Overview of 10Gb/s EPON Status, Requirements and Applications

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Executive Summary

The wide adoption of 1 Gigabit Ethernet passive optical networks (EPON) (per IEEE Std 802.3™-2008, which incorporates IEEE Std. 802.3ah™-2004) provided a significant jump in access network capacity and created demand for greater bandwidth-intensive applications and services such as Internet Protocol Television (IPTV), Video-on-Demand (VoD) and high-grade internet protocol (IP) telephony known as Voice over IP (VoIP). To address these market demands, the IEEE P802.3av Task Force was created in September 2006 and its 10G-EPON draft builds upon the compatibility with the existing 1G-EPON specifications. The 10G-EPON effort has been focused on defining a new physical layer supporting both asymmetric and symmetric line rate operations. The asymmetric data rate system (at 10 Gb/s downstream and 1 Gb/s upstream) takes advantage of the fact how video services create capacity pressure mostly in the downstream direction. The symmetric data-rate system will use 10 Gb/s in both downstream and upstream directions. In both scenarios, the specification for downstream transmission channel leans heavily on the technologies used in mature and mass-deployed 10 Gb/s point-to-point devices. The pre-standard 10G-EPON prototypes have already been demonstrated by vendors for lab tests. Commercial 10G-EPON products are expected by 2010.

The IEEE P802.3av Task Force has released P802.3av/D3.0 for 10 Gb/s Ethernet Passive Optical Networks (10G-EPON), and has entered Sponsor Ballot phase of draft review. The standard ratification is expected to be released in the second half of 2009.

1.0 Introduction

The rapid growth of IP traffic with ever-increasing volume of video traffic has spurred the demand for high-bandwidth, low-cost and flexible broadband access. The deployment of fiber-to-the-home (FTTH) in the access networks continues unabated in all geographic areas. Standardized in June 2004, 1G-EPON, in particular, is being widely deployed in the Asia Pacific region and there is no foreseeable slow-down in sight. For example, the NTT Holding company has announced its fiber-optic services passed the 10 million subscribers mark and plans to hit 20 million fibre-optic subscribers by March 2011 [1]. Other service providers such as CTC and CNC had rolled out initial deployments of their fiber-to-the-building (FTTB) and FTTH networks in advance of the 2008 Beijing Olympics.

Encouraged by the fast and wide adoption of 1G-EPON-based access networks, IEEE has initiated standardization activities for next-generation 10 Gb/s EPON systems under the IEEE P802.3av Task Force [2]. A parallel activity of defining NG-PON is taking place in Full Service Access Networks (FSAN) consortium [3].

The IEEE P802.3av Task Force, formed in September 2006, was chartered to improve upon the 1G-EPON by defining a set of new physical layers for 10G-EPON. Its draft specifications are currently in Sponsor Ballot review phase. The final standard ratification is expected in the second half of 2009. The industry is confidently moving forward using the current draft specifications as a basis for product development. 10G-EPON prototypes have been announced [4-6] and products are expected to mature enough for initial commercial deployments to occur as early as the end of 2010.

2.0 High-bandwidth Requirements

An old question often asked is: *How much bandwidth will be enough for an end user*? The demand for bandwidth is obviously driven by the contents and services available in the network, which is only limited by user imagination [7]. The wide adoption of 1G-EPON provided a significant jump in access network capacity and created the demand for bandwidth-intensive application and services such as IPTV and VoIP. Users have accepted these new services with great enthusiasm, which in return drives up the surge for even more bandwidth-intensive applications and services, rendering the need for next-gen access technologies such as 10G-EPON [8].

The most critical application driving the deployment of 10G-EPON in the access network is high definition IPTV and VoD. Telecom service providers (Telcos) experience intense pressure from cable, satellite, and wireless providers. To meet the new market requirements, carriers worldwide are rapidly deploying triple-play - bundled voice, data and digital TV services over common IP networks. For video-centric residential services, 1G-EPON networks support the first generation of IPTV solutions. However, the video industry is now completing the transition to high-definition TV (HDTV), fast becoming the minimum standard for today's consumers.

There is a clear trend among service providers deploying IPTV to significantly increase the number of channels available to subscribers. These intentions coupled with the need to provide simultaneous multi-channel support such as picture-in-picture or the ability to watch one channel while recording another, greatly increases the consumers' bandwidth demands. It is predicted that as most countries move to all-digital television broadcasting by 2010, the number of HDTV-equipped homes will rise from 48 million in 2006 to 151 million in 2011 [9]. In 2010, more than half of US households will use Internet TV (streaming or faster-than-real-time-download), and about 25% of households will watch HDTV programming over the Internet. By 2020, these numbers projected to be around 90% and 80% respectively. This will put a severe burden on access network capacity (see Figure 1). 10G-EPON has the bandwidth necessary to handle high definition programming.

