A Review on Evolution Trends in Passive Optical Networks

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doi: https://doi.org/10.21467/proceedings.114.30

Abstract

In this paper, the passive optical network (PON) evolution trend has been discussed. The literature of PON standards which are ATM PON (APON), Broadband PON (BPON), Gigabit PON (GPON), 10-Gigabit-capable passive optical networks (XG-PON) and next-generation PON2 (NG-PON2) has been reviewed extensively. From the literature review, a comparison of the PON technologies is made. The GPON, XG-PON and NG-PON2 are the most recent PON generations, and these are simulated to find the split per wavelength supported. The Q-factor below 6 is considered unacceptable in the analysis. The results show that the GPON can support 32 ONU when transmitted power set to 3dB. In the case of XG-PON, the Q-factor remains more than 6 for a split ratio up to 16. For the NG-PON2, the observed Q-factor is more than 6 for split up to 32. However, as the split increases above 32, the Q-factor falls below the acceptable level of 6.

Keywords: BPON, GPON, XG-PON, NG-PON2, Split.

1 Introduction

With the increase of bandwidth demand, operators look for new network technologies that can provide higher capacity and flexibility to satisfy the increasing traffic demands. PON is a new emerging technology to fulfil these requirements. In this paper, the architecture of existing PON networks has been studied and analyzed. This paper is organized into three. In Section II, the PON standard evolution is discussed based on ITU-T recommendations. The performance of GPON, XG-PON and 40 Gbps NG-PON2 is investigated by observing Q-factor in section III.

2 Evolution of PON

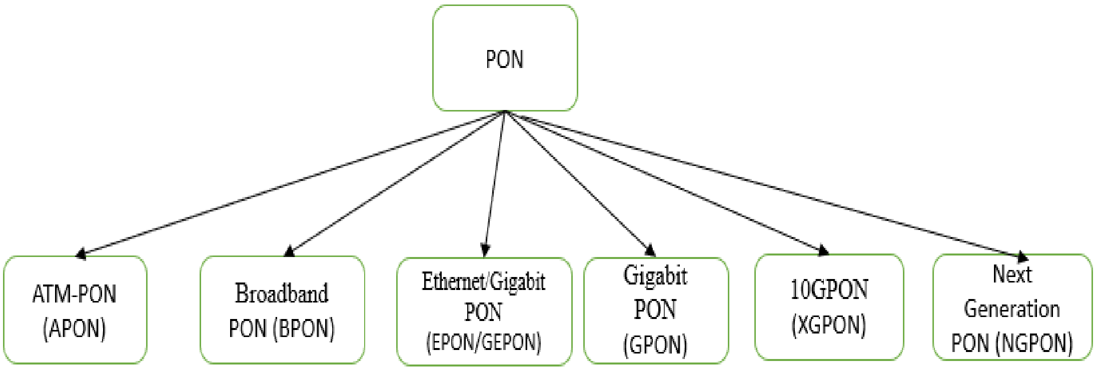
The PON emerged as the most powerful broadband access network technology in the communication system since the first ITU Recommendation G.983.1 [1] created by full-service access network (FSAN). PON consists of three main parts:

a. Optical Line Terminal (OLT): OLT is located at the central office (CO). It provides the interface between PON and the backbone network. It is responsible for managing all the functionality of the PON.
b. Optical Network Unit (ONU): ONU provides the interface between the service provider to the end-users. It is located at the premises of the end-user.
c. Optical Distribution Network (ODN): ODN provides transmission between OLT and ONU through the fiber and splitter.

