# What is Next for Ethernet PON?

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**Abstract**

Standardized in 2004, EPON has emerged as a highly successful technology – 3 million lines has been deployed in less than 2 years. The next generation of EPON will bring 10 Gb/s bandwidth to access networks.

## 1 Brief history of EPON

In 2003, the Ethernet protocol celebrated its 30th birthday. All these years it has been adapting and evolving to become the very inexpensive and ubiquitous networking protocol that we know it today.

In January 2001, IEEE formed a study group called Ethernet in the First Mile (EFM). This group was chartered with extending existing Ethernet technology into the subscriber access area, focusing on both residential and business access networks. Keeping with Ethernet tradition, the group set a goal of providing a significant increase in performance while minimizing equipment, operational, and maintenance costs. Ethernet Passive Optical Networks (EPONs) became one of focus areas of EFM.

Ethernet PON is a PON-based network that carries data traffic encapsulated in Ethernet frames as defined by the IEEE 802.3 standard. Where possible, EPON utilizes the existing 802.3 specification, including usage of the existing 802.3 full-duplex Media Access Control (MAC).

## 2 Various PON architectures

There exist several standards for PONs:

- *BPON* – Broadband Passive Optical Network specification was developed by FSAN and standardized by the ITU-T (recommendation G.983) over the period 1998-2003. BPON uses ATM as a bearer protocol.
- *GPON* – Gigabit-Capable Passive Optical Network was standardized by ITU-T G.984 in 2003-2004. It is based on unique derivative of the Generic Framing Procedure (G.7041)
- *EPON* – Ethernet Passive Optical Network was developed by the IEEE and standardized in June 2004. EPON uses Ethernet and Multi-Point Control Protocol.

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 very strict timing and synchronization requirements.

In BPON, an upstream frame consists of 53 timeslots, were each timeslot comprised of one ATM cell and 3 bytes of overhead. When two consecutive timeslots are given to different ONUs, these 3 bytes, or approximately 154 ns, of the overhead should be sufficient to shut down the laser in the first ONU, turn on the laser in the second ONU, and perform gain adjustment and clock synchronization at the OLT.



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Similarly, very tight timing is specified for GPON. For example, in GPON with 1.244 Gbps line rate, only 16 bit times (less than 13 ns) are allocated for the laser-on and laser-off times. Such short intervals require more expensive, higher-speed laser drivers at the ONU. Similarly, a very tight bound of 44 bit times (less than 36 ns) is allotted for the gain control and clock recovery. In many cases, the dynamic range of the signal arriving from different ONUs will require a longer AGC time than the allotted overhead (guard interval). To reduce the range of necessary gain adjustment, BPON and GPON perform a power-leveling operation in which the OLT instructs individual ONUs to adjust their transmitting power so that the level of signals received by the OLT from different ONUs is approximately equal.

In the IEEE 802.3ah task force, a subject of selecting EPON PHY timing parameters, such as laser turn-on and turn-off times, and gain control time required a technical discussion lasting almost a year. The task force has considered several alternatives for burst-mode timing specification, including a proposal to use very short laser-on, laser-off, AGC, and CDR time intervals, similar to GPON spec.

After extensive analysis the task force has decided to take an approach different from GPON specification and has settled on relaxed timing parameters, arguing that this would lead to higher component yields, and therefore would lower the costs. The IEEE 802.3ah standard specifies the following parameters: laser-on time = 512 ns, laser-off time = 512 ns, and a gain adjustment time ≤ 400 ns (negotiable). The reasoning was that the ONUs, being mass-deployment devices, must be as simple and inexpensive as possible. For this, the PMD components should have high yield and should not mandate implementation of digital interfaces, which otherwise would be mandatory if ONUs were required to negotiate laser on/off times. The OLT device can be more expensive as only a single device is used per EPON network. Therefore, the OLT is allowed to negotiate and adjust its receiver parameters such as the automatic gain control (AGC) time.

Time has shown that the relaxed physical specification of EPON to be one of the most important and insightful decisions made by the EFM task force. There are many suppliers for EPON optics, the performance and yield are increasing while the cost decreasing. At the same time, suppliers of GPON transceivers are struggling with the more demanding optical requirements on the ITU-T specification [1, 2].

