IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Volume-6, Issue-4 E-ISSN: 2347-2693

# Q Factor Based Performance Evaluation of Bidirectional TDM PON Network Using Hybrid Amplifier Configurations

**D. Sharma[1*], Payal[2], S. Kumar[3]**

[1]ECE Department, University Institute of Engineering and Technology(UIET), MDU, Rohtak, Haryana, India
[2]ECE Department, University Institute of Engineering and Technology(UIET), MDU, Rohtak, Haryana, India
[3]ECE Department, University Institute of Engineering and Technology(UIET), MDU, Rohtak, Haryana, India

*Corresponding Author:d.29deepak@gmail.com*

**Available online at: www.ijcseonline.org**

Received: 06/Apr/2018, Revised: 13/Apr/2018, Accepted: 25/Apr/2018, Published: 30/Apr/2018

***Abstract*:** Passive Optical Networks (PONs), designed by Full Service Access Network (FSAN) working group, is the converged infrastructure standardized by ITU and IEEE. PONs support services such as traditional telephony, VoIP and various other multimedia services upto a logical reach of 60km with a split ratio of 1:128. Hence to enhance the reach and performance of PONs, one of the foremost solutions is the use of hybrid optical amplifiers. In this present paper, a model of bidirectional Time Division Multiplexing (TDM) PON using hybrid optical amplifiers configuration (Semiconductor Optical Amplifier (SOA), Raman Amplifier and Erbium Doped Fiber Amplifier (EDFA)) is presented. The performance of the designed system is evaluated for variation of Q Factor with transmission distance using (i) SOA-Raman (ii) SOA-EDFA and (iii) EDFA-EDFA hybrid configuration by carrying out simulations.

***Keywords***: PON, FSAN, Optical Line Terminal (OLT), Optical Network Unit (ONU), Optical Distribution Network (ODN), EDFA, TDM, WDM SOA

## I. INTRODUCTION

Current Fiber to home networks provides broadband and other multimedia services to consumers effectively. But for handling ever increasing bandwidth hungry services, the capacity of traditional fiber to home networks must be enhanced in a scalable manner. PONs designed by FSAN working group is the converged infrastructure standardized by ITU and IEEE [1]. PONs supports services such as traditional telephony, VoIP and various other multimedia services. PONs uses passive network elements that reduce deployment costs and power consumption. However, the maximum logical reach of PONs is upto 60km with a split ratio of 1:128 [2].

In practical scenario, due to inherent fiber and component losses, splice and connector losses, the maximum reach is limited. Hence to extend the reach of PONs, one of the foremost solutions is the use of hybrid amplifiers. However the use of optical amplifiers and repeaters contradict the basic idea of PONs. But their use considerably extends the transmission reach while reducing the number of local exchanges which lead to cost savings in infrastructural setups and operations. The novel architectural design and technological advancements in PONs has enabled low cost optoelectronic communication.

PONs works in two modes, downstream and upstream. Upstream transmission is called as burst mode transmission and occurs randomly as required by user. The upstream data rate is always slower than downstream rate. The basic architecture of PONs is shown in Figure 1. The PON architecture consists of three main units OLT, ONU and ODN. OLT located in CO is the interface between PON and the optical backbone network. OLT distributes PSTN, Internet and CATV services to as many as 16 to 128 end users per fiber line.

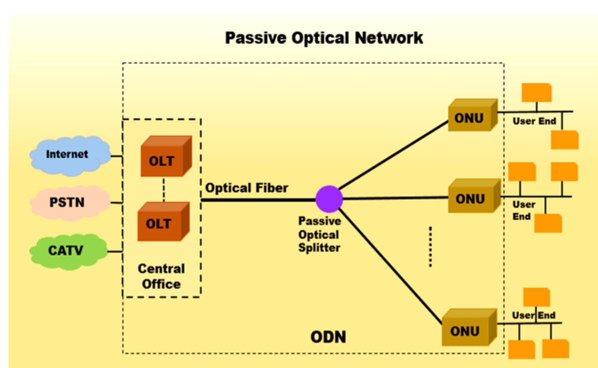



Figure 1: Passive Optical Network Architecture

Passive optical splitter divides an optical signal into multiple equal low power signals and distributes them to end-users during downstream and in case upstream transmission these acts power combiners. ONU provides service interface to end users. ODN connects OLT and end users using optical fibers.

In this paper, we have presented a detailed description of PONs, its technologies and standards along with the related work found in literature. We have also designed a PON network model for extending reach of communication using hybrid amplifiers (SOA –Raman amplifier, SOA-EDFA and EDFA-EDFA). We have also compared the performance of this configuration of hybrid amplifiers on the basis of variation of Quality Factor with transmission range. In section II, various technologies and standards related to PONs are discussed followed by recent related work in section III. Section IV contains the proposed network design followed by results and discussion in section V and conclusion in section VI.

