

10G EPON: No boundaries for bandwidth under evolution of PON for FTTx Broadband Access Applications

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Abstract

In the background of the global information, broadband access is developing rapidly. Because fibre access has the great advantage of capacity and cost, all countries have started deploying the FTTx fibre access as an important part of the national strategy. As the deployment of Fibre to the Home (FTTH) technologies in the access network accelerates, vendors and technology innovators are looking ahead to solve next-generation application's bandwidth requirements. These applications, such as high-definition IPTV delivery and multimedia distribution systems will demand far greater bandwidth than current broadband access technologies provide. One attractive new option is 10 Gigabit Ethernet Passive Optical Network (10G EPON) technology. It offers a ten-fold leap in bandwidth to 10 gigabits per second in the broadband access network over fibre while providing core protocol compatibility with current 1G EPON solutions. Through 10GE PON, Network Operators can serve a very large number of subscribers and that too with high bandwidth demands. The 10G EPON technology is somewhat new for Indian telecom network and growing gradually for higher data rate applications. This paper provides an overview of the IEEE 802.3av 10Gbit/s Ethernet

PON (10G EPON) driving the requirement of future last mile access networks.

Keywords

IEEE, ITU-T, FTTH, PON, Broadband, Gigabit, Next Generation Network, Triple Play Services, Internet Protocol, Ethernet, Wavelength, P802.3.av.

1. Introduction

The Internet has produced higher demands for broadband services, leading to extensive growth in Internet Protocol (IP) data traffic and putting pressure on service providers to upgrade their existing networks. The General schematic of passive optical network applications is shown below: -

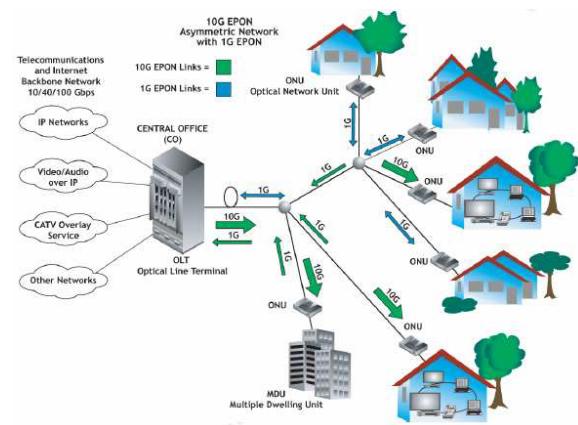


Fig. 1: General schematic of 10G EPON Architecture

A passive optical network, on the other hand, does not include electrically powered switching

equipment and instead uses optical splitters to separate and collect optical signals as they move through the network. A passive optical network shares fibre optic strands for portions of the network. Powered equipment is required only at the source and receiving ends of the signal.

Fibre-To-The-Home (FTTH) using 10G EPON for broadband access applications may be considered as an effective solution for higher data rate networks as optical fibre in telecommunications have huge capacity, small size, light in weight, very high bandwidth, and immunity to electromagnetic interference, etc. 10G EPON is a combination of network elements in an ODN (Optical Distribution Network) based optical access network that includes an optical line termination (OLT) and multiple optical network units (ONU) and implements a particular coordinated suite of physical medium dependent layer, transmission convergence layer, and management protocols.

2. Evolution of 10G EPON

In term of evolution, PON can be divided in to the following PON technologies: -

- APON & BPON
- EPON
- 10G EPON

2.1 APON and BPON: Asynchronous Transfer Mode Passive Optical Networks (APONs) were developed in the mid 1990s through the work of the full-service access network (FSAN)

initiative. FSAN was a group of 20 large carriers that worked with their strategic equipment suppliers to agree upon a common broadband access system for the provisioning of both broadband and narrowband services. British Telecom organized the FSAN Coalition in 1995 to develop standards for designing the cheapest, fastest way to extend emerging high-speed services, such as Internet protocol (IP) data, video and 10/100 Ethernet, over fibre to residential and business customers worldwide. At that time the two logical choices for protocol and physical plant were ATM and PON. ATM was thought to be suited for multiple protocols, PON because it is the most economical broadband optical solution. The APON format used by FSAN was accepted as an International Telecommunications Union (ITU) standard (ITU-T Rec. G.983.x series). The ITU started releasing the G.983 series recommendations and amendments in 1998. The APON format developed by the FSAN alliance was used as the basis for an international standard released by ITU-TS (Rec. G. 983.x), designated by BPON (Broadband PON). This standard supports more broadband services, including high-speed Ethernet and video distribution. After some initial deployment of BPON, the industry belatedly realized that a BPON ODN could not be incrementally upgraded to any next-generation technologies.