## 3 Myths and Facts about EPON

In the literature, there have been many claims about EPON's shortcomings compared to alternatives, especially GPON. Most of these claims are simply a result of misunderstanding of IEEE 802.3ah standard specification. In reality, IEEE 802.3ah provides a quite flexible EPON specification that allows and expects future extensibility and improvements.

### *3.1 Maximum Distance and Split Ratio*

There have been some incorrect claims that the EPON specification has a maximum distance and a split ratio that are inadequate deployments in access networks.

The first step in understanding the EPON specification is to look at the objectives that the EFM task force established for self- guidance. Related to EPON, these objectives were:

*Provide a family of physical layer specifications:*

- *PHY for PON, >= 10km, 1000Mbps, single SM fiber, >= 1:16*
- *PHY for PON, >= 20km, 1000Mbps, single SM fiber, >= 1:16*

In simpler terms, this means that the task force's objective was to produce a specification for the physical layer of a PON, supporting distances of *at least* 10 km, using single strand of a single-mode fiber for bidirectional communications, and supporting *at least* a 1:16 split ratio. The second item specifies a separate physical-layer specification that supports *at* *least* a 20 km distance, all other parameters being the same. In the IEEE Std. 802.3, these physical layers are referred to as 1000BASE-PX10 and 1000BASE-PX20.

It is important to understand that the IEEE 802.3ah specification only defines a minimum boundary that a PON device should achieve to be considered standards-compliant. A performance exceeding the minimal level is acceptable. In fact, today most EPONs are deployed with a 1:32 split ratio, with some trials done for 1:64 or even 1:128 split ratios.

*The physical layer specification in EPON does not limit the maximum distance or the maximum split ratio. The physical layer performance is dependent on the state of the art for optical transceivers and is improving as this technology matures. No physical phenomenon limits the split or distance in EPON more than it limits them in GPON.*

In addition to physical layer specifications, PON systems require arbitration protocols to provide the necessary connectivity and resource allocation in a point-to-multipoint environment. These arbitration protocols may and sometimes do limit the split ratio and maximum distance of the PON. Table 1 shows a few such *logical* parameters: *maximum logical reach* (distance to the farthest ONU), *maximum logical range* (distance differential between the farthest and the closest ONUs), and *maximum logical split ratio*. It can be seen that the GPON protocol specification imposes stricter constraints on the distance and the split, compared to that of EPON.

**Table 1: Protocol constraints in GPON and EPON**

| | GPON | EPON |
|---|---|---|
| Max Logical Reach (km) | 60 | unlimited |
| Max Logical Range (km) | 20 | unlimited |
| Max Logical Split | 128 | 32767 |

### *3.2 Security*

Although, PONs are vulnerable to eavesdropping and theft-of-service attacks, proposals to include security mechanisms in objectives of 802.3ah task force did not find the necessary support. Instead, security mechanism has just been standardized by IEEE 802.1ae task group.
The Ethernet security specification mechanism has just been standardized by IEEE 802.1ae task group. Because, the 802.1ae specification was not completed by the time the EPON standard was approved, most EPON deployments in the world today use proprietary security solutions. In several cases, large telecommunications operators issued their own security specifications. In several cases, large telecommunications operators have issued their own security specifications, which not only tailored to their specific technical requirements, but also with regard to local regulatory environment. For example, the AES cipher suite does not have a regulatory approval for use in China and EPON vendors are implementing a China-specific churning mechanism developed by China Telecom to enhance the downstream data security.

By comparison, ITU-T recommendation G.984.3 specifies an AES-based encryption mechanism for GPON, thus making GPON's use in China problematic.

## 4 EPON is a Successful Technology

The Ethernet in the First Mile task force completed its charter in June 2004, culminating in ratification of IEEE Std. 802.3ah-2004 (now merged into IEEE Std. 802.3-2005). EPON became the first optical technology cost-effective enough to justify its mass-deployment in an access network. Today, only 2 years after the standard ratification, more than 3 million EPON lines are deployed and the CO-installed capacity exceeds 10 million lines.