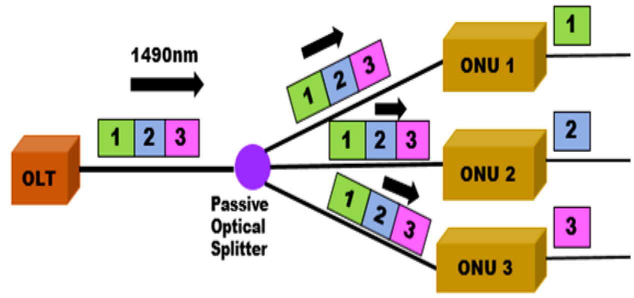
## II. PON TECHNOLOGIES AND STANDARDS

On the basis of multiplexing scheme used, PON is of three types which are Time Division Multiplexed PON (TDM PON), Wavelength Division Multiplexed PON (WDM PON) and Orthogonal Frequency Division Multiplexed PON (OFDM PON).

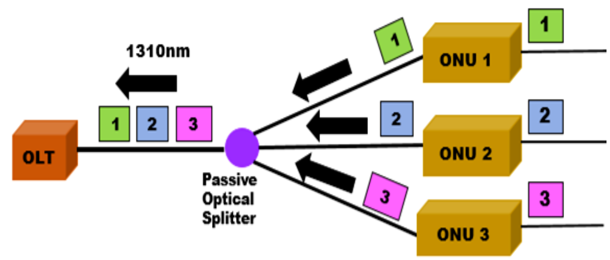
### *A. TDM PON*

TDM PON permits all the users to share a single wavelength channel and allocates them a high bandwidth through an optical network arrangement. This network uses TDM technique for combining incoming traffic from ONUs onto upstream and downstream wavelength links. Two TDM techniques can be used: Fixed and Statistical TDM. In the former case, a firm amount of delay is offered among two OLT's while for the latter case, delay is decided by the amount of information transmitted from OLT's [3]. TDM PON is the most widely used network due to several advantages such as lower maintenance costs and more reliable operation. Figure 2 shows the architecture of TDM PON.

For downstream communication, the OLT located in CO transmits continuously and the ONU's at the ends find their data through the address labels rooted in the signal. While for upstream communication, each ONU transmits data for an allocated time slot to OLT.




(a) Downstream Link




(b) Upstream Link

Figure 2: TDM PON architecture

Depending upon the data rate requirements, TDM PONs are of different types which are ATM PON, Broadband PON (BPON), Ethernet PON (EPON), Gigabit PON (GPON), 10G EPON, and Next-generation PON (NG-PON). Figure 3 shows the evolution of various standards for PONs.

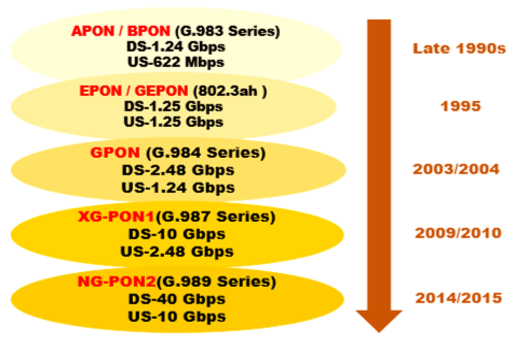



Figure 3: PON Standards [4]

In ATM PON uses data rate of 622.08 Mb/s and 155.52Mb/s for downstream link and for upstream link it uses burst of ATM cells. ITU-T G.983 series specifies the standards for BPON. BPON is an improvement over APON and provides broadband services including video and other multimedia applications.

EPON is a P2P network topology that handles packet based data traffic in scalable and cost effective manner. A symmetric bandwidth of 1.25Gbps is achieved using EPONs in both downstream and upstream links and a reach of 20 km is achieved. EPONs are also termed as Gigabit Ethernet PON or GEPON. EPON being compatible with other Ethernet standard does not require any conversion or encapsulation while communicating with other standards [4].

ITU-T G.984 series specifies GPON standards. GPON supports two different data rates for both upstream and downstream links. It can provide symmetrical data rate of 622 Mb/s or 1.244 Gb/s in both downstream and upstream links. It can also support a data rate of 2.488 Gb/s and 1.244Gb/s in downstream and upstream links respectively. GPONs along with supporting multiple data rates, provides high efficiency and also incorporate real-time suggestions from service provider.

XG-PON or 10G PON is the recent standard for GPON standardized by ITU-T G.987.It provides a data rates of 10Gbps for downstream and 2.48 Gbps for upstream link. XG-PON supports advanced multimedia applications requiring higher bandwidths such as high definition video transmissions.