PON is a vastly deployed access network to fulfil the continuously increasing demands of users. The communication network between OLT and ONU is entirely passive. It means it does not require an external power supply or battery backup. This passive network makes it more fault-tolerant, which decreases the maintenance cost of the infrastructure. The first idea was presented in the 1980s to make a network completely passive [1]. The main PON standards proposed by the ITU are the ATM PON (APON) [2], Broadband PON (BPON) ITU-T G.983 [3], Gigabit PON (GPON) ITU-T G. 984 [4], Ethernet PON

Proceedings DOI: 10.21467/proceedings.114; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-8-8

(EPON) IEEE 802.3 [5], 10-Gigabit-capable passive optical networks (XG-PON) ITU-T recommendation series G.987 [6] and next-generation PON2 (NG-PON2) ITU-T G989 [7]. The PON standards that emerged while the PON technology was evolving are shown in figure 1.



PON Evolution

2.1 ATM-PON (APON)

APON represents the first PON standard defined in G.983.1 recommendation approved by ITU-T in 1998 [2]. In APON, ATM technology is used to provide networking for simultaneous transmission of voice and data services. The data rate for downstream/upstream is 155.52Mbps/622.08Mbps. The upstream transmission is based on ATM cells to solve network-based problems on the circuit and packet-switched technology. The first testing of this standard was done in the 1990s [8]. In 2001, the APON standard was considered for deploying FTTH access networks [9].

2.2 Broadband PON (BPON)

BPON is the second PON standard defined by ITU-T in G.983.3 recommendation. This recommendation was approved in 2001 [3]. The BPON standard is based on the previous APON standard. Its data rate transmission for downstream and upstream is the same as that of APON [10].

S.F. Shaukat et.al.[11] have successfully evaluated the performance of the BPON access network. They optimized the performance by taking essential parameters like the number of users, scalability and system reach. They have developed the relation based on these parameters where a network can be judged for practical deployments. For the BPON system, different modulation formats were also tested. The results found that the system performance degrades with increased fiber distance in the case of downstream transmission. They have observed that the data rate must decrease to achieve the same BER level with increased fiber distance. The number of users increases corresponds to a decrease in fiber distance. The BPON standard gradual deployed network has now reached its peak. The possible speed of the BPON network is 622 Mbps which is insufficient for a higher data rate when this speed split among 32 ONUs. PON network development is focused on a new standard that can provide a higher data rate and supports many users [12].

2.3 Gigabit Passive Optical Network (GPON)

The GPON standard is defined by ITU-T G.984 recommendation [4]. The primary characteristics of GPON have been approved in G.984.1 recommendation in 2003 [4]. The GPON supports existing telecommunication services. For downstream transmission, the data rate 1244 Mb/s or 2488 Mb/s can be used, and for an upstream transmission data rate of 155 Mb/s, 622 Mb/s, 1244 Mb/s and 2488 Mb/s can be used. The split ratio can be 1:64 and 1:128, which is still relevant for many users. The logical reach of the GPON network is 60 km, and the physical distance is 10 km to 20 km [4].

Won et al. [13] proposed a colorless OLT and ONU based architecture of WDM-PON. In colorless OLT, the injection locking of Fabry–Perot laser diode and optical carrier suppression were used. Both OLT and ONU colorlessly operated within the 25 nm range. The observed BER was less than 10-9 for both 1.25 Gbps downstream and upstream signal at 1530.36 nm, 1540.14 nm, and 1556.71 nm wavelengths.

2.4 Next-generation PON1 (XG-PON)

XG-PON is the next PON standard defined by ITU-T G.987 recommendation [6]. XG-PON's primary characteristics are explained in G.987.1 recommendation and were approved in 2010 [14]. XG-PON is called as 10G-PON, here 'X' is a ROMAN numerical, represents the data rate of 10Gbps. As the GPON network was maturing, FSAN and ITU-T turned their attention to develop a new generation PON. The requirements for new generation PON were completed during 2009 [15]. The XG-PON adopted many features of GPON, XG-PON's main advantage was to ensure a higher bandwidth for end users compared with previously deployed PON standard [16]. The performed studies indicate that the demand for higher bandwidth continues to increase. The XG-PON standard was named NG-PON1, as it was the best candidate for the next generation network [17].