2.2 EPON: EPON system supporting transmission rates in excess of 1.25 Gbit/s in at

least one direction, and implementing the suite of protocols specified in the IEEE P802.3ah is said to be EPON Ethernet Passive Optical Network. Therefore, EPON is based on IEEE P802.3ah standards. The development of EPONs has been spearheaded by one or two visionary start-ups that feel that the APON standard is an inappropriate solution for the local loop because of its lack of video capabilities, its insufficient bandwidth, its complexity, and its expense. Also, as the move to fast Ethernet, gigabit Ethernet, and now 10-gigabit Ethernet. It is believed that EPONs will eliminate the need for conversion in the wide-area network (WAN)/LAN connection between ATM and IP protocols.

2.3 10G EPON: Efforts on NG-PON are also currently being done in standardization for 10G EPON by IEEE P802.3av standards. 10G EPON provide physical layer specifications: -

2.3.1 PRX 10G/1G Asymmetric: 10 Gbps downstream/1 Gbps upstream, single SM fibre.

2.3.2 PR 10G/10G Symmetric: 10 Gbps downstream/10 Gbps upstream, single SM fibre define up to 3 optical power budgets that support split ratios of 1:16 and 1:32, and distances of at least 10 and at least 20 km.

3. 10G EPON Components

10G EPON has a point-to-multipoint tree topology that carries data frames between an optical line termination (OLT) and multiple

optical network units (ONU) via a passive optical splitter. The various elements of 10G EPON architecture are shown in following diagram: -

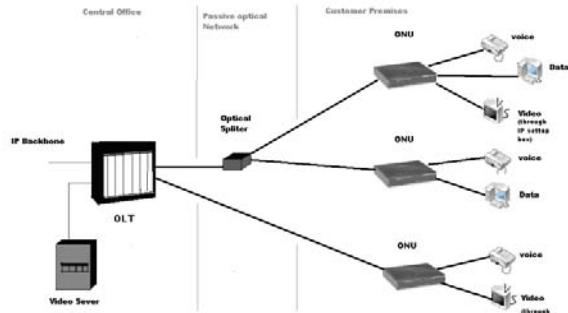


Fig. 2: Various components of 10G EPON

To share the upstream bandwidth among ONUs without collisions, robust and efficient medium access control is required. Optical-access networks have been developed to remove the access-network bandwidth bottleneck. However, the current solutions do not adequately address the network economics to provide a truly cost-effective solution. Long-reach optical-access networks introduce a cost-effective solution by connecting the customer directly to the core network, bypassing the metro network, and, hence, removing significant cost.

4. 10G Ethernet-based PON Technology

The IEEE P802.3av PON standard was developed for 10G Ethernet-based PON (10G EPON) to increase the data rate of EPON systems from 1 Gbit/s to 10 Gbit/s, in keeping with the 10 Gbit/s Ethernet interface. Many protocols are shared between 10G EPON with

EPON. A combination of coarse wave division multiplexing (CWDM) and time division multiplexing (TDM) is used in order to allow EPON and 10G EPON systems to co-exist on the same PON. As with EPON, 10G EPON relies on VoIP for carrying voice traffic and circuit emulation service (CES) for carrying other TDM client requirements.

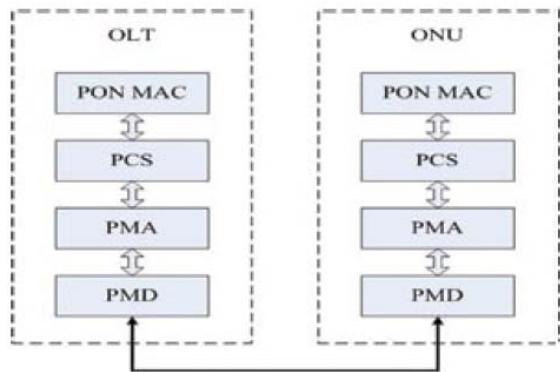


Fig. 5: 10G EPON Protocol Stack

5. Features of 10GE PON Technology

The key features of 10GE PONs include the following: -

5.1 Forward Error Correction (FEC): The 10G-EPON system uses Reed Solomon (255, 223) forward error correction (FEC) mechanism. The FEC is mandatory for all channels operating at 10 Gb/s rate, i.e., both downstream and upstream channels in symmetric 10 Gb/s EPON and the downstream channel in the 10/1 Gb/s asymmetric EPON. (Upstream channel in the asymmetric EPON is the same as in 1 Gb/s EPON, i.e., optional frame-based FEC using RS (255, 239). The 10G-EPON task force also

focuses on defining a new physical layer, keeping the MAC architecture. This means that users of 10G-EPON can expect backward compatibility of network management system (NMS), PON-layer operations, administrations, and maintenance (OAM) system, DBA and scheduling.