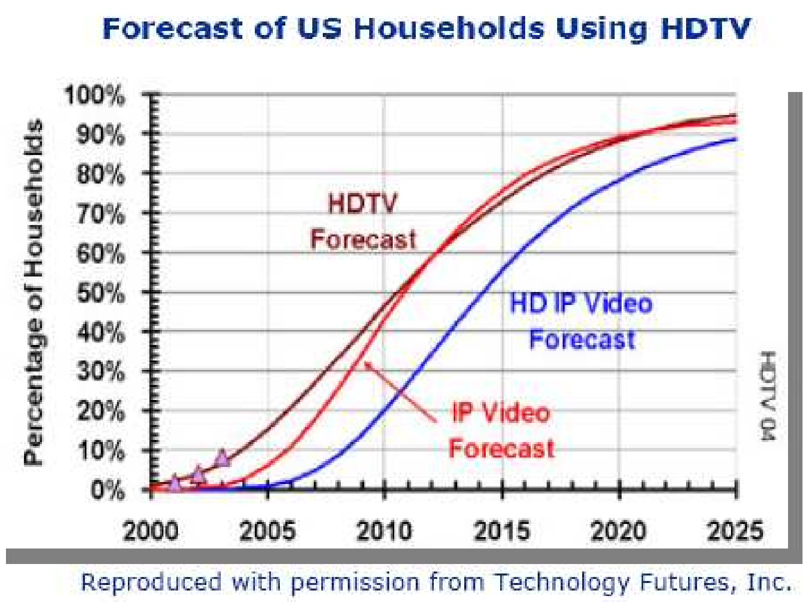


Figure 1 – The forecast of US Homes using HDTV

Other bandwidth-intensive applications include video-conferencing, interactive video, online interactive gaming, peer-to-peer networking, karaoke-on-demand, IP video surveillance, and cloud applications where remote storage and computing resources provide online service on demand to users with thin-client local systems. Even relatively low bandwidth applications, such as VoIP, contribute to the bandwidth demand. It is estimated that VoIP service subscribers may exceed 150 million by 2011, up from 35 million in 2006 [9].

In addition to raw bandwidth for delivery of multi-channel HD IPTV and other bandwidth-intensive applications, 10G-EPON will be a cost-effective access architecture supporting digital home networking including multimedia delivery systems in the near future. It is expected that each household will typically have as many as 3-5 HD set-top boxes (STBs) with built-in digital video recorders. In addition, a large fraction of television sets will support HD signal, while gigabit user network interface (UNIs) and audio visual (AV) bridges in home networks will become increasingly ubiquitous. Thus the residential gateways will require much more bandwidth than 1 Gb/s per household.

10G EPON deployment opportunities also exist in residential areas such as multiple dwelling units (MDUs) and apartments where a large fraction of broadband users resides, especially in Asia and Europe. Hotels, hospitals, schools and business campuses as well as governmental and educational institutions are further examples of environments with a large number of data access points (both wireless and wired), representing natural deployment grounds for 10G-EPON. The MDU market is rapidly growing and now receives much more attention. An estimation of bandwidth demand for MDU site is depicted in Figure 2. For a single 10G-EPON system, each of 16 MDU optical network units (ONUs) can provide services to 24-48 subscribers, a total of 384-768 subscribers, which results in the required PON bandwidth has to be ~7Gb/s per EPON in the downstream.

Broadcast Video	100 channels x 10 Mbps/channel =	1.0 Gbps
Video on Demand	10 Mbps/channel x 2 channels/user x 24 users/ONU x 16 ONUs/PON x 30% active users* =	2.304 Gbps
Video Conferencing	10 Mbps/user x 24 users/ONU x 16 ONUs/PON x 30% active users =	1.152 Gbps
Internet	5 Mbps/user x 24 users/ONU x 16 ONUs/PON x 50% active users =	1.92 Gbps
Gaming	10 Mbps/user x 24 users/ONU x 16 ONUs/PON x 10% active users =	0.384 Gbps
	Required PON bandwidth =	6.76 Gbps

* Take rate estimates are from "Service Review, QOS and Customer base for an FSAN compliant GPON", by K.W. Cobb (BT Exact) and R. Mercinelli (Telecom Italia), ISSLS'2004.