True to its Ethernet heritage, EPON products keep evolving; they gain functionality and performance, all while lowering the cost. Since the standard introduction, EPON system costs have decreased by 50% or more, while the cost of optical transceivers has decreased by about 70%. Recent industry announcements have introduced a slew of new EPON offerings such as a quad-OLT ASIC, EPONs supporting T1/E1 circuit emulation with jitter and wonder well within ITU-T specs, or even an entire ONU integrated in a GBIC module (Figure 1).


**Figure 1: ONU integrated into a GBIC module**

The GBIC ONU is a representative example of EPON evolution: from a stand-alone device with a large number of sub-components (EPON ASIC, external SerDes, external memory, external PHY) to a cost-reduced stand-alone device using a highly-integrated EPON SoC, and then to a mass-produced sub-component used in a larger system. The GBIC module integrates a burst-mode transceiver and an ONU ASIC. The ONU ASIC itself is a highly-integrated system-on-a-chip device, which includes an 802.3ah EPON MAC/MPCP, a SERDES, a line-rate L2/L3/L4 classification engine, encryption, forward error correction, a switch, an integrated packet buffer, and an embedded processor. All these functions are packed in a small LQFP package consuming a paltry 0.6 W. This evolutionary step allows turning any switch or router with a GBIC interface into an ONU switch or router (Figure 2).

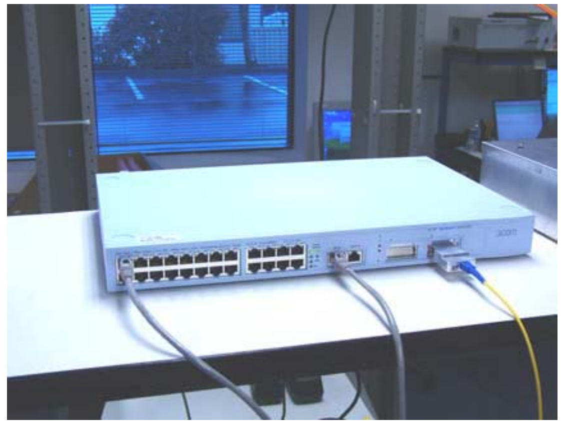

**Figure 2: A 24-port switch attached to EPON using GBIC ONU module.**

## 5 The Road Ahead

What is in store for EPON? Recently, this question was answered by the IEEE 802.3 working group during its March 2006 Plenary session when it approved formation of 10 Gb/s EPON study group.

The 10 Gb/s EPON call-for-interest materials identify several major drivers for an increased capacity EPON: emergence and growing acceptance of high-definition television, continued development of markets with a significant share of the population living in multi-dwelling units, and the need to support next generation wireless back-haul [3].

Support for HDTV and other advanced video services is arguably the main driving force for higher-speed EPON.

Wide adoption of 1 Gb/s EPON provided a significant jump in access network capacity and allowed carriers to deploy advanced digital video services. For example, in Japan, KDDI is offering DVD-grade multi-channel broadcasting and video on demand (VOD), as well as high-grade IP telephony and high-speed Internet connections ("*Hikari Plus*" FTTH service).

In the Hikari Plus service, a subscriber can view 30 channels of broadcasting TV programs supported by

IP multicast technology and more than 2,000 VOD programs. Karaoke-on-demand service is also available.

Subscribers have accepted the new services, enabled by gigabit-capable optical access networks, with great enthusiasm, driving up the demand for yet more bandwidth-intensive applications and services. Many R&D labs around the world are working to supplement the IP broadcast and VoD services available today with such services as time-shifted broadcast/narrowcast, all-channel personal video recorder, picture-in-picture/split screen, digital cinema distribution, personal multimedia publishing, residential and business digital video surveillance, and so on. Another example - distribution of DVD content to in-home DVD recorders through FTTH systems, is being field-tested by Poweredcom, Toshiba and Tokyo Electric Power Company.