5.2 10-G EPON Co-existence with 1G EPON:

One of the key features of the 10GE EPON architecture is that it allows 10G EPON to operate on the same ODN backbone that is already being used for 1G EPON. The simultaneous operation of 1 Gb/s and 10 Gb/s EPON systems on the same outside ODN plant is possible in this technology. In the downstream direction, the 1 Gb/s and 10 Gb/s channels are separated in the wavelength domain, with 1 Gb/s transmission limited to 1480-1500 nm band and 10Gb/s transmission using 1575-1580 nm band. In the upstream direction, the 1 Gb/s and 10 Gb/s bands overlap. 1 Gb/s band spreads from 1260 to 1360 nm; 10 Gb/s band uses 1260 to 1380 nm band. This allows both upstream channels to share spectrum region characterized by low chromatic dispersion, but requires the 1 Gb/s and 10 Gb/s channels to be separated in time domain. Since burst transmissions from different ONUs now may have different line rates, this method is termed dual-rate TDMA. The following figure illustrates a network where an OLT supports a mix of EPON ONUs, ONUs with 10Gbit/s downstream and 1Gbit/s upstream, and ONUs 10Gbit/s upstream and

downstream: -

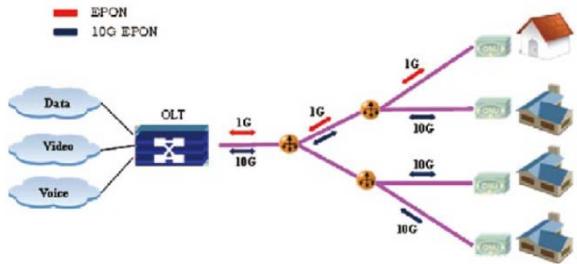


Fig. 6: 10G and 1G EPON co-existence

The WDM technique is used to separate the 1Gbit/s and 10Gbit/s traffic in the downstream direction and combination of WDM and TDM is used in the upstream direction.

5.3 10G EPON Optical Spectrum Allocation: PMD layer is used to represent the 10G EPON wavelength allocation and optical power budget. Figure shows the IEEE P802.3av wavelength allocation spectrum. For downstream data transmission, it adopts 1575 – 1580 nm bands. For upstream, the band is 1260 – 1280 nm which is lapped over 1G EPON. The wavelength allocation enables 10G upstream wavelength to overlap 1G upstream wavelength. So 1G ONU and 10G ONU must use wavelength division multiplexing mode to transmit upstream data. In downstream direction, 10G wavelength and 1G wavelength are separated. This guarantees the downstream data to enjoy broad bandwidth.

5.4 10G Convergence: ITU and IEEE in 10G PON would allow for the shared and convergence of the chips, optics and hardware platforms, thus driving costs reductions. Carriers would still have a choice of technologies in 10G

PON, but would have the advantages of a single physical layer. That converged system is possible feasible in which only differences will be left at higher level. As a result convergence brings unified OAM, ODN and service models.

5.5 10G EPON Industrial Chain: The series of equipment evolves based on current xPON equipment smooth migration and enable to improve the capability of system access bandwidth enlargement and service access.

5.6 Dynamic Bandwidth Allocation (DBA): 10GEPON system is the ability to overcome system bottlenecks and log jams via adjustments in the EPON DBA algorithm. The DBA cycle length and bandwidth allocation per ONU can be adjusted and as a result total OLT upstream transmission going into the switch will be "smoother", less bursty in nature, allowing carriers to overcome blocking elements in their network topology (e.g. assigning more bandwidth to the OLT ports then the uplink ports in the switch connected to the OLT to save CAPEX).

