IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

STUDY THE PASSIVE OPTICAL NETWORK EVOLUTION TO NEXT GENERATION PASSIVE OPTICAL NETWORK

[1]Shailendra Kumar Singh , [2]Devendra Pradhan,
[2]Associate Professor
[1]MGU Bhopal, M.P,India
[2]MGU Bhopal, M.P,India

Abstract **:** The explosive development of emerging telecommunication services has stimulated a huge growth in bandwidth demand as people seek universal access to telecommunication networks. In addition, the kinds of services of an existing optical access network are becoming more flexible.The rapid expansion of Internet traffic shoves the communication networks to optical access networks for enhancing the transmission information rate. Passive optical network (PON) is a developed and most encouraging access network which provides the high bandwidth, information rate and low cost architecture for home and business enterprises. The main aim of this paper is to review the standardization evolution of PON to next generation passive optical network (NG-PON). Additionally, the literature review of PON and NG-PON based technologies are discussed. Also, it presents the possible challenges in NG-PON alongside their strengths and weakness in different techniques.

Keyword- PON, EPON, GPON, XG-PON, Optical network

INTRODUCTION

An optical network is a „light" based communication network, which uses the optical fibre cables for information transmission from transmitter to receiver. This network has several merits as compared to other networks such as high bandwidth, high speed (up to Tbps), immune to electrical interferences, low power requirement, low signal distortion, low cost and so on. Out of various optical access network, PON is a promising and future based optical access network and created the fibre to the x (FTTx) services, video telephony, e-services etc. applications among users from households to enterprises [1-2]. PON optical access network was developed in 1980 and derived its name because of utilization of passive components like combiner, splitters and couplers. It is a bi directional (upstream/downstream), less costly, highly resource efficient, transparent, secure, adaptable and upgradable for next generation optical access network as compared to other optical access networks. PON does not need electrical power and it is widespread optical access networks as compared to active optical access network [3-4] Fig. 1 [5] demonstrates the block diagram of PON. It consists of an optical line terminal (OLT) or central office (CO), optical distribution network (ODN) and several optical network units (ONUs). OLT/CO is located at service provider's central office. It is connected to the 1×N splitter through optical fibre. It is used to control the data flow across the optical distribution network (ODN), in both directions; upstream as well as downstream and provides services to end users. Upstream means to get the data, audio and video traffic from end users and downstream means to get the data, audio and video traffic from long haul access network. ODN provides transmission physical medium from ONT to ONUs for point to multipoint PON architecture.

It consists of optical fibres, optical connector, splitters, couplers and auxiliary components. In ODN, a feeder fibre from OLT and to optical distribution fibre for long-distance transmissions is used. The distribution fibre, points to different optical access points and distributes the optical fibres to different areas ONU converts optical signals to electrical signals to send the data individually to end users. It connects the ODN through twisted-pair/coaxial/optical fibre cable or wireless access. It allows the efficient bandwidth allocation (for smooth data delivery) and grooming (for efficient delivery) [5-8]. In this paper, evolution of PON to NG-PON has been reviewed.

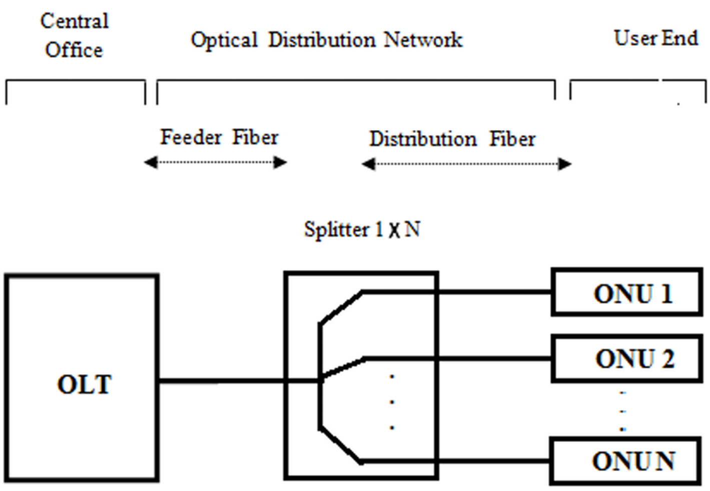

Figure 1. Basic passive optical network architecture

NEED OF STUDY.