The evolution of NG-PON is divided into two phases: NG-PON1 and NG-PON2. NG-PON1 depends on PON technologies that show compatibility with GPON standards (ITU-T G.984 series).NG-PON 2 provides backward compatibility with previous standards and supports traditional video services along with new generation multimedia applications on existing optical distribution networks.

*B. WDM PON*

WDM PON allows each user to access the entire bandwidth rather than sharing it among several users in TDM PON. It enhances the capacity of the medium by using multiple optical wavelengths in a single fiber. Since each home receives its own wavelength, these networks are secure and scalable.

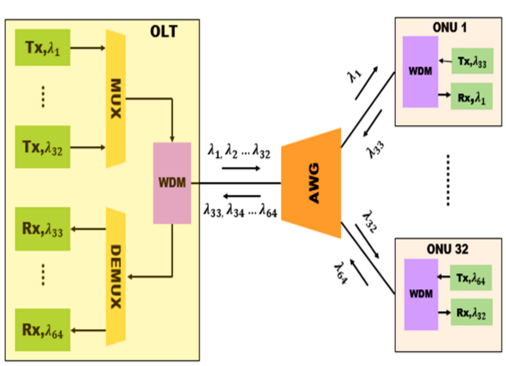



Figure 4: WDM PON Architecture

Figure 4 shows the architecture of WDM PON. Here, passive splitter is replaced by a wavelength router in the PON fiber plant. As, each OLT-ONU pair is assigned a keen and permanent wavelength. Therefore, it requires two transmitter/receiver pairs to establish a point to point connection. Arrayed Waveguide Grating (AWG) is employed to realize the passive wavelength router positioned at remote node. An AWG can operate over numerous spectral ranges, allowing same device to be used for both upstream and downstream transmissions. AWGs have an optical loss of around 5 dB, which is about 12 dB less than that of a 1 × 32 power splitter [5].WDM-PON has a major drawback that it requires multiple optical ports at the central office as compared to TDM-PON.

*C. OFDM PON*

OFDM PON improves the bandwidth of optical networks due to its superior transmission capability. It employs Orthogonal Frequency Division multiplexing as the modulation scheme. Figure 5 shows the architecture of OFDM PON.

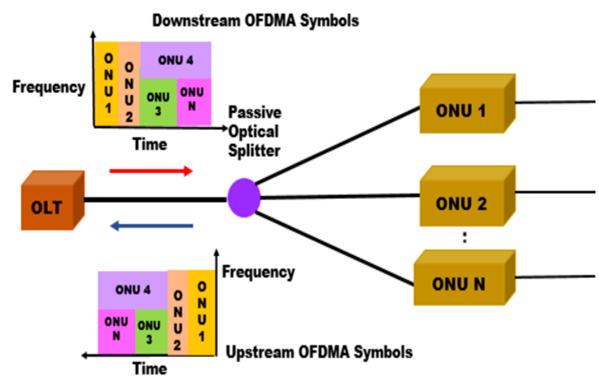



Figure 5: OFDM PON Architecture

It uses a number of closely spaced orthogonal subcarriers for data transmission each modulated at a low symbol rate. Due to low data rate, the duration of each symbol is reasonably large. This efficiently reduces the Inter Symbol Interference (ISI) in a wireless multipath channel. The polarization mode dispersion and chromatic dispersion in optical communications have similar effects as those of multipath. Therefore, using the OFDM modulation scheme in the optical access network can greatly increase the network provisioning data rate and lengthen the network reach [5].

## III. RELATED WORK

In [2], the authors have presented a model of 4 TDM-PON using SOA-Raman amplifier over CWDM wavelength plan serving 128 end users. In [3], the authors have presented model of TDM based PONs with multiple channels that use different coding schemes and transmit data over nonlinear fiber in an efficient manner with optimum use of resources. The Simulative result shows that for both upstream and downstream links, reach extension of 60 km is achieved with a bandwidth of 75 nm is obtained.

In [4] the authors have presented and analyzed a hybrid model of WDM/TDM PON at variable data rates and the proposed model supports upto 48Gbps with better performance in terms of BER. In [5], the authors have provided a detailed description of G-PON and E-PON and their architecture and their adaptability to ever increasing bandwidth requirements.

In [6], the authors have presented a model of 4 TDM-PON with a symmetric data rate of 2.5GHz using SOA-Raman amplifier over CWDM wavelength plan serving 128 end users. The Simulative result shows that for both upstream and downstream links, reach extension of 60 km is achieved with a bandwidth of 75nm is obtained.

In [7], the authors have proposed a CWDM PON for 2.5Gbps data rate with a fiber length of 20km.Simulative results shows that designed system works optimally and provides better SNR performance and can accommodate higher bandwidth applications.