During the development in XG-PON, the research was focused on two standards which are NG-PON1 and NG-PON2. The main difference between the two is based on the transfer rate. The technologies which were not implemented during this period were included in the NG-PON2 study. For downstream, the supported data rate for XG-PON is 10 Gbps, and the data rate is 2.5 Gbps for upstream. The wavelength range for downstream transmission is 1575 nm to 1580 nm, and the wavelength range for upstream transmission is 1260 nm to 1280 nm as per the ITU-T G.987 recommendation. WDM was selected for downstream as well for upstream, and TDM was set for upstream [18]. The minimum split ratio is 1:64 to ensure the coexistence of GPON and XG-PON standard. The split ratio can extend up to 1:256 to support transmission at a 20 km distance. The distance can be possible for up to 60 km [14]. The performance of the system for different optical network topologies was evaluated by Sanjeev Dewra et al. [19]. They reported that bus topology supports 18 nodes for a minimum signal input power of -20 dBm, ring topology supports 30 nodes for -30 dBm input power at 10 Gbps data rate with 30 km reaches between successive nodes in the presence of hybrid amplifier. However, in hybrid topology, they found that the number of nodes supported for bus topology is 6, and for the ring it is 10 at -20 dBm signal input power.

2.5 Next-Generation Passive Optical Network Stage 2 (NG-PON2)

NG-PON2 is defined by the ITU-T G.989 recommendation [7]. The basic requirements of NG-PON2 described in G.989.1 recommendation and were approved in 2013 [20]. The NG-PON1 and NG-PON2 were independently standardized in 2010.

The NG-PON2 system must support a 40 Gbps data rate in the downstream direction and 10 Gbps in the upstream direction as per recommendation G.989. The fiber reach must be at least 20 km, and it can be extended up to 60 km. The allocated wavelength band for the NG-PON2 downstream is 1596 nm to 1603 nm. For the upstream, the range is 1524 nm to 1544 nm [20].

The set of requirements and parameters that the NG-PON2 should support include:

- 40 Gbit/s downstream capacity and 20 km reach with at least 1:64 split
- 10 Gbit/s upstream capacity and 20 km reach with at least 1:64 split
- Access to peak rates of 10/2.5 Gbit/s downstream/upstream
- Longer distances with lower split ratios are also possible

According to the ITU-T G989.2 recommendations, the NG-PON2 should be based on TWDM. A group of wavelengths are used, and each wavelength is shared between multiple users/ONUs based on TDM. According to FSAN and ITU-T, the NG-PON1 (XG-PON) has a role to perform the midterm upgrade to GPON without affecting the infrastructure, while NG-PON2 is a long-term solution in PON evolution. According to the standards, NG-PON2 technology should outperform NG-PON1 technology in the optical distribution network (ODN) compatibility, bandwidth, capacity, and cost-efficiency. As per the G.989.2 recommendation of ITU-T, time and wavelength division multiplexing PON (TWDM-PON) is the best hybrid multiplexed technique for NG-PON2. TWDM utilizes the bandwidth of optical fiber efficiently [20].

Areez Khalil Memon et al. [21] analyzed different energy-efficient techniques in the PON network. They proposed a 40 Gbps NG-PON RZ-DQPSK high data rate network. The proposed system works up to 20 km, with only a 3.3 dB power penalty.

Salem Bindhaiq et al. [22] presented symmetric 40 Gbps TWDM-PON based on directly modulated lasers (DMLs) and dispersion compensation fiber (DCF) for the improvement of the power budget. They investigated the bandwidth enhancement factor (α) characteristics to minimize DML chirp's effect on system performance improvement. They achieved the dispersion compensation up to 140 km of fiber length with a power budget of 56.6 dB with less than 2 dB dispersion penalty.