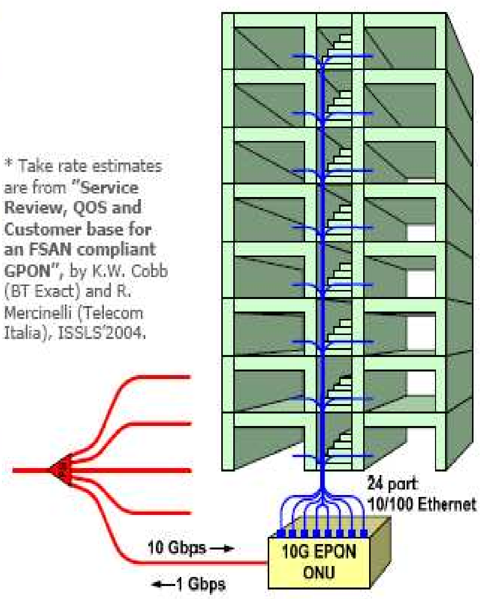


Figure 2 – 10G-EPON deployment scenario for an MDU site [10]

It is also worthwhile to mention the benefits of 10G-EPON for wireless backhaul. Wireless access is yet another way of providing connectivity to online contents (e.g. multimedia, email etc.), and the bandwidth demand increases with each new generation of mobile phones and other wireless appliances. A 3G network base station typically requires approximately 10 Mb/s of bandwidth. In a 4G network, where three antennas form an arc to provide high capacity area coverage, each antenna will need a 100 Mb/s of bandwidth, or about 300 Mb/s in total. Combined with the rapid growth of Wi-Fi (IEEE P802.11n, up to 100Mb/s, though the majority of available hot-spots run IEEE Std 802.11g™-2003 networks) and WiMAX (IEEE Std 802.16e™-2005, up to 70 Mb/s) usage, the access bandwidth per access point must quickly grow beyond 1 Gb/s to facilitate efficient wireless connectivity.

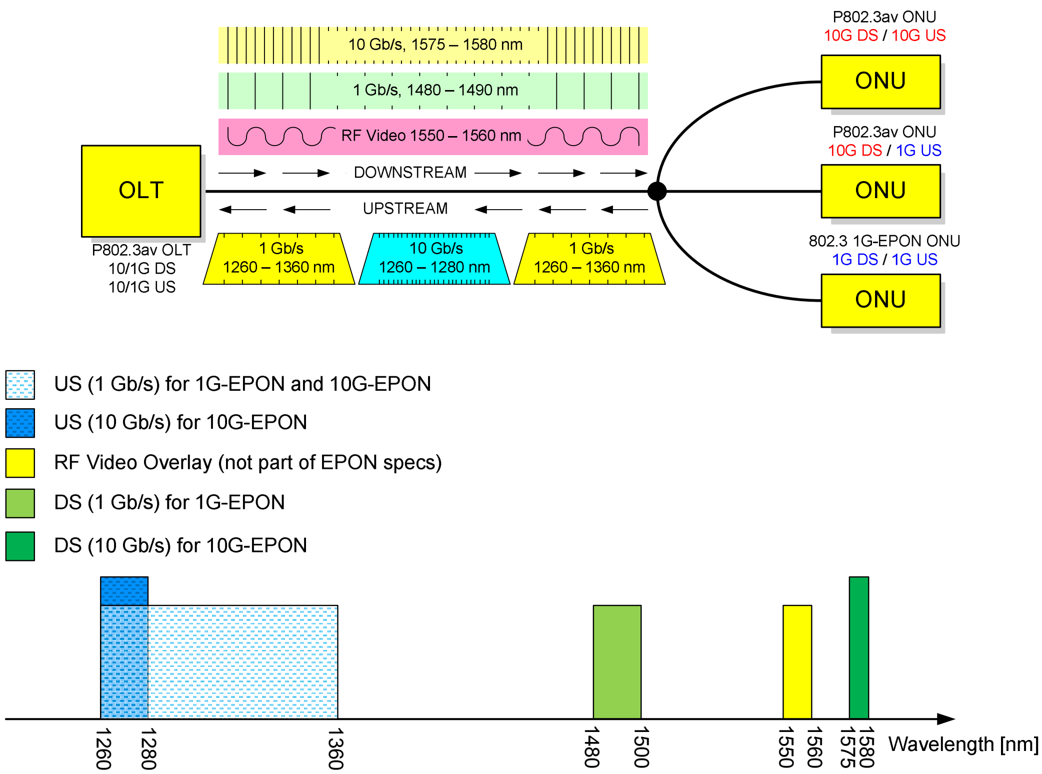


Figure 3 – 10G-EPON Downstream and Upstream Wavelength Plan [11]