5.7 Power Budgets: The 803.av defines several power budgets, denoted either PR or PRX. PRX power budget describes asymmetric rate PHY for PON operating at 10 Gb/s downstream and 1 Gb/s upstream. PR power budget describes symmetric-rate PHY for PON operating at 10 Gb/s downstream and 10 Gb/s upstream. Each power budget is further identified with a numeric representation of its class, where value

of 10 represents low power budget, value of 20 represents medium power budget, and value of 30 represents high power budget. To increase optical power budget, it is regulated that 10G EPON technology must be able to achieve FEC which uses RS (255, 223) coding. 10G EPON currently standardize three types of power budget: PR10/PRX10, PR20/PRX20 and PR 30/PRX30. Following Table lists power budget information.

Items	PRX10	PR10	PRX20	PR20	PRX30	PR30	Unit
Maximum Channel insertion loss	20		24		29		dB
Minimum Channel insertion loss		5		10		15	dB

Table2: 10G EPON Power Budget

6. Comparison of PON Technologies

The key difference among various PON technologies are as follows: -

6.1 Bandwidth and Data Rates: Bandwidth guarantees vary between the two protocols: GPON promises 1.25-Gbit/s or 2.5-Gbit/s downstream, and upstream bandwidths scalable from 155 Mbit/s to 2.5 Gbit/s. EPON delivers 1-Gbit/s symmetrical bandwidth. EPON's Gigabit Ethernet service actually constitutes 1 Gbit/s of bandwidth for data and 250 Mbit/s of bandwidth for encoding. The approach of EPON, as part of the Gigabit Ethernet standard, parallels that of Fast Ethernet, which also uses 25 percent for encoding. GPON's 1.25-Gbit service specifies a

usable bandwidth of 1.25 Gbit/s, with no requirement for encoding. Gigabit Ethernet interfaces to the aggregation switch, central office, and metro are currently the cost-effective way to aggregate 1-Gbit ports for transport. With no cost-effective switches for 1.25 Gbit available, the added bandwidth promised by GPON, although measurable, could come at a significant premium over the price of EPON equipment. In other words, the low-cost uplink for the foreseeable future is likely to be Gigabit Ethernet, which is the exact bit rate of EPON. In that light, GPON's "added" bandwidth may not prove advantageous for carriers.

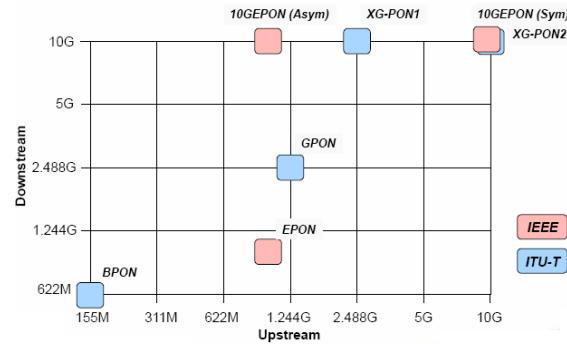


Fig. 54: PON Technologies: nominal data rate map

6.2 Higher distance and splitting ratio: With either protocol, the practical limitation to reach comes from the optical-link budget. With the reach of both protocols currently specified at approximately 20 kilometers, the difference in split rates - the number of optical network units (ONUs) supported by one optical line terminal (OLT) - is a point of differentiation. GPON promises to support up to 128 ONUs. With the EPON standard, there is no limit on the number of ONUs. Depending on the laser diode

amplitude, when using low-cost optics, EPON can typically deliver 32 ONUs per OLT, or 64 with forward error correction (FEC). As per the evolution of PON technologies, the various data rates of GPON and EPON technologies have been shown in following figure.

6.3 Per-subscriber costs: The use of EPON allows carriers to eliminate complex and expensive ATM and Sonet elements and to simplify their networks, thereby lowering costs to subscribers. Currently, EPON equipment costs are approximately 10 percent of the costs of GPON equipment, and EPON equipment is rapidly becoming cost-competitive with VDSL.

6.4 Encryption: With GPON, encryption is part of the ITU standard. However, GPON encryption is downstream only. EPON, on the other hand, uses an AES-based mechanism, which is supported by multiple silicon vendors and deployed in the field. Furthermore, EPON encryption is both downstream and upstream.

