10G-EPON: Drivers, Challenges, and Solutions

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Abstract *Responding to market demand for increased access capacity, the IEEE 802.3av has standardized 10G-EPON. The new specification has successfully resolved a number of technical challenges, including the coexistence with the mass-deployed 1G-EPON, resulting in a highly efficient architecture.*

Introduction

Standardized in June 2004 as part of IEEE Std 802.3 "Ethernet in the First Mile" specification, 1 Gb/s EPON has emerged as a highly successful technology. EPON specification builds upon existing Ethernet standards and shuns any superfluous features, protocols, framing formats, or interfaces, making EPON the first gigabit-per-second FTTx architecture cost-efficient enough to be mass deployed in access environment. Reusing the extensive expertise gained with other Ethernet products, numerous manufacturers today supply EPON optical transceivers, EPON chips, and systems, as well as test equipment. EPON per-line cost approaches that of DSL or cable modem, while offering a significant increase in bandwidth capacity. As a result, 30 million lines have been deployed worldwide during the last 5 years and the rate of EPON deployments is accelerating.

Wide adoption of 1 Gb/s EPON provided a significant jump in access network capacity and allowed carriers to deploy advanced digital services, such as IPTV multi-channel broadcasting and video-on-demand (VOD), as well as high-grade IP telephony and high-speed Internet connections, or even such exotic services as karaoke-on-demand.

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.

While the rich offering of new services provides a boost to subscriber take-rates, bandwidth consumption per subscriber is growing 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., 40% of US households will be using HDTV by 2010, and more than 20% will be using HD-IPTV. By 2020 these numbers are expected to grow to 90% and 80% respectively [1].

Support for HDTV and other advanced video services is arguably the major driving force for higher-speed EPON, but there are other factors as well: 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.

All these market conditions prompted the IEEE 802.3 working group to initiate a project for next generation EPON specification. The technical work was largely driven by network operators and vendors who have gained experience with 1G-EPON.

10G-EPON Efficiency

To lower and optimize the cost of 10G-EPON implementations, it is extremely crucial to find the right balance among optical transceivers and complexity of electronic parts. To extend the power budget while improving the technical and the economic feasibility of optical transceivers, the 10G-EPON specification includes a mandatory forward error correction (FEC) based on Reed-Solomon (255, 223) channel encoding.

The FEC overhead, reaching 12.9%, is the major overhead component in 10G-EPON. Other components include burst mode overhead, control channel overhead, and various unit conversion steps (bytes, time-quantum, FEC codewords). The burst-mode overhead depends on the speed of the laser driver at the transmitter or gain control and clock recovery circuits at the receiver. The control channel overhead represents the bandwidth taken by in-band REPORT messages.

Efficiency of 10G-EPON also depends on such parameters as the number of ONUs and the frequency of granting. These parameters are generally provisionable or configurable. Table 1 and Table 2 show 10G-EPON downstream and upstream utilization for various combinations of these parameters. The presented numbers assumed the following optical parameters:

- Laser On time = 64 ns
- Laser Off time = 64 ns
- Gain Adjustment Interval = 200 ns [2]
- Clock and Data Recovery time = 200 ns [2]

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Tab. 1: 10G-EPON downstream utilization

Num. of ONUs	Grant cycle time			
	1 ms	**2 ms**	**4 ms**	**8 ms**
32	86.88%	86.99%	87.04%	87.07%
64	86.67%	86.88%	86.99%	87.04%
96	86.45%	86.77%	86.94%	87.02%
128	86.24%	86.67%	86.88%	86.99%

Tab. 2: 10G-EPON upstream utilization

Num. of ONUs	Grant cycle time			
	1 ms	**2 ms**	**4 ms**	**8 ms**
32	85.00%	86.05%	86.57%	86.84%
64	82.91%	85.00%	86.05%	86.57%
96	80.82%	83.96%	85.53%	86.31%
128	78.72%	82.91%	85.00%	86.05%

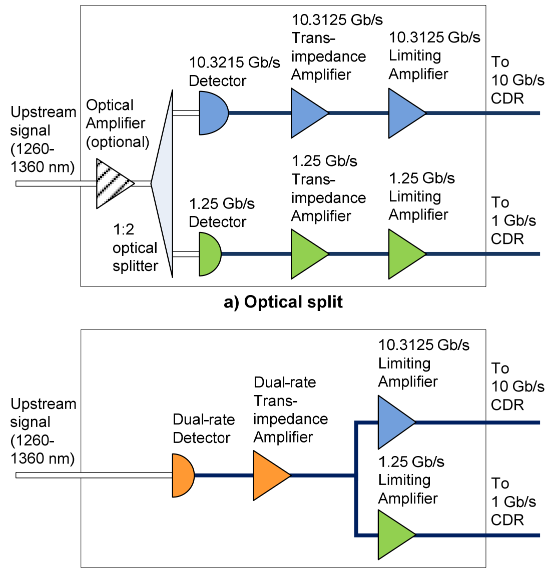
Upgradability and Coexistence

The success of 1G-EPON technology is both a boost and a challenge for 10G-EPON. On one hand, the staggering volumes of 1G-EPON deployments create a favourable environment for acceptance of 10G-EPON technology: network operators and vendors are very familiar with the EPON technology and significant portion of previously-developed software and hardware modules can be reused in 10G-EPON products. On the other hand, 10G-EPON needs to coexist with 1G-EPON on the same outside plant – a challenge that the first generation of EPON didn't face.