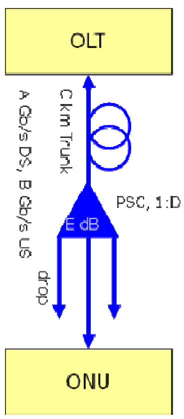
3.0 Overview of 10G-EPON Technology

To respond to the aforementioned growing user bandwidth demand, the 10G-EPON Task Force set forth to specify a higher capacity access network based on extensions to broadly adopted and well-understood 10 Gb/s Ethernet physical layer device (PHY). To assure a cost-effective evolution path, the Task Force objectives were set to support both symmetric and asymmetric modes of operation. The asymmetric data-rate system (10 Gb/s downstream and 1 Gb/s upstream) is specified in recognition of the fact that advanced video services create capacity pressure mostly in the downstream direction. The symmetric data rate system (10 Gb/s in both downstream and upstream directions) involves an additional cost factor particularly on the ONU side. The 10G-EPON specification defines a set of new physical medium dependent layers (PMDs), and relies on existing 10G and EPON technologies for the high sublayers, for example, the physical coding sublayer and multipoint media access controller (MAC) control sublayer to the greatest extent possible. Therefore carriers can expect architectural continuity, backward compatibility, and smooth upgrade paths from existing 1G-EPON networks.

10G-EPON wavelengths are allocated with a specific goal of allowing coexistence with 1G-EPON and RF video (Figure 3) thereby enabling support of symmetric 10 Gb/s ONUs, asymmetric 10/1 Gb/s ONUs, and symmetric 1Gb/s ONUs, as well as radio frequency (RF) video overlay on the same optical distribution networks (ODN) [11]. In the downstream direction, the 3 wavelength bands for RF video (1550-1560nm), 1Gb/s downstream at 1480-1500nm, and 10 Gb/s downstream (1575-1580nm) are multiplexed together into the fiber. In the upstream, the optical line terminal (OLT) receivers operate in dual-rate 10/1 Gb/s burst-mode reception mode at partially overlapping wavebands: 1Gb/s ONUs transmit 8b/10b coded packet bursts in 1260-1360nm at 1.25Gb/s, while 10 Gb/s ONUs transmit 64b/66b coded packet bursts at 1260-1280nm band at 10.3125Gb/s.

The 10G-EPON link budgets match the currently deployed 1G EPON ODNs. For 1G EPON, the most common link budget in use has a channel insertion loss (ChIL) of 29 dB (Class B+), with some deployments using 26 dB. However, the 1G-EPON specification is limited to only 20dB and 24dB. The situation was rectified in the 10G-EPON by adding high (PR30) power class into the 10G EPON specifications, allowing for support of ChIL of 29 dB (Class B+) as shown in Figure 4.

The sensitivity of optical receivers decreases with the increase in signal’s rate. To compensate for loss of optical sensitivity in 10Gb/s receivers, 10G-EPON specification employs strong forward error correction (FEC) and high-power transmitters to meet the high power budget requirements. The selected FEC code is based on RS(255,223) and belongs to the same Reed-Solomon (RS) family as 1G-EPON FEC, though it operates on the bit stream rather than on frames like in the case of 1G-EPON devices. It has, however additional 1dB of gain, which comes at the expense of some additional overhead, estimated at about 13% of total channel capacity. FEC operation is also mandatory for all 10G-EPON links operating at 10 Gb/s (in asymmetric configurations, 1 Gb/s links can optionally use IEEE 1G-EPON FEC). This stream-based FEC provides constant overhead and simpler integration with the 64b/66b encoding used by the 10G-EPON physical coding sublayer (PCS). It should be mentioned that 64b/66b line coding has low coding overhead at only 3%, so coding efficiency is enhanced when compared with 8b/10b coding used in 1G-EPON.