The need for connection is at its zenith and is expected to stay so throughout the 21st century. Annually, the demand for data rates and bandwidth per user is growing, with a rise in the number of electronic devices. Advancements in electronics, electrical engineering, automotive technology, transportation, finance, and several other sectors have led to a rising need for connection devices per user. The access network offers internet connectivity to user-owned devices to facilitate triple play services. The access network consolidates internet traffic requirements and transmits it to the optical access network port. The optical access network thereafter directs the traffic via the metro and core optical networks to fulfil the requirements of the device and, therefore, the user. Our endeavour is to address the present traffic demand for optical access networks while also accommodating future requirements using the existing optical infrastructure.

Research Methodology

This work proposes a model and evaluate the downstream data transmission of 112Gbit/s in NG-PON 2 using a consistent detection in a phase-shift modulation format of advanced polarisation (PM-QPSK). We suggest the use of various digital signal processing algorithms on the receiver to enhance device efficiencies in the face of fibre attenuation and nonlinear deficiencies. A digital signal processing (DSP) device, suggested in this work to improve the accuracy of the signal in the face of dispersal and nonlinear effects. The empirical examination of the planned NG-PON method is carried out by using BER, power receipt and the constellation signal parts as measurement parameters to increase the transmission time of the optical fibre. In terms of propagation duration and bit transmission rate, the efficiency of the proposed NG-PON method is also contrasted with the current literature. For a variety of different optical network units (e.g. 64, 128, and 256) the proposed NG-PON 2 system is simulated and compared to the measurement parameters using a bit error rate(BER), data signal receiver capacity, and constellation graphs. The sensitivity of the sensor was also numerically examined for various end users of the proposed device.

In addition, the transmission efficiency of the proposed NG-PON 2 device was also compared to established literature. The proposed model evaluates the co-existence of GPON transmission with a data rate at 2.5 Gbit/s and XG-PON transmission with a data rate at 10 Gbit/s for both downstream as well as upstream transmission. For PIN and APD photodiodes, the proposed device output was compared using Q Factor and eye diagrams of the obtained signals as the performance measurement parameters through variations of the propagation duration of the optical fibre for downward and upstream transmission.

1. Evolution of PON

An access network is defined as the last mile network which connects the end users and CO or a remote feeder node. In today's access networks, twisted-pair and coaxial cables are still dominant transmission medium in cable-TV and telecommunication networks. But in future, optical fibre based access networks will change the world [8]. The generation of the PON architectures and their corresponding capacity features are shown in Fig. 2 [5]. Around mid-1980s, fibre-based access networks were not encouraging because of its high cost than copper.

But service providers have always been interested in `future-proof' fibre based access networks due to high information-carrying capacity, ease of maintenance, immune to electrical interference, others external signal disturbances, resistance to environmental and chemical effects [4], [8].