In our previous work, we have investigated an 80 Gbps NG-PON2 network for different modulation formats (non-return to zero (NRZ), return to zero (RZ), carrier suppressed return to zero (CSRZ) and duobinary modulation formats) for PIN and Avalanche photodiodes (APD). It was observed that duobinary modulation formats perform better among others with APD. The power budget for the proposed network was improved by using a Raman amplifier. The power budget achieved was 44.5dB with forward error correction (FEC) and 40.5 dB without FEC for 20km fiber distance [23].

In other previous work, we proposed an encryption method using an all-optical exclusive-OR gate to maintain security in NG-PON 2 network. The security was verified by creating the eavesdropping attempt scenario at the user premises. This method of unique keys and all-optical encryption eliminates the eavesdropping threat in NG-PON2 [24].

We proposed two optical line terminal (OLT) designs based on polarization split state for NG-PON2 in our previous work. The data rate doubles in the first case of polarization split based modulation. In this case, the two polarisation states were modulated separately. In the second method, the data rate increases four times where differential phase-shift keying (DPSK) modulates another data on already amplitude-modulated states. For the proposed method, the coexistence with the GPON and XG-PON was also tested [25].

Doutje van Veen et al. proposed a novel wavelength-stable burst-mode (BM) laser based on a multi-electrode distributed- feedback (DFB) laser. The application of their proposed laser is in time and wavelength division multiplexed passive optical networks. The property of burst mode made this laser a candidate for future demonstrations in the field of Next-generation PON. They mentioned that the proposed laser is suitable for TWDM-PONs using a 100 GHz wavelength grid [26]. KwangOk Kim et al. presented a time-controlled tactile optical access technology. The authors claimed that the proposed method is capable of bandwidth-intensive services for 5G Networks by using channel bonding and low-latency oriented dynamic bandwidth allocation (DBA). They experimentally tested the 50 Gb/s transmissions without packet loss during 48-hour for 20 km reach and 1:64 split ratio [27].

Zhengxuan Li et al. [52] presented a power budget of 53 dB for the symmetric 40 Gbps TWDM-PON using DI and optical amplifiers (Erbium-doped fiber amplifier (EDFA), Raman amplifier). The system could support 1024 ONUs for 100km without a repeater. Zhengxuan Li et al. [53] reported a 40 km reach for 28 Gbps signal with a 31dB power budget supporting 64 users; DI with duobinary modulation format was used to compensate for dispersion effect. The final comparison of all existing PON standards is explained in table 1 as per the ITU-T recommendations

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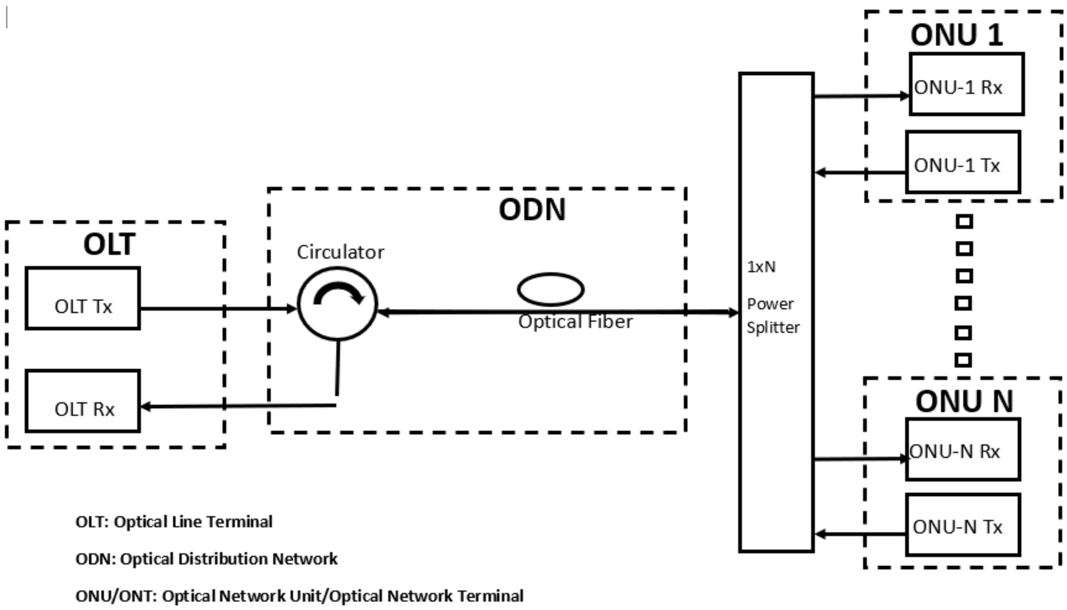
COMPARISON OF EXISTING PON STANDARDS/RECOMMENDATIONS