In [8] the authors have designed a passive GPON using Raman amplifier with a split ratio of 1:64 at 2.5 Gb/s data rate. Simulative results show that the designed network works optimally and link losses of 43dB and 36.6dB were obtained for 1310 nm and 1490 nm signals, respectively without any error floors. In [9] the authors have proposed an all-optical virtual private network (VPN) based OFDM – PON using 16QAM and a data rate of 10Gbps. The use of VPN in OFDM –PON works optimally and enhances the security.

In [10] the authors have proposed a reliable WDM PON architecture for protection against feeder fiber failure. In proposed architecture, in case of fiber failure the OLT and ONU switches can switch automatically to protection link.

In [11], the authors have described a model for coexistence of XG-PON and GPON with Raman Amplifier for both upstream and downstream links. Upon simulation, a transmission reach of 50 km and a loss budget of 39dB were obtained for both GPON and XG-PON with a split ratio of 1:96.

In [12] the authors have proposed a hybrid OFDM-baseband signal with a data rate of 2.5GHz using direct modulation. The proposed system works optimally upto a distance of 20 km with a data rate of 11.2 and 15 Gbps.

In [13], the authors have proposed hybrid OFDO-TDM architecture with statistical allocation of bandwidth as an improvement over the WDM PONs. The performance of proposed model was evaluated using constant bit rate (CBR), Variable Bit Rate (VBR) and best effort for accessing traffic load. The designed model works optimally and provides better usage of resources.

The authors in [14] have proposed a model of integrated bidirectional XG- PON using direct modulated duo-binary modulation of ultrahigh definition television .The analysis of designed shows enhanced performance upto 20km with reduced power penalties upto 32 ONUs.

In [15] the authors have proposed a modified WDM PON architecture using subcarrier multiplexing at OLT. For improving modulation efficiency, authors used a combination of IM and PM. Simulative analysis shows that the proposed architecture provides protection against fiber failure in case of downstream and broadcast signal.

In [16], the authors have proposed a low cost high capacity design model of WDM/TDM PON that provides a gain of 23dB with extended transmission reach. In [17], the authors have evaluated the performance of WDM/TDN PON with for 128 ONUs for communication of voice, video and data using NRZ and RZ modulation. The designed hybrid system works optimally with high fidelity upto a distance of 28 km using NRZ modulation.

In [18], the authors have proposed a model of WDM-RoF-PON for providing last mile connectivity for high speed broadband and multi-service transmission. The experimental analysis shows that the designed model works in consonance with theoretical assumptions and provides better optimal performance with lower energy consumption.

In [19] the authors have proposed a novel architecture of WDM-PON using Optical Carrier Suppression (OCS). Simulative analysis of proposed system at symmetric rate of 2.5Gb/s for both upstream and downstream signals shows efficient working of the system and it provides protection against feeder fiber failures.

In [20] the authors presented a review of polarization division multiplexing techniques WDM-RoF-PON with multiple data rate .The authors have also analyzed the impact of cross polarization using three channel SCM system. Simulative results show that cross polarization provides an improvement of 4dB and optimal performance is achieved for high speed data transmission.

In [21] the authors have evaluated the performance of various compensation methods in a WDM PON system using optical Differential Quadrature Phase Shift Keying (DQPSK), Optical Differential Phase Shift Keying (DPSK) and the different modulation formats including non-return-to-zero (NRZ), return-to-zero (RZ), carrier-suppressed return-to-zero (CS-RZ) at 40Gb/s. Simulative analysis shows that CS-RZ-DQPSK modulation format provides better performance .

## IV. HYBRID OPTICAL AMPLIFIERS

To increase the transmission capacity, optical amplifiers such as Raman, SOA and EDFA are used in optical communication. SOA having compact size and requiring low power consumption are suitable for Opto-electronic circuits. Raman amplifiers provide improved noise figure, signal power gain and OSNR. EDFA amplifies multiple channels without any gain reduction and coupling losses and also the power requirements of EDFA can be met using diodes.
For optimum utilization of available optical bandwidth, hybrid combination of optical amplifiers (SOA, EDFA and Raman) either in series or parallel can be used in different wavelength ranges. The net gain of hybrid optical amplifiers is equal to the sum of gain of individual amplifiers.

$$G_{hybrid} = G_{OA1} + G_{OA2}$$

In hybrid configuration of SOA-Raman, the nonlinearities produced by SOA are compensated by using Raman amplifier. This configuration provides optical regeneration, wavelength conversion with low noise figure and higher gain.
The SOA-EDFA hybrid configuration provides higher gain and large output power with minimum variation in gain. However, in this configuration ASE noise increase BER while degrading receiver sensitivity [22].
The EDFA-EDFA hybrid configuration provides high gain with gain flatness using lower pump power. Using this configuration, entire short wavelength region bandwidth can be amplified and several channels can be multiplexed [23].