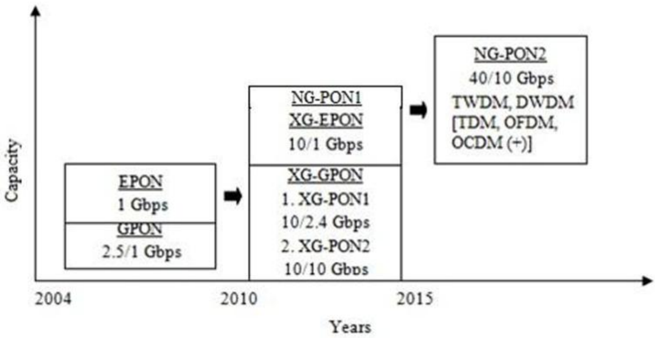

Figure 2. Evolution of PON w.r.t capacity and data rates per wavelength

In late 1990s effective optical technologies progressed for reducing component and system cost such as optoelectronic, optical device fabrication, application specific integrated circuits (ASICs), optical assembly and optical packaging. But, the rise of competition among services provides of many countries motivate towards the number of optical access technologies such as FTTx. FTTx network can be PON or an active optical network (AON), based on the use of active or passive components respectively. The Ethernet switch based AONs networks are suitable for small management overhead. They are difficult to deploy for the large-scale service provider (10-20km). But PON offers the large-scale services to end users due to the use of less cost passive components between OLT and ONUs [4], [8]. By the mid-1990s, optical technology has grown with core and metro network for large bandwidth demand users and last-mile/access networks. Full-service access network (FSAN) consortium using time-division multiplexing/ time division multiple-access (TDM/TDMA) was an important development with low cost in 1995. In 1996, FSAN technical membership agreed for asynchronous transfer mode (ATM) at 155/155Mbps data rates and it becomes international telecommunication union (ITU-T) G.983.1. Further, the increase of interested service providers upgrades ATM-PON (A-PON) to broadband passive optical network (B-PON) ITU-T G.983 series, at specified 622/155Mbps data rates over 20km distance between the OLT and 32 ONUs using wavelength division duplex [4],[8]. A. First Generation PON In March 2001, E-PON (IEEE 802.3ah standard) was ideal for Internet access services at 1/1Gbps data rates over 10 or 20km transmission distance with 16 ONUs per OLT. EPON has gained success in East Asia. Then to carry packetized traffic more natively, GPON (ITU G.984 series) was selected at 2.5/1.25Gbps data rates. GPON became popular in Italy and Spain, England, France, Germany and many more countries. Although, the “over the top” service EPON systems replace the cable modem or digital subscriber line (DSL) to eliminate the copper wiring issues, but also raises the fibre cabling potential trouble inside customer's home. GPON systems deployed for full service to become the customer's complete home networking device. The word NG-PON got famous with the EPON, which make the use of cheap and omnipresent Ethernet hardware at 1Gbps broadcast speed [4],[9]. These are described as follows:

a) Ethernet Passive Optical Network (EPON): EPON is an optical tree (point-to-multipoint) topology that carries 802.3 Ethernet frames from an OLT to various ONUsthrough a passive optical splitter. To allocate the bandwidth of upstream transmission (from ONU to OLT)) among ONUs, access control is required. In tree topology, downstream (from OLT to ONUs) and upstream transmission are considered as a point-to-multipoint and multipoint-to-point PON network respectively. An EPON in the downstream transmission, utilizes as a broadcast wavelength division multiplexing passive optical network (WDM-PON), GPON etc. The OLT broadcasts the 802.3 Ethernet frames to all shared-medium ONUs [4], [9].

b) Gigabit Passive Optical Network (GPON): It is defined in the ITU standards (ITU-T G.984.n). This is an attractive technology in backhaul with the ability of GPON encapsulation mode (GEM) protocol. This protocol is employed to transmit both data and TDM traffic simultaneously over the same fibre. As a result, GPON systems can handle high-bandwidth scenarios effectively as compared to other data-centric protocols. In addition to maximum backhaul data traffic capacity, it provides the protection mechanisms and suitable for high peak traffic demand as compared to EPON. It uses with maximum split ratio of 128 over the 60km distance at 2.5/1Gbps data rates. Hence, with careful selection of reach and the split ratio at selected nodes, GPON systems could serve such nodes in various regions [4],[10]. Some features of EPON and GPON are summarized in Table 1[5].As the first generation PON is based on TDM but it provides lower data rates and less speed. Hence, the next generation NG-PON access network fills the gaps of first generation PON. There are two next generations PONs with physical and data link layer modifications [4],[5].