Coexistence in the downstream direction is achieved by allocating a separate wavelength of 1577 nm for 10 Gb/s channel. The choice of wavelength was determined by the desire to support optional RF video overlay at 1550 nm and OTDR channel at 1600 nm.

The first generation of PON standards, ITU-T G.983 (BPON), ITU-T G.984 (GPON), and IEEE 802.3ah (EPON) alike, where quite excessive with allocating the upstream wavelength band. All there standards reserve the entire O-band (1260-1360 nm) for the upstream channel. While using such a wide band may have been well justified at that time to ensure low cost and high yield of optical components, it makes the task of ensuring coexistence of the first and the second generations more difficult.

10G-EPON uses the same O-band for the upstream transmission, though it adopts a narrower region of 1260-1280 nm). To support 1 Gb/s and 10 Gb/s upstream transmission, the OLT employs a *dual-rate burst-mode receiver*. As the name implies, the single receiver is able to receive upstream bursts of either 1 Gb/s signal or 10 Gb/s signal. Such dual-rate receivers may be implemented using an optical splitter and two separate detectors tuned to either 1 Gb/s or 10Gb/s signals, as shown in Fig. 1.a. Or, they can be built using specialized dual-rate detector and TIA, as shown in Fig. 1.b.



b) Dual-rate detector

Fig 1: Block diagrams of dual-rate receiver implementations

The coexistence method described above assumes that the 1G-EPON ONU transmitters use the entire 1260-1360 nm band. However, in certain cases, network operators had their own, more stringent requirements to the optical components they deployed. As a result, in some networks, 1 Gb/s upstream transmission never extends below 1300 nm. These networks have an option of achieving upstream coexistence using WDM approach.

When the dual-rate burst-mode is used, the 1 Gb/s ONUs and 10Gb/s ONUs operate in the same time domain, and thus should be controlled by a single DBA/scheduler. This requires replacing 1 Gb/s OLT card with a new, dual-rate OLT card (see Fig. 2.a).

The WDM upgrade method uses separate DBA/schedulers for 1 Gb/s and 10 Gb/s ONUs. WDM upgrade still may be achieved by replacing the old OLT card with a new one, capable of receiving two upstream wavelength channels on the same port, and internally implementing two DBAs to control each channel separately (see Fig. 2.b). Alternatively, the WDM-based upgrade may be accomplished by keeping the 1 Gb/s OLT card in place and adding a new 10 Gb/s OLT card and a WDM splitter/combiner to connect the two cards to a single trunk fiber.

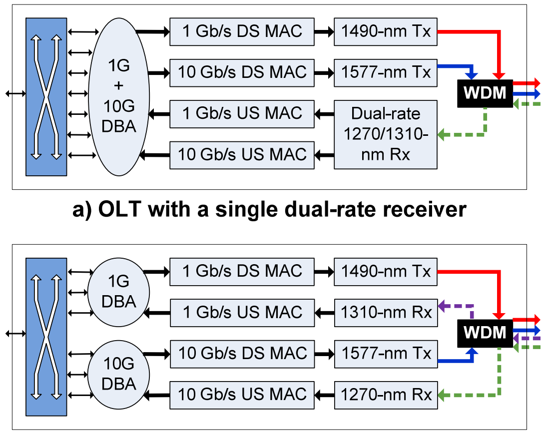


Fig 2: 1G-EPON and 10G-EPON coexistence scenarios

Replacing an old OLT card with a single new OLT card capable of supporting 1 Gb/s ONUs and 10 Gb/s ONUs achieves higher subscriber density per OLT port, conserves power, and saves CO rack space.

Whichever upgrade method is used, one of the most important accomplishments of 10G-EPON specification is that it protects the investments operators made in the existing 1 Gb/s EPON ONUs. With 10G-EPON, the network operators are able to selectively upgrade subscribers who are willing to pay for premium services and higher data rates, while keeping existing 1 Gb/s ONUs in service.

Conclusion

Wide adoption of 1G-EPON is both a boost and a challenge for 10G-EPON. It is a boost because increased access capacity brought by 1G-EPON encouraged more bandwidth-intensive applications and led to higher subscriber take rates, thus, generating the demand for more bandwidth. It is a challenge, because 10G-EPON has to coexist with the mass-deployed 1G-EPON. The coexistence and other technical issues where successfully resolved in the IEEE 802.3av 10G-EPON standard, resulting in a highly efficient architecture

References

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