## V. PROPOSED DESIGN AND SIMULATION FRAMEWORK

We have designed a four-channel bidirectional TDM PON model using optisystem simulator. The input optical transmitters operate in a wavelength band of 1490-1550nm for downstream transmission. Figure 6 shows the block diagram of the proposed model. The optical transmitter inputs are time division multiplexed over a single bidirectional optical fiber. The signal is then optically attenuated and applied to a Hybrid amplifier followed by CWDM. In this hybrid Amplifier configuration, we have used combination of SOA-Raman amplifier, SOA-EDFA and EDFA-EDFA for extending the transmission reach up to 70km and fidelity of the designed system. A passive splitter is used to split the multiplexed signal into four equal power signals in case of downstream link

At the receiving ONU end, the outputs from the splitter are filtered using Bessel filter and 3R Regenerator is used for recovering the original electrical signal. In upstream communication, each end user acts as a transmitter and the input signal is filtered and then applied to passive splitter which acts as a power combiner. The power combined signal is then amplified and applied to the optical fiber. At the CO, a fork is used to apply the received signal to required number of optical filters succeeded by optical receiver at the end users.

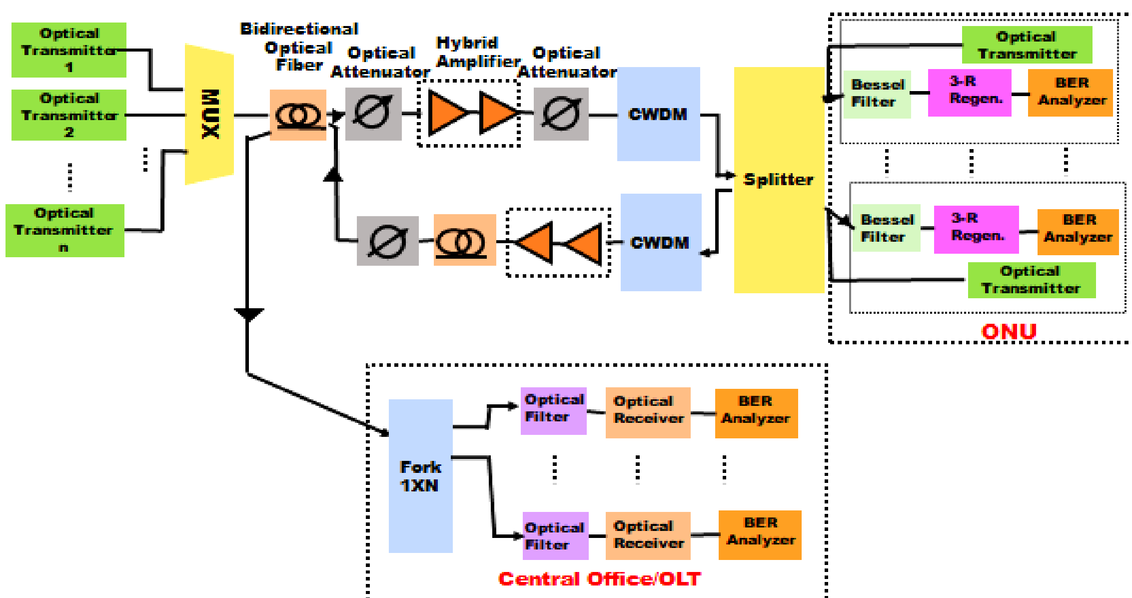



Figure 6: Proposed TDM PON model

The optical filters employed are the Butterworth optical filters operating in wavelength band of 1290-1350nm for upstream communication. The BER analyzer is used for visual realization of eye diagrams depicting Q-factor.

The various parameters used during simulation are shown in Table 1 given below.

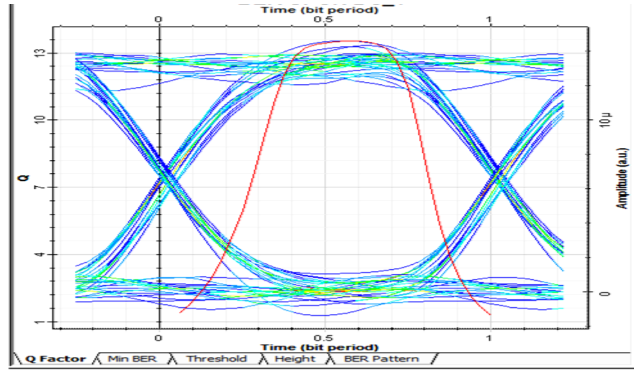
TABLE1. Simulation Parameters

| Simulation Parameters | |
|---|---|
| Simulator | Optisystem V 14 |
| Transmission distance | 60-70km |
| Data rate | 10 Gbps |
| Downstream/Upstream Wavelength | 1490/1290, 1510/1310, 1530/1330, 1550/1350 |
| Passive Splitter | 1:128 |
| Effective area of Raman fiber | 18.7 $\mu m^2$ |
| Attenuation | 0.32 dB/km |
| Dispersion | -20 ps/nm/km |
| Raman gain coefficient | 2.5 $W^{-1}$ /km |
| Pseudo-Random Bit Sequence | $2^{31}$ - 1 |
| EDFA gain | 25 dB |
| Cut off frequency of Low pass Bessel filter | 0.75*Bit rate Hz |