6.5 Efficiencies of GPON & EPON Standard: With both PON protocols, a fixed overhead is added to convey user data in the form of a packet. In EPONs, data transmission occurs in variable-length packets of up to 1518 bytes according to the IEEE 802.3 protocol for Ethernet. In ATM-based PONs, including GPONs, data transmission occurs in fixed-length 53-byte cells (with 48-byte payload and 5-byte overhead) as specified by the ATM protocol. This format makes it inefficient for GPONs to

carry traffic formatted according to IP, which calls for data to be segmented into variable-length packets of up to 65,535 bytes. For GPONs to carry IP traffic, the packets must be broken into the requisite 48-byte segments with a 5-byte header for each. This process is time-consuming and complicated and adds cost to the central-office OLTs as well as the customer premise-based ONUs. Moreover, 5 bytes of bandwidth are wasted for every 48-byte segment, creating an onerous overhead that is commonly referred to as the "ATM cell tax". (This is the case with GPON's ATM encapsulation mode. In its other encapsulation mode, called GEM, the ATM cell tax does not apply). By contrast, using variable-length packets, Ethernet was made for carrying IP traffic and can significantly reduce the overhead relative to ATM. One study shows that when considering trimode packet size distribution, Ethernet packet encapsulation overhead was 7.42 %, while ATM packet encapsulation overhead was 13.22 %. In addition, since Ethernet frames contain a vastly higher ratio of data to overhead than GPON, that high utilization can be reached while using low-cost optics. The more precise timing required with GPON results in more expensive optics. High-precision optics are mandatory as part of the GPON standard.

6.6 Single management systems: EPON requires a single management system, versus three management systems for the three Layer 2

protocols in GPON, which means EPON results in a significantly lower total cost of ownership. EPON also does not require multiprotocol conversions, and the result is a lower cost of silicon. GPON does not support multicast services, which makes support for IP video more bandwidth-consuming.

6.7 Comparative summary of various Next Generation PON system: The basic difference among 10G EPON and other 10G PON technologies is summarized in the following table: -

PON Technology	10 GEPON	10 G PON (XG-PON1/ XG-PON2)	WDM PON
Standard	IEEE P802.3av	ITU-T G.987/ FSAN	ITU G.983
Maximum Bandwidth	10.3125 Gb/s	2.5 Gb/s & 10 Gb/s	1 - 10 Gb/s per channel
Maximum Downstream Line Rate	IP; 2.4 Gbps, Broadcast; 5 Gb/s On-demand; 2.5 Gb/s	10 Gbit/s	1 - 10 Gbit/s per channel
Maximum Upstream Line Rate	2.5 Gbps	2.5 Gb/s	1 - 10 Gbit/s per channel
Downstream wavelength	1577 nm	1577 nm	Individual wavelength /channel
Upstream wavelength	1270 nm	1270 nm	Individual wavelength /channel
Traffic Modes	Ethernet	GEM	Protocol Independent
Video	RF/IP	RF/IP	1550 nm overlay/IP
Max PON Splits	128	128	16 - 32
Max Distance	10 Km	20 Km	20 Km
Average Bandwidth per User	> 100 Mbit/s	> 100 Mb/s	1 - 10 Gbit/s
Cost	High	High	Very high

Table -1: Comparison of NG PON technologies.

7. Benefits of 10GE PON Technologies

10 G EPON is simpler, more efficient, and less expensive than alternate multiservice access solutions. Key advantages of 10GE PONs include the following: -

7.1 Very High Bandwidth: The higher BW of 10G EPON provides a number of benefits: -

- More subscribers per PON
- More bandwidth per subscriber
- Higher split counts
- Video capabilities
- Better QoS
- Cost - reduction applications

7.2 Lower Costs: 10G EPON systems are riding the steep price/performance curve of optical and Ethernet components. As a result, 10G EPON offers the features and functionality of fibre-optic equipment at price points that are comparable to DSL and copper T1s. Further cost reductions are achieved by the simpler architecture, more efficient operations, and lower maintenance needs of PON. 10G PONs deliver the following cost reduction opportunities: -

- Reduced OpEx and CapEx cost associated with this migration of network.
- Eliminate complex and expensive ATM and SONET elements and dramatically simplify network architecture.
- Long-lived passive optical components reduce outside plant maintenance.

- Standard Ethernet interfaces eliminate the need for additional DSL or cable modems.
- No electronics in outside plant reduces need for costly powering and right-of-way space

7.3 Higher distance and Splitting Ratio: The splitting ration may be more than 1:128. The distance may be extended upto 100 km.