Standard	APON	BPON	GPON	XG-PON (NG-PON1)	NG-PON2
ITU-T	G.983	G.983	G.984	G.987	G.989
Approved	1998	2001	2003	2010	2013
Wavelength range for downstream	1480 nm-1580 nm	1480 nm-1580 nm	1480 nm-1500 nm	1575 nm-1580 nm	1596 nm-1603 nm
Wavelength range for upstream	1260 nm-1360 nm	1260 nm-1360 nm	1260 nm-1360 nm	1260 nm-1280 nm	1524 nm-1544 nm
Data rate downstream	622 Mbps	1.25 Gbps	2.5 Gbps	10 Gbps	40 Gbps/80 Gbps
Data rate upstream	155 Mbps	622 Mbps	1.25 Gbps	2.5 Gbps/10 Gbps	10 Gbps/40 Gbps/80 Gbps
Split ratio	Up to 1:32	Up to 1:32	Up to 1:64	Up to 1:256	Over 1:256

2.6 Performance Investigation of Existing GPON, XG-PON and 40 Gbps NG-PON2

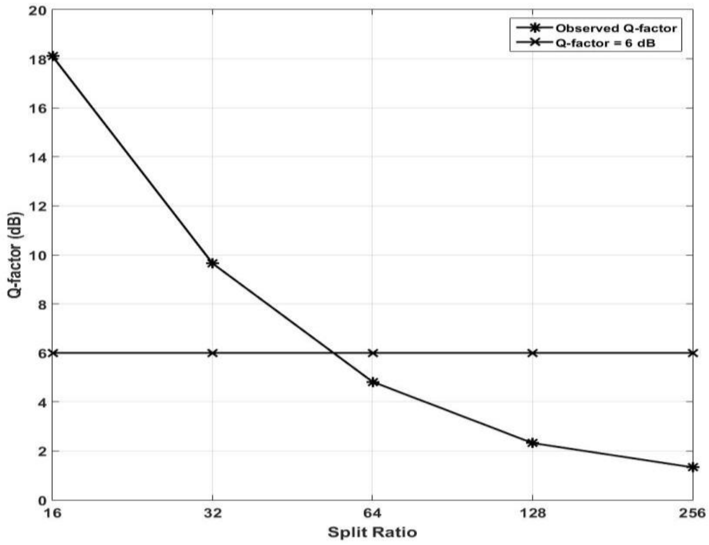
In this Section, the performance of GPON, XG-PON and 40 Gbps NG-PON2 networks has been analysed by observing the number of users supported by the corresponding network. Figure 2 shows the basic architecture of PON. For different PON standard the number of wavelengths, split ratio used are different as per the recommendations. In this work the performance of GPON, XG-PON and NG-PON 2 standard is investigated.