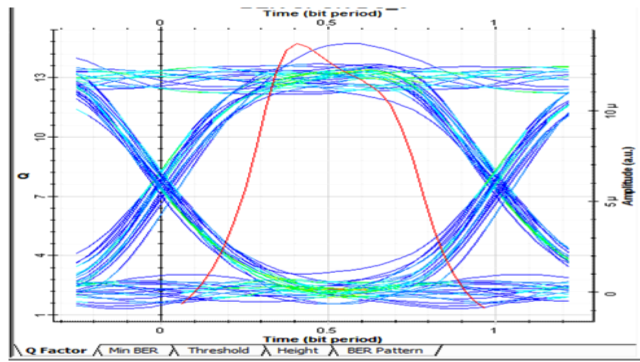
## VI. RESULTS AND DISCUSSION

We have designed a network model of four-channel bidirectional TDM PON using OPTISYSTEM simulator. We have simulated and compared the performance of the network with three different combinations of hybrid optical amplifier SOA-Raman, SOA-EDFA and EDFA-EDFA. To carry out performance comparison, we have taken the values of Q-Factor at Channel 2 and Channel 3 for both upstream and downstream link for a distance of 60, 65 and 70km.

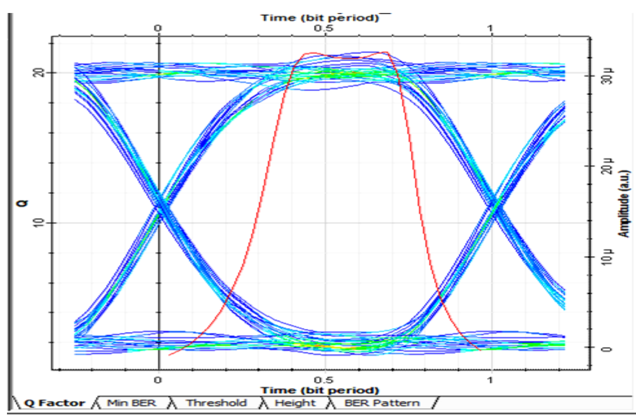
Figure 7 shows the Eye diagrams obtained at 70km of fiber length for the three respective hybrid amplifier configurations in downstream transmission. From the eye diagram, the EDFA-EDFA configuration has larger eye opening for downstream transmission.




(a)SOA-Raman




(b) SOA-EDFA




(c) EDFA-EDFA

Figure7. Eye diagrams At 70 km of fiber length for downstream transmission

Figure 8 shows the graphical results of Q-factor variation of Hybrid amplifiers with transmission distance at Channel 2 for the downstream link.

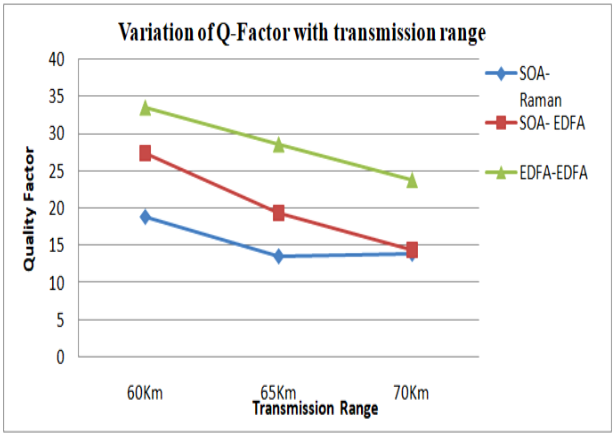



Figure8. The variation of Q Factor of hybrid amplifiers with distance at Channel 2 for downstream link

The value of Q Factor decreases with increase in transmission range for each hybrid amplifier configuration for both channels.

The combination of EDFA-EDFA provides better Q Factor as compared to other configurations even at higher transmission distance.

Figure 9 shows the graphical results of Q-factor variation of Hybrid amplifiers with transmission distance at Channel 3 for the downstream link.