Table 1. EPON versus PON

S.No.	Features	EPON	GPON
1.	Standard	IEEE	ITU-T
2.	Transmission speed	Downstream: 1.2Gbps Upstream: 1.2Gbps	Downstream:1.2/ 2.4Gbps Upstream:1.5/6.2/ 1.2/2.4Gbps
3.	Split ratio	1:16	1:64
4.	Line code	8B/10B	Non return to zero (NRZ)
5.	Protocol	Ethernet	ATM
6.	Security	Not ensured	Advanced encryption standard (AES)
7.	Quality of service (QoS)	Not supported	Supported
8.	Forward error correction (FEC)	Optional RS(255,239)	Optional RS(255,239)

2. Next Generation Passive Optical Network (NG-PON)

NG-PON is subdivided into two standards as following: 1) Next Generation Passive Optical Network stage 1 (NG-PON1): It consists of next generation evolution of EPON and GPON at higher bit rate as compared to XG EPON and XG-GPON. These are given as following: a) From EPON to Next Generation EPON (XG EPON): XG-EPON inherits many features from EPON. There are some modifications in physical layer. In terms of bit rate, XG-EPON supports two physical layer modes: (1)symmetric transmission at 10Gbps or (2) asymmetric transmission at 10/1Gbps data rates. The TDM technique used in EPON enables the deployed EPON and XG-EPON to coexist. However, a multi-rate OLT is required to provide pre-amplification by utilizing semiconductor optical amplifiers (SOA) [5], [11]. b) From GPON to Next Generation GPON (XG GPON): XG-GPON has characteristics which are similar to the deployed GPON with some divergences in the physical layer that provide considerable performance improvements.

The XG-GPON is divided into two classes: (1) XG-GPON1 provides an asymmetrical transmission with 10/2.5Gbps data rates and (2) XG-GPON2 which provides 10Gbps symmetrical transmission. In particular, the XG-GPON1 physical layer has been defined in ITU-T G.987.2 series. According to the ITU G.987.1, for XG-GPON1 recommendation, two scenarios have been proposed to enable migration from GPON to XG-GPON1. The first scenario is a green-field migration, which is the replacement of the copper connection into premises with an optical connection. The other option is the PON migration scenario, which is an up gradation of the existing GPON system. This includes the replacing or upgrading some network components such as ONU units or OLT modules [5], [11-13]. 2) Next Generation Passive Optical Network stage 2 (NG-PON2): NG-PON2 is defined in ITU-T G.989 series. It is a successor standard of EPON, GPON, and NG-PON1. It supports the multiple wavelengths per direction and compatibility over ODNs. NG-PON2 has various multiplexing technologies PON e.g. WDM-PON, TDM PON, orthogonal frequency division multiplexing passive optical network (OFDM-PON), optical code division multiplexing passive optical network (OCDM-PON) and their combinations such as TDM/WDM-PON, OCDM/WDM-PON, OFDM/WDM-PON, OCDM/TDM PON, OFDM/TDM-PON etc. [5], [13].The international standards of PON are summarized in Table 2 [14].

Table 2. International standards of PON

S.No.	Technology (Year)	Standard	Downstream bit rate (Gbps)	Upstream bit rate (Gbps)
1.	BPON (2001)	ITU-T G.983.1 - G.983.5	$\leq$1.25	$\leq$0.625
2.	EPON (2004)	IEEE 802.3ah	1.25	1.25
3.	10G-EPON (2009)	IEEE 802.3av	10	1
4.	GPON (2004)	ITU-T G.984	2.5	1.25
5.	NG-PON1 (2010)	ITU-T G.987	$\leq$10	10
6.	NG-PON2 (2013)	ITU-T G.989.1	40	10

3. Multiplexing techniques in PON

As PON comprise various multiplexing techniques with high speed from first to next generation PON. The basic multiplexing techniques TDM, WDM, OFDM and OCDM are as follows: [14].

3.1 TDM-PON

TDM is the first used multiplexing technique in PON, which consists of three basic parts ONT, ONU and ODN as in PON architecture. TDM is used in GPON and NG-PON1 access networks. Also, in NG-PON2 access network, it can combined with others multiplexing techniques e.g. TDM/WDM, TDM/OCDM, TDM/OFDM etc. The basic TDM-PON architecture is shown in Fig. 3 [5].