Architecture of PON

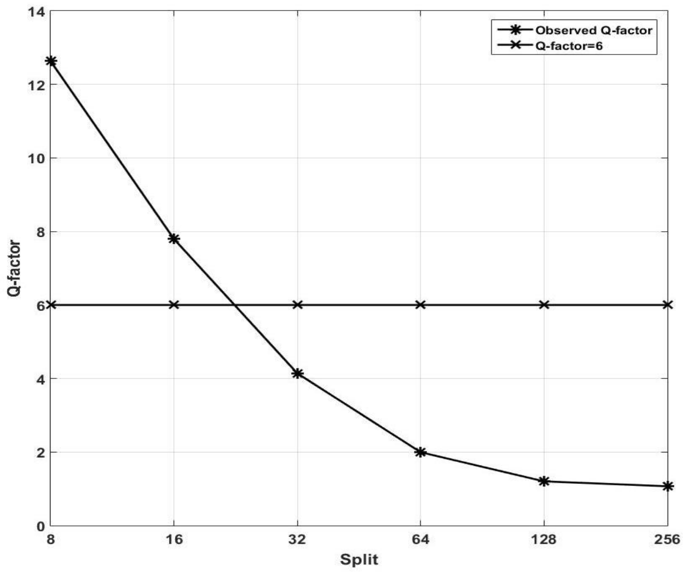
The performance of the system is evaluated in the terms of Q-factor. The Q-factor value equal to '6' is considered as the reference Q-factor below which the system performance is assumed to be unacceptable. In every PON, the power at the output of the splitter decreases as the split ratio increases. As power decreases the signal deteriorates, which leads to a reduction in the value of Q-factor.

Figure 3 shows the split ratio supported by GPON. The downstream wavelength for the GPON is 1490 nm which is defined by ITU-T recommendations. The 1490 nm wavelength lies outside the low attenuation window; to compensate for the loss the transmitted power is set to 3 dB. From figure 3, it is observed that the GPON can support 32 ONUs. For higher split, the Q-factor decreases below the acceptable level of 6.



Q-factor vs. Split Ratio for GPON

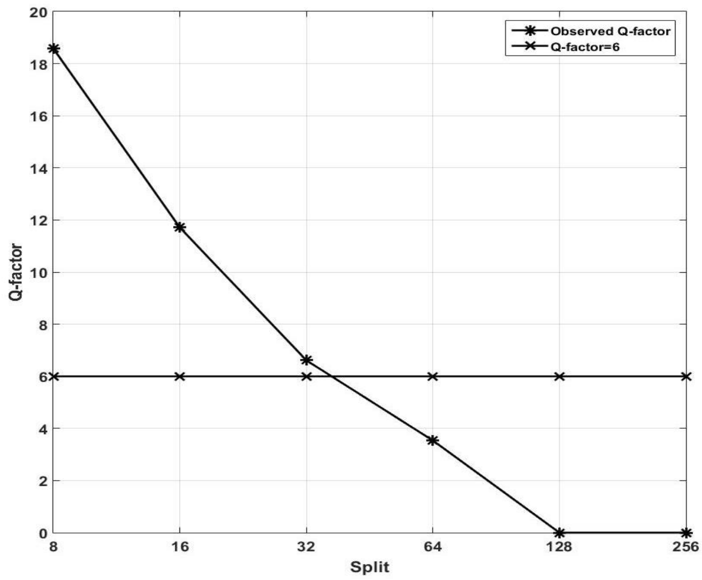
Similarly, the performance of the XG-PON is evaluated by varying the split ratio of the splitter. The downstream wavelength for the XG-PON is 1575 nm which is defined by ITU-T recommendations. The transmitted power in case of XG-PON is set to 0dB.



Q-factor vs. Split Ratio for XG-PON

Figure 4 shows the Q-factor variation in case of XG-PON. The Q-factor remains more than 6 for a split ratio up to 16. The performance of the system is not acceptable for 32 or higher split. Figure 5 shows the Q-factor variation as a function of the split in case of 40Gbps NG-PON2. The data rate supported by NG-

PON2 is kept equal to 40 Gbps using 4 wavelengths starting from 1596 nm with 0.8 nm channel spacing. Each wavelength carrying 10 Gbps data rate.