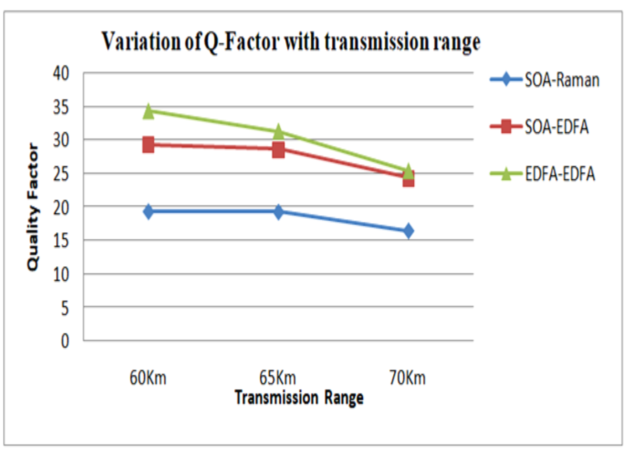
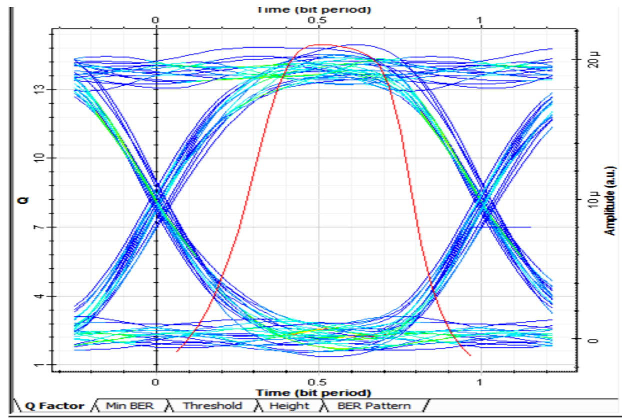
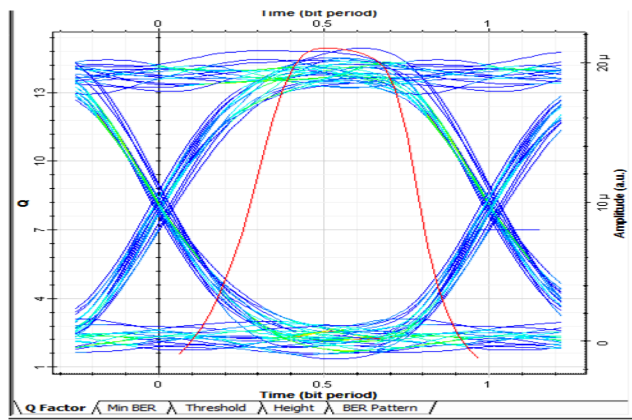



Figure9. The variation of Q Factor of Hybrid Amplifiers with distance at Channel 3 for downstream link

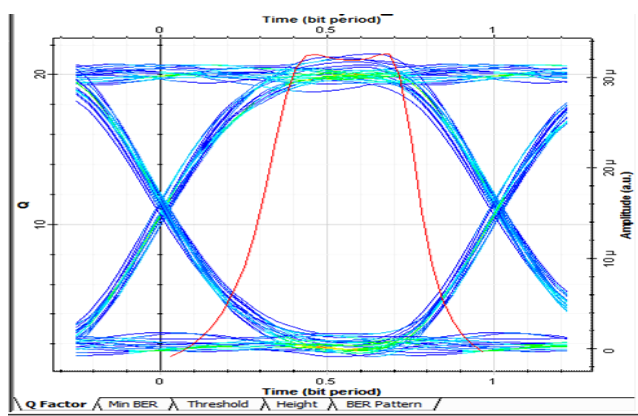
Figure 10 shows the Eye diagrams obtained at 70km of fiber length for the three respective hybrid amplifier configurations in upstream transmission.




(a)SOA-Raman




(b) SOA-EDFA




(c) EDFA-EDFA

Figure10. Eye diagrams At 70 km of fiber length for upstream transmission

From the eye diagram, the value of Q-factor for EDFA-EDFA configuration is 23.42 for upstream transmission.

Figure 11 and 12 shows the graphical results of Q-factor variation of Hybrid amplifiers with transmission distance at Channel 2 and Channel 3 for the upstream link respectively.

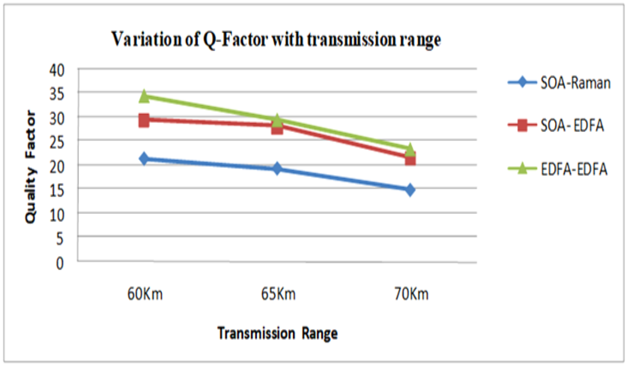



Figure 11: The variation of Q Factor of Hybrid Amplifiers with distance at Channel 2 for upstream link