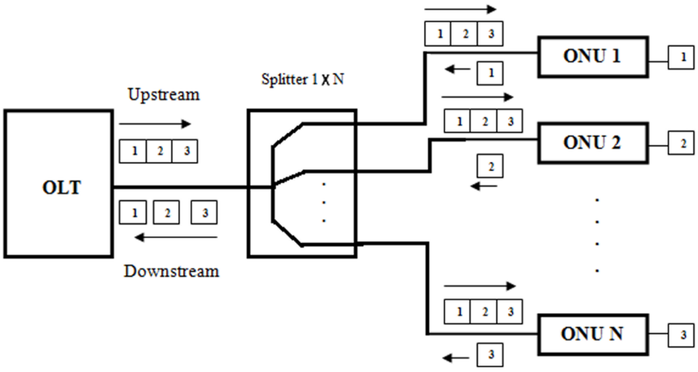

Figure 3. TDM-PON architecture

TDM-PON is a point to multipoint network. Here, OLT transmits the data to the ONUs (downstream traffic). The OLT transmit data to the ONUs by connecting through the passive components viz. optical combiner or splitter and optical fibre. The passive components split or combine the signal from OLT to ONUs. The ONUs used as the optoelectronic components. The data transmission proceeded in packets with a definite time delay to distinguish the packets meant for each ONU [4], [15].

3.2 WDM-PON

As TDM-PON architecture offers an economical and high data rate network as compared to DSL and coaxial networks. But this network is not optimum network due to restricted bandwidth utilization and requires time synchronization.The WDM-PON block diagram is shown in Fig. 4 [5]. WDM-PON is used by assigning an individual wavelength to each end user with high bandwidth, high user mobility and low transmission loss as compared to TDM-PON. For NG PON2 access network, WDM can be combined others multiplexing techniques based on desired requirements for optical access networks [16-18].

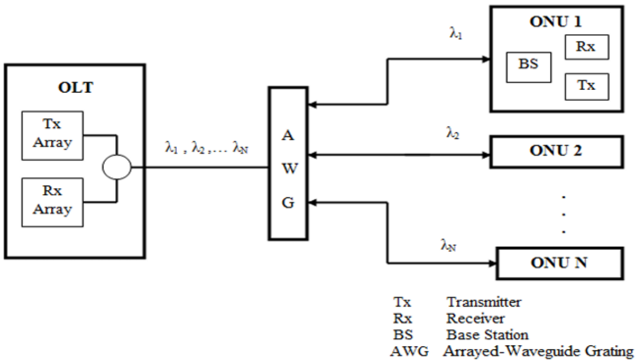

Figure 4. WDM-PON architecture

As shown in Fig. 4 [5], data is transmitted to all ONUs by assigning a particular wavelength. Here, multiple arrayed waveguide gratings (AWGs) or optical filters are used to increase the number of wavelengths [19].

3.3 OCDM-PON

In an OCDMA-PON technique each simultaneous user uses a unique optical code sequences to send the data from the transmitter to receiver. This increases the protocoltransparency, security, flexibility and performance of PON. The spectral amplitude coding optical code division multiple access (SAC-OCDMA) networks reduce the multiple access interference (MAI) and phase-induced intensity noise (PIIN) using different codes. These codes can be 1D, 2D or 3D code. Each code has its own advantages and disadvantages. The best code is chosen on the basis of simplicity, flexibility to add users, minimum cross-correlation and maximum autocorrelation [20].