		Downstream data rate [Gb/s] A	Upstream data rate [Gb/s] B	Nominal maximum distance [km] C	Nominal split D	Maximum CHIL* [dB] E
Symmetric data rate	PR10	10.3125	10.3125	10	16	20
	PR20	10.3125	10.3125	20	16	24
	PR30	10.3125	10.3125	20	32	29
Asymmetric data rate	PRX10	10.3125	1.25	10	16	20
	PRX20	10.3125	1.25	20	16	24
	PRX30	10.3125	1.25	20	32	29

*CHIL = Channel Insertion Loss

Figure 4 - 10G-EPON Defined Power Budgets

The 10G-EPON efforts are focused on the physical layer changes. At the multipoint MAC control layer, the protocol is based on the existing multipoint control protocol (MPCP) control protocol of 1G-EPON [6], with changes to the discovery process, registration as well as several minor operational aspects including reporting, overhead calculation, etc. The implemented changes in the MPCP for 10G-EPON also serve as optional support for dual-rate operation, where 1 Gb/s and 10 Gb/s ONUs coexist on the same ODN and send interleaved bursts at 1 Gb/s and 10 Gb/s.

As noted earlier, 10G-EPON draft is moving rapidly towards its anticipated ratification in the second half of 2009.

4.0 Moving forward from 1G to 10G-EPON

Figure 5 shows an asymmetric 10G/1G-EPON network deployment configuration, thanks to the complete backward compatibility with already mass-deployed 1G-EPON. Similarly the symmetric 10G/10G-EPON further provides an upgrade path towards higher data rate in the upstream direction. It becomes possible to provide smooth migration from 1G to 10G one ONU at a time and without any changes to the ODN, or the already deployed ONUs. As a result, carriers can maximize life cycles for existing fiber systems by deploying and/or upgrading to more bandwidth demanding services using next generation access network structure of 10G-EPON.

It should be noted that for both symmetric and asymmetric 10G-EPON scenarios, the downstream transmission takes advantage of the wide deployment 10GbE point-to-point devices. The upstream burst timing is again relaxed (following closely in the footsteps of 1G-EPON, where a small decrease in efficiency was traded off for a significant reduction in device). Such a timing relaxation allows for the possible use of existing off-the-shelf components. It is expected that the cost of 10G-EPON equipment will be comparable to that of 1G-EPON, therefore, accelerating the adoption of 10G-EPON in the commercial networks.

Fortunately, the 1G-EPON standard also provides a solid foundation for multi-vendor interoperability, which is another key factor for driving the 10G-EPON market acceptance. Ensuring standard compliance also guarantees interoperability for layers that are in scope for IEEE 802.3. Historically, interoperability at higher layers was ensured by either telcos themselves, or other SDOs, such as Chinese Communications Standardization Association (CCSA) creating system-level specifications and interoperability test plans to demonstrate the interoperability between multi-vendor products. Such specifications could easily be extended for 10G-EPON products in the near future as well.

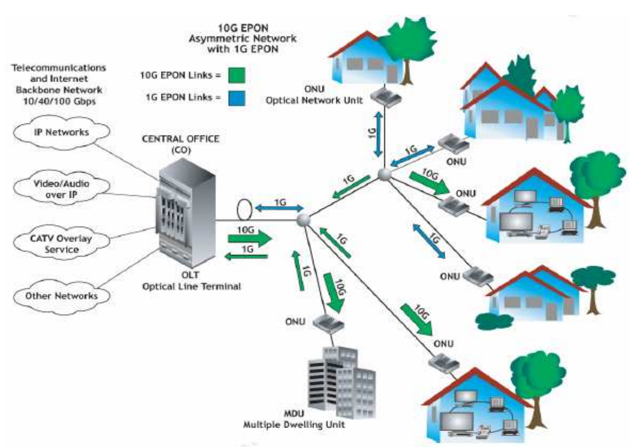


Figure 5 – Asymmetric 10/1G-EPON Network Deployment Diagram

5.0 Conclusions

1G-EPON has been rapidly deployed to reach several tens of millions of subscribers. Recently IEEE 802.3 and ITU-T has held joint workshop on next-gen optical access systems [12]. There is potential that next generation 10Gb/s PON system will follow common specifications to the greatest possible extent. 10G-EPON will offer a ten-fold increase in bandwidth when compared with current 1G-EPON, delivering the bandwidth required for next generation applications using an evolutionary overbuild rather than revolutionary rebuild upgrade approach. It is also expected 10G-EPON will be deployed at a cost comparable to the existing generation of 1G-EPON systems. This attractive cost coupled with the ever-increasing bandwidth demand in the fiber access networks has the potential to further accelerate the adoption of 10G-EPON as next generation access technologies.

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