schemes. Redundancy may be added to an entire PONs topology (i.e., duplicated tree), or to only a part of the PON, say the trunk of the tree, or the branches of the tree. How should protection be done in an efficient and economical manner?

Another important issue is protection from malicious user or misconfiguration. Path transparency is an important future-proving factor for PON, and at the same time, it is a handicap. Consider a situation when instead of an ONU, a simple media converter is connected to EPON. This device will keep its laser on all the time, possibly inhibiting all upstream communications from other ONUs. How can network operator detect at which location this device is connected? And, consequently, since the access to the culprit device may not be available, how can network operator disable such device remotely? Very little research is done in this direction.

References

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