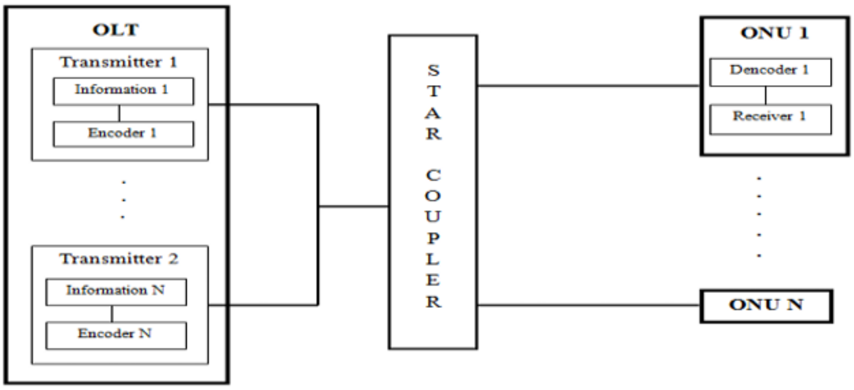

Figure 5. OCDM-PON Architecture

The OCDM-PON architecture is shown in Fig. 5 [5]. In transmitter side, OLT section encodes the data and then transmits the data over ODN (using optical fibre star coupler). At the receiver side, the data received at ONUs by using decoder. This increases the data security in PON. It can be multiplied with TDM, WDM, OFDM etc. to secure the transmission data [20].

3.4 OFDM-PON

OFDM-PON has been highlighted as one of the strong candidates due to great lack of fibre dispersion, high spectral efficiency, adaptability on multiple services provisioning and dynamic bandwidth allocation in PON. The OFDM-PON architecture is shown in Fig. 6 [5].

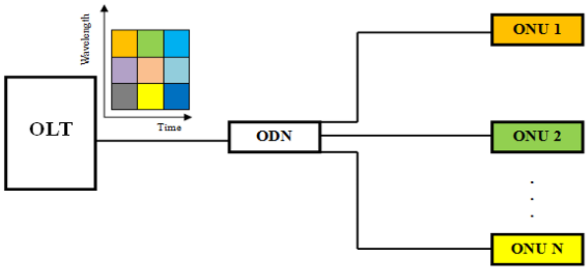

Figure 6. OFDM-PON architecture

4. Significant findings

Another multiplexing technique used in PON are space division multiplexing (SDM) and polarization division multiplexing (PDM) which is based on the exploitation of orthogonal polarizations at single wavelength [14]. Table 3 [14] describes the merits and demerits of multiplexing techniques used in PON and NG-PON.

Table 3. Multiplexing techniques for PON and NG-PON

S.No.	Techniques	Merits	Demerits
1.	TDM	Mature and inexpensive technology	Limited scalability, Need synchronization, Bandwidth wastage
2.	WDM	Security; transparency to protocols, modulation formats and bit rates'; simplified unbundling and scalability	Power consumption in OLT, Photonics technology not yet consolidated
3.	OCDM	Network security with codes and modulation formants, soft-limited technique	MAI noise, Complexity due to codes
4.	OFDM	High spectral efficiency and scalability	Expensive and complex receivers Multiplexing techniques not yet consolidated
5.	PDM	Increased information capacity	Expensive and complex receivers
6.	SDM	Increased information capacity	Expensive
7.	TWDM	Gradual migration from commercial solutions	Limited scalability Inefficient energy usage

The WDM PON network performed better than TDM PON network performance of Manchester coding as compared to return to zero (RZ) and non-return to zero (NRZ) coding techniques at 10Gbps bit rate over 100km distance for 16 users [22]. Further, the symmetric and bidirectional WDM/OCDMA-PON system byutilizing superstructure fibrebrag grating (SSFBG) and 127 Gold sequence over 22km at 1.25Gbps. The results show that this system reduces fibre noises for long haul communication [23]. To reduce the energy consumption at OLT, an online TWDM-PON scheduling protocol is highly useful. Results shows that it improves the energy by 25% for 64 ONUs with high load [24].Despite of having high bandwidth, transmission speed, coverage area and energy efficiency, there are some challenges in NG-PON technologies. These challenges are as follows: [5], [14] • Presently, GPON and NG-PON technologies are competing for low bit rate, low capacity and high cost because of TDM multiplexing technique which have limited time slots, inefficient use of scalability and limited capacity for end users. Hence, GPON and NG-PON do not meet the rapid increase of high Internet services and high bandwidth capacity. • The basic optical multiplexing techniques are lacking in performance such as WDM-PON lacking in inefficient bandwidth usage and high cost; OCDMA PON lacking in dependence of network performance on designed address code, MAI noise and structure of a receiver in the presence of various noises and OFDM-PON lacking in complex receivers, optical beat noise, frequency offset and high cost. • The increase in signal dispersion loss, signal nonlinearities such as self-phase modulation (SFM),(FWM) appears as the low bandwidth and low transmission capacity risk in current GPON and NG PON. • In today's competitive networks, the information privacy is one of the main concerns due to context information exchanged among different nodes. • The cost of ONUs in NG-PON is high because of use of complex optical and electronic components. Thus these challenges motivate towards some preferable hybrid WDM/OCDM, WDM/OFDM and OCDM/OFDM etc. multiplexing techniques in NG-PON.