Q-factor vs. Split Ratio for NG-PON2

The observed Q-factor is more than 6 for split up to 32. However, as the split increases above 32, the Q-factor falls below the acceptable level of 6.

3 Conclusion

In this paper the evolution trend of PON has been discussed. The literature related to ATM-PON, BPON, GPON, XG-PON and NG-PON2 has been reviewed in detail. From the literature review of PON standards the comparison of existing PON standards/recommendations is presented. The GPON, XG-PON and 40 Gbps NG-PON2 systems have been simulated to find the supported split ratio by these standards. The downstream wavelength for the different PON standards is different also the data rate is not same. Therefore, all the systems behave differently. The Q-factor value equal to '6' is considered as the reference Q-factor below which the system performance is assumed to be unacceptable. In every PON case, the power at the output of the splitter decreases as the split ratio increases. As power decreases the signal deteriorates, which leads to a reduction in the value of Q-factor. It is observed that the GPON can support 32 split with PIN photodiode. For higher split, the Q-factor decreases below the acceptable level of 6. In case of XG-PON with PIN photodiode, the Q-factor remains more than 6 for a split ratio up to 16. The performance of the system is not acceptable for 32 or higher split. The data rate supported by NG-PON2 is kept equal to 40 Gbps using 4 wavelengths carrying 10 Gbps data rate each. The observed Q-factor is more than 6 for split up to 32. However, as the split increases above 32, the Q-factor falls below the acceptable level of 6.

4 Acknowledgment

The authors wish to convey thanks to the Ministry of Electronics and Information Technology, Government of India, for the Visvesvaraya PhD scheme.

References

[1] J. R. Stern, J. W. Ballance, D. W. Faulkner, S. Hornung, D. B. Payne, and K. Oakley, "Passive optical local networks for telephony applications and beyond," Electron. Lett., vol. 23, no. 24, p. 1255, 1987.

[2] ITU-T, "Broadband optical access systems based on Passive Optical Networks (PON)," ITU-T Recomm. G.983.1, 2005.

[3] ITU-T, “A Broadband Optical Access System with Increased Service Capability by Wavelength Allocation,” ITU-T Recomm. G.983.3, pp. 1–59, 2001.

[4] ITU-T, “Gigabit-capable Passive Optical Networks (GPON): General characteristics,” ITU-T Recomm. G.984.1, 2003.

[5] G. Pesavento, J. Kuo, and T. Koyama, “IEEE Access Standards, 802.3 ah GE-PON status,” ITU-T Workshop IP/Optical, Chitose, Japan. pp. 9–11, 2002.

[6] ITU-T, “10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms,” ITU-T Recomm. G.987, 2012.

[7] ITU-T, “40-Gigabit-capable passive optical networks (NG-PON2): Definitions, abbreviations and acronyms,” ITU-T Recomm. G.989, 2015.

[8] P. Chanclou, S. Gosselin, J. F. Palacios, V. L. Álvarez, and E. Zouganeli, “Overview of the optical broadband access evolution: A joint article by operators in the IST network of excellence e-photon/ONe,” IEEE Commun. Mag., vol. 44, no. 8, pp. 29–35, 2006.

[9] E. Ringoot, N. Janssens, M. Tassent, J. Angeloupoulos, C. Blondia, and P. Vetter, “Demonstration of dynamic medium access control for APON and SuperPON,” in IEEE Global Telecommunications Conference, San Antonio, TX, USA, vol. 3, pp. 1570-1574,25–29 Novemeber, 2001.

[10] Biswanath Mukherjee, Optical WDM Networks. Springer, New York, 2006.

[11] S. F. Shaukat, U. Ibrahim, and S. Nazir, “Monte Carlo Analysis of Broadband Passive Optical Networks,” vol. 12, no. 8, pp. 1156–1164, 2011.

[12] D. Hood, Gigabit-Capable Passive Optical Networks, First Edit. Wiley: Hoboken, NJ, USA, 2012.