7.4 More Revenue: Revenue opportunities from 10GE PONs includes: -

- Support for legacy TDM, ATM, and SONET services.
- Delivery of new gigabit Ethernet, fast Ethernet, IP multicast, and dedicated wavelength services.
- Provisioning of bandwidth in scalable 64 kbps increments up to 10 Gbps.
- Tailoring of services to customer needs with guaranteed SLAs.
- Quick response to customer needs with flexible provisioning and rapid service reconfiguration.
- Innovative improvement on device, enhanced network capability and optimization synergy
- Same OAM for stronger end to end monitoring will be used intensively.

7.5 Upgradation of network: The network can be upgraded and no disruption of the services in network operations during the upgradation of the network. Migration from EPON to 10G EPON by upgrading the OLT then migrating the ONUs as needed.

7.6 Cost - Reduction Applications: 10GE PONs offer service providers unparalleled opportunities to reduce the cost of installing, managing, and delivering existing service offerings. For example, 10GE PONs do the following: -

- Uses cost efficient ONU for the required desired service.
- Replace active electronic components with less expensive passive optical couplers that are simpler, easier to maintain, and longer lived.
- Conserve fibre and port space in the central office (CO).
- Share the cost of expensive active electronic components and lasers over many subscribers.
- Deliver more services per fibre and slash the cost per megabit.
- Promise long-term cost-reduction opportunities based on the high volume and steep price/performance curve of Ethernet components.
- Save the cost of truck rolls because bandwidth allocation can be done remotely.

8. Conclusion

The 10G EPON protocol are developing very fast. The 10G EPON can not only inherit EPON large-scale deployment experiences but also co-exist with other EPON/GPON without changing existing ODN network, thus it saves a lot of cost for carriers. The 10GPON has many advantages in terms of standardization, maturity, cost and power consumption etc. In respect of management, point-to-point systems are

typically easier to maintain than point-to-multipoint systems. Thus, the trend is that 10G EPON is envisioned for residential applications. However, for longer distances e.g. 100 km or more, the solutions are needed with remote monitoring from the CO to the end-user. As today however, Triply Play services (telephony, data and TV down one single line) are transmitted to the subscriber, therefore QoS applies more than ever. The 10G EPON architecture is proving to be a cost-efficient way to deliver converged voice, video and high-speed data services to the home or business. One of the most distinctive features of the Fibre Path PON system is its ability to support both upstream and downstream data transmissions at equally fast speeds - speeds. The more future work is required on high data rate media streaming services over 10G EPON architecture, which enhances the client Quality of Services and security.

References

1. ADC Krone “*The Book on Next Gen Networks*” The essential information you need to know when deploying FTTX, from the central office to the outside plant to the customer premises.
2. FTTxtra Tutorial, ‘*10G GPON*’ web <http://www.fttxtra.com/ftth/10g-gpon-brief-overview>.
3. Hilbk U., Hermes T., Saniter J. and Westphal F. J., ‘*High-capacity upgrade of a PON by means of wavelength-routers and WDM techniques*’ WDM Technology and Applications (Digest No. 1997/036), IEE Colloquium on Volume, Issue, 6 Feb 1997 Page(s) 3/1 to 3/5.
4. Kyeong Soo Kim, ‘*On The Evolution of PON-Based FTTH Solutions*’ Advanced System Technology, STMicroelectronics Stanford Networking Research Center, Packard Building, Room 073, Stanford, CA 94305.
5. Shea D.P. and Mitchell J.E. ‘*A 10-Gb/s 1024-Way-Split 100-km Long-Reach Optical-Access Network*’ Lightwave Technology, Journal of Volume 25, Issue 3, March 2007 Page 685 to 693.
6. *Next-Generation PON Evolution*, Huawei Technologies Co., Ltd.
7. Ram Krishna, R. K. Siddhartha, Naveen Kumar, White Paper ‘*Higher Capacity Passive Optical Network [HCPON] for FTTX Broadband Access Applications*’, TEC, DoT, Govt. of India, New Delhi.
8. Ashutosh Pandey, Naveen Kumar, ‘*Next Generation Passive Optical Network [HCPON] for FTTX Broadband Access Applications*’, Technical Article in Compendium-II, 2010, TEC, DoT, Govt. of India, New Delhi.
9. White Paper ‘*10G EPON- Unleashing the Bandwidth Potential*’, www.zte.com.cn
10. Frank Chang et. al., ‘*Overview of 10Gb/s EPON Status, Requirements and Applications*’, www.ethernetalliance.org.
11. Onn Haran, Design Article, ‘*EPON vs. GPON: A Practical Comparison*’ <http://www.eetimes.com/design/communications-design/4009354/EPON-vs-GPON-A-Practical-Comparison>