5. Conclusion

Passive optical Networks (PONs) have become a popular fibre access network solution due to its service transparency, cost effectiveness, energy savings, and higher security over other access networks. PON utilizes passive low-power components which removes the need for power-feeding in the fibre distribution network. NG-PON2 is still suffering from a number of challenges include cost, reach, capacity and power consumption. EPON has a simple layering model where it supports a native Ethernet frame to carry data, voice, and video. On the other hand GPON uses two layers of encapsulation. Furthermore, GPON equipment needs virtual channel, segmentation and reassembly, multiple protocol conversions, and point-to-point protocol. Whereas, in the EPON standard, all of the required devices are ubiquitous all the way to the backbone network which in turn makes EPON implementation cost effective. Moving from the deployed PON to NG-PON1 that provides up to10Gbps bit rate includes three scenarios that are from EPON to XG-EPON, from GPON to XG-GPON, and from GPON to XG-EPON.TDM-PON is the simplest technology that utilizes the band width effectively. However, it suffers from a capacity limitation where the bandwidth is shared among all of the users and each user is assigned to a certain time interval, which leads to reduced bandwidth per user. Furthermore, security is not guaranteed due to the fact that the downstream traffic is broadcast to all the users which lead to the possibility of eaves dropping and to overcome this limitation data encryption is required. WDM-PON on the other hand eliminates the capacity limitation and security issues in TDM by assigning a wavelength to each user; thus, building a virtual point to point connection between the OLT and ONUs. In future, hybrid technologies have been introduced to improve performance. Although TWDM-PON has been considered as the most prominent solution that meets the next generation requirements, experimental investigation of other hybrid technologies is needed to find out whether it is possible to achieve better performance. Hybrid technologies that include OCDM or/and OFDM based LR-PON are a key solution to overcome the major challenges of increasing network capacity and reach, and reducing the total cost and power consumption. Research is ongoing and applying the methods discussed previously might provide data rates of 100Gbps and beyond. The use of OCDM or/ and OFDM for LR-PON is an important research direction that could lead to improved long reach networks at reduced overallcost.

Reference

[1] S. Rajalakshmi, A. Srivastava, and A. Pandey, "Rsoa based 10G Wdm for long reach Pon using manchester coding for remodulation," Int. J. Eng. Sci. Technol., vol. 4, no. 04, pp. 1767 1775, April 2012.

[2] G. Pandey and A. Goel, "Performance analysis of symmetrical 10 Gbps colorless WDM-PON using subcarrier modulated downstream and wavelength converted upstream through RSOA," Optik (Stuttg)., vol. 125, no. 17, pp. 4951–4954, September 2014.

[3] M. De Andrade, M. Maier, M. P. McGarry, and M. Reisslein, "Passive optical network (PON) supported networking," Opt. Switch. Netw., vol. 14, no. PART 1, pp. 1–10, August 2014.