[13] Y.-Y. Won, H.-C. Kwon, M.-K. Hong, and S.-K. Han, “Bidirectional colorless gigabit WDM-passive optical networks by use of injection locking and optical carrier suppression,” Opt. Fiber Technol., vol. 15, no. 1, pp. 10–14, 2009.

[14] ITU-T, “10-Gigabit-capable passive optical networks (XG-PON): General requirements,” ITU-T Recomm. G.987.1, 2010.

[15] E. Wong, “Next-Generation Broadband Access Networks and Technologies,” J. Light. Technol., vol. 30, no. 4, 2012.

[16] M. Hajduczenia, M. Ieee, J. A. Henrique, and S. Member, “Next Generation PON Systems – Current Status,” in IEEE, 11th International Conference on Transparent Optical Networks, Azores, Portugal, pp. 1–8, 28 June–2 July, 2009.

[17] T. Muciaccia, F. Gargano, and V. M. N. Passaro, “Passive Optical Access Networks: State of the Art and Future Evolution,” pp. 323–346, 2014, doi: 10.3390/photonics1040323.

[18] F. J. Effenberger and S. Member, “The XG-PON System : Cost Effective 10 Gb / s Access,” vol. 29, no. 4, pp. 403–409, 2011.

[19] S. Dewra and R. S. Kaler, “Performance analysis of optical network topologies in the presence of hybrid optical amplifier,” Optoelectron. Adv. Mater. Rapid Commun., vol. 11, no. 1–2, pp. 54–58, 2017.

[20] ITU-T, “40-Gigabit-capable passive optical networks (NG-PON2): General requirements,” ITU-T Recomm. G.989.1.1, pp. 1–26, 2013.

[21] A. K. Memon, A. M. Khan, S. Hyder, A. Musav, G. Kumar, and A. Latifmemon, “40Gbps DQPSK Transmission System for High Data Rate Energy Efficient Next Generation Passive Optical Network (NG- PON),” pp. 2–9, 2017, doi: 10.1109/ICIEECT.2017.7916554.

[22] S. Bindhaiq, N. Zulkifli, A. S. M. Supa’at, S. M. Idrus, and M. S. Salleh, “Power budget improvement of symmetric 40 Gb/s TWDM based PON2 system utilizing DMLs and DCF technique,” Opt. Commun., vol. 407, no. September 2017, pp. 153–164, 2018, doi: 10.1016/j.optcom.2017.09.027.

[23] R. Kaur, S. Singh, and M. L. Singh, “Power budget calculations of high-speed TWDM based next-generation passive optical network for different data types,” Optoelectron. Adv. Mater. Rapid Commun., vol. 15, no. 1, pp. 39–48, 2021.

[24] R. Kaur and S. Singh, “All-optical encryption in 80-Gbps next-generation passive optical network stage 2,” Opt. Eng., vol. 59, no. 07, p. 1, 2020, doi: 10.1117/1.oe.59.7.076117.

[25] K. Ramandeep and S. Simranjit, “Polarization multiplexing and hybrid modulation-based bandwidth efficient NG-PON2 coexisting GPON and XG-PON,” J. Opt. Technol., vol. 88, no. 4, pp. 1–8, 2021, doi: 10.17586/1023-5086-2021-88-04-.

[26] D. Van Veen, V. Houtsma, S. Porto, N. Basavanhally, C. Bolle, and H. Schmuck, “Wavelength-stable burst-mode laser for next-generation PONs,” J. Opt. Commun. Netw., vol. 11, no. 2, pp. A155–A165, 2019, doi: 10.1364/JOCN.11.00A155.

[27] K. O. Kim et al., “High Speed and Low Latency Passive Optical Network for 5G Wireless Systems,” J. Light. Technol., vol. 37, no. 12, pp. 2873–2882, 2019, doi: 10.1109/JLT.2018.2866805