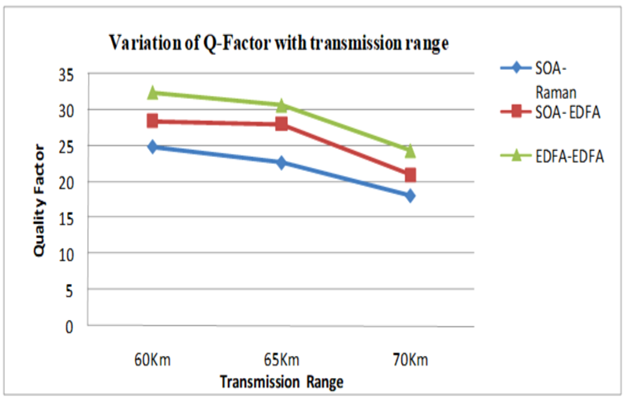



Figure 12: The variation of Q Factor of Hybrid Amplifiers with distance at Channel 3 for upstream link

From the figures, a decrease in Q-factor with increase in transmission distance is depicted. Also, a higher value of Q-factor is obtained with EDFA-EDFA Hybrid amplifier configuration.

The graphical results shown are tabulated as below. Table 2,3 ,4and 5 shows the variation of Q-Factor for Channel 2 and Channel 3 with transmission range for both downstream and upstream link.

TABLE2. Variation of Q Factor for channel 2 with transmission range (Downstream)

| Transmission Range(Km) | Quality Factor Channel 2 Downstream | | |
|---|---|---|---|
| | *SOA RAMAN* | *SOA-EDFA* | *EDFA-EDFA* |
| 60 | 18.85 | 27.32 | 33.46 |
| 65 | 13.86 | 19.33 | 28.49 |
| 70 | 13.53 | 14.32 | 23.68 |

TABLE3. Variation of Q Factor for channel 2 with transmission range (Upstream)

| Transmission Range(Km) | QUALITY FACTOR CHANNEL 2 UPSTREAM | | |
|---|---|---|---|
| | *SOA RAMAN* | *SOA-EDFA* | *EDFA-EDFA* |
| 60 | 33.46 | 21.41 | 34.42 |
| 65 | 28.49 | 19.37 | 29.62 |
| 70 | 23.68 | 14.95 | 23.42 |

TABLE4. Variation of Q Factor for channel 3 with transmission range (Downstream)

| Transmission Range(Km) | QUALITY FACTOR CHANNEL 3 DOWNSTREAM | | |
|---|---|---|---|
| | *SOA RAMAN* | *SOA-EDFA* | *EDFA-EDFA* |
| 60 | 19.26 | 29.32 | 34.42 |
| 65 | 18.27 | 28.64 | 31.42 |
| 70 | 16.44 | 24.32 | 25.46 |

TABLE4. Variation of Q Factor for channel 2 with transmission range (Upstream)

| Transmission Range(Km) | QUALITY FACTOR CHANNEL 3 UPSTREAM | | |
|---|---|---|---|
| | *SOA RAMAN* | *SOA-EDFA* | *EDFA-EDFA* |
| 60 | 18.62 | 28.42 | 32.41 |
| 65 | 18.41 | 28.10 | 30.62 |
| 70 | 13.69 | 21.02 | 24.60 |

From the graphical and tabular results, it is evident that the combination of EDFA-EDFA provides better Q-Factor as compared to other configurations even at higher transmission distance. The designed model with EDFA-EDFA hybrid configuration works optimally and provides better performance and a higher transmission reach is obtained with better quality factor.

## VII. CONCLUSION

In this paper we have presented a network model of four channel bidirectional TDM PON using hybrid amplifier configuration. We have also discussed the architecture of PONs, their enabling technology, standards and the recent work related to PONs. The performance of the model is evaluated by carrying out simulations using OPTISYSTEM simulator. The hybrid amplifier configuration has been found to be effective in enhancement of range by approx 16% while maintaining the optimum Q factor and data rates. Also the simulative results shows that the PON model using EDFA-EDFA configuration works more efficiently and optimally and an improvement in Q Factor is obtained as compared to SOA-EDFA and SOA- Raman even at higher transmission range of 70 Km.

## REFERENCES


[1] R. Kaur, Sanjeev Dewra, "A Review on Passive Optical Network", International Journal of Innovative Research in Computer and Communication Engineering, Vol. 3, Issue 4, April 2015.

[2] M. Agarwal, M.G.Wani, "Four Extended-Reach TDM PONs Sharing a Bidirectional Hybrid CWDM Amplifier," International Journal of Current Trends in Engineering & Research (IJCTER) e-ISSN 2455–1392 Volume 2 Issue 6, June 2016 pp. 321 – 327

[3] S. Khant, A. Patel, "