[4] F. Effenberger and T. S. El-Bawab, “Passive optical networks (PONs): Past, present, and future,” Opt. Switch. Netw., vol. 6, no. 3, pp. 143–150, July 2009.
[5] H. S. Abbas and M. A. Gregory, “The next generation of passive optical networks: A review,” J. Netw. Comput. Appl., vol. 67, pp. 53–74, March 2016.
[6] R. Q. Shaddad, A. B. Mohammad, and A. M. Al-Hetar, “Analysis of physical layer performance of hybrid optical-wireless access network,” Opt. Commun., vol. 284, no. 20, pp. 4894–4899, September 2011.
[7] D. T. Van Veen and V. E. Houtsma, “Proposals for cost-effectively upgrading passive optical networks to a 25G line rate,” J. Light. Technol., vol. 35, no. 6, pp. 1180–1187, March 2017.
[8] C. Mas Machuca, L. Wosinska, and J. Chen, “Assessment methodology of protection schemes for next generation optical access networks,” Opt. Fibre Technol., vol. 26, pp. 82–93, December 2015.
[9] N. Kashima, “Upgrade of passive optical network using Raman amplification,” J. Opt. Commun., vol. 34, no. 4, pp. 315–323, January 2013.
[10] T. Nishitani, Y. Hirano, M. Noda, and K. Motoshima, “Protection Systems for Optical Access Networks,” J. Light. Technol., vol. 35, no. 6, pp. 1197–1203, January 2017.
[11] N. Kashima, “Transmission properties of passive optical network using hybrid raman amplifiers,” J. Opt. Commun., vol. 35, no. 1, pp. 1–7, January 2014.
[12] T. Gilfedder, “Deploying GPON technology for backhaul applications,” BT Technol. J., vol. 24, no. 2, pp. 20–25, April 2006.
[13] M. Sahafi, A. Rostami, and A. Sahafi, “All-optical high speed logic gates using SOA,” Opt. Commun., vol. 285, no. 9, pp. 2289–2292, May 2012.
[14] T. Muciaccia, F. Gargano, and V. Passaro, “Passive optical access networks: State of the art and future evolution,” Photonics, vol. 1, no. 4, pp. 323–346, October 2014.
[15] P. Brandao Harboe and J. Rodolfo Souza, “Passive optical network: characteristics, deployment, and perspectives,” IEEE Lat. Am. Trans., vol. 11, no. 4, pp. 995–1000, June 2013.
[16] T. P. Horikis and M. J. Ablowitz, “Passive mode-locking under higher order effects,” vol. 31, no. 11, pp. 2748–2753, October 2014.
[17] D. Carmona, J. Prat, I. Tomkos, and M. P. S. Marco, “Costs of fibre to-the-home passive optical network unbundling,” Fibre Integr. Opt., vol. 32, no. 1, pp. 28–41, January 2013.
[18] M. Zhu, “Cost-effective centralized automatic protection switching scheme for reliable wavelength division multiplexing passive optical network,” Opt. Eng., vol. 51, no. 5, p. 055005, May 2012.
[19] D. Patel and U. D. Dalal, “A novel wavelength reused bidirectional RoF-WDM-PON architecture to mitigate reflection and Rayleigh backscattered noise in multi-Gb/s m-QAM OFDM SSB upstream and downstream transmission over a single fibre,” Opt. Commun., vol. 390, no. November 2016, pp. 26–35, May 2017.
[20] B. C. Yeh, “Noncoherent spectral optical CDMA system using 1-D multi method codes in one optical ring network,” Optik (Stuttg)., vol. 130, pp. 633–643, February 2017.
[21] W. Zhou and J. Ma, “A novel multi-band OFDMA-PON architecture using signal-to-signal beat interference cancellation receivers based on balanced detection,” Photonic Netw. Commun., vol. 32, no. 1, pp. 54–60, October 2015.
[22] S. Rajalakshmi, A. Srivastava, and A. Pandey, “Analysis of TDM and WDM PON using different coding schemes for extended reach,” vol. 11, no. 7, pp. 171–177, July 2011.
[23] C. Q. Gan and Y. N. Cao, “Novel architecture of WDM/OCDMA PON based on SSFBG and wavelength re-modulation technology,” J. Shanghai Univ., vol. 15, no. 2, pp. 96–100, April 2011.
[24]S. Dutta, D. Roy, C. Bhar, and G. Das, “Online scheduling protocol design for energy-efficient TWDM-OLT,” J. Opt. Commun. Netw., vol. 10, no. 3, pp. 260–271, February 2018.