While the rich offering of new services is expected to provide a boost to subscriber take-rates, bandwidth consumption per subscriber is expected to grow as well. Newer TV sets and set-top boxes, in addition to standard definition television (SDTV) channels (~2Mb/s) now support high-definition television (HDTV) channels (~10Mb/s). According to a market research report published by Technology Futures, Inc., 45% of US households will be using HDTV by 2010, and that number will continue to grow to approximately 90% by 2020 [4]. The recently approved ITU-T standard J.601 for Large Screen Digital Imagery (LSDI) requires 40 to 160 Mb/s per channel.

The increasing demand for advanced video services, together with the need to support multi-dwelling units and next-generation wireless backhaul, prompted the IEEE 802.3 working group to initiate a study of 10 Gb/s EPON architectures.

### *5.1 Next-Generation EPON*

The 10 Gb/s EPON effort in IEEE 802.3 will focus on defining a new point-to-multipoint physical layer, keeping the MAC, MAC Control and all the layers above unchanged to the greatest extent possible. This means that carriers can expect architectural continuity and backward compatibility of network management system (NMS), PON-layer operations, administrations, and maintenance (OAM) system, DBA and scheduling, and so on.

The 10 Gb/s EPON study group has set objectives of specifying both symmetric line rate operation as well as asymmetric line rate operation. The symmetric option will operate at 10 Gb/s in both the downstream and upstream directions. The asymmetric option will use 10 Gb/s in the downstream and 1 Gb/s upstream, most likely reusing the existing IEEE 802.3ah specification for the upstream.

The asymmetric option reflects the fact that the advanced video services create capacity pressure mostly in the downstream direction.

The asymmetric EPON product will most likely appear first, as this specification relies on fairly mature technologies. The upstream transmission will remain identical to that of the existing 1 Gb/s EPON, and will rely on field-proven and mass deployed burst-mode optical transceivers. The downstream transmission, which uses continuous-mode optics, will rely on the maturity of 10 Gb/s point-to-point devices.

The main emphasis of the symmetric option will be on defining burst-mode operation at 10 Gb/s. The 64b/66b line coding used by the 10 Gb/s Ethernet PHY, would likely necessitate a new FEC scheme.

## 6 10 Gb/s EPON Efficiency

As described in [5], EPON efficiency depends on the values of various overhead components associated with frame encapsulation and scheduling. These components include *line-coding overhead*, *encapsulation overhead*, *control message overhead*, *guard-band overhead*, *discovery overhead*, and *frame delineation overhead*. There also may be present an *FEC overhead*, if FEC is implemented. The effects of the above components were analyzed in [5] for 1 Gb/s EPON. Among the above components, only the line-coding overhead, control message overhead, and frame-delineation overhead would change for 10 Gb/s EPON. We will refrain from any guesswork regarding the expected FEC overhead, since the 10Gb/s FEC method has not been determined.

### *6.1 Line-Coding Overhead*

The 64b/66b line coding reduces the bit-to-baud overhead from 20% in the current 1 Gb/s EPON to only 3.03%.

### *6.2 Control Message Overhead*

The control channel overhead represents bandwidth lost due to use of in-band control messages such as GATEs and REPORTs. The amount of overhead depends on the number of ONUs and cycle time, i.e., an interval of time in which each ONU should receive a GATE message and send a REPORT message. For 32 ONUs and a 1 ms cycle time, we can estimate a control channel overhead of 0.215%.

### *6.3 Frame Delineation Overhead*

According to the IEEE 802.3 standard, the variable-sized Ethernet frames cannot be fragmented. The non-fragmentability of Ethernet frames was the main reason for introducing multiple queue sets in the REPORT messages – the scheduler always selects one of the reported queue lengths, so that the granted timeslot is filled completely. In this case, as it is the case in most commercially deployed EPONs, the delineation overhead will be zero. However, even if the scheduler completely ignores the reported frame boundaries, the total bandwidth lost due to unused slot remainders will only be ~1.52%.

## 7 Conclusion

10 Gb/s EPON is expected to be a highly-efficient specification. As was indicated in the IEEE call-for-interest materials[3], the 10 Gb/s EPON provides more bandwidth capacity than CATV network using DOCSIS 3.0. This makes 10 Gb/s EPON a good candidate replacement architecture for next generation CATV networks; it will allow significant increase in data bandwidth available to subscribers without forcing any drastic changes to the existing video distribution model employed by cable operators.

## 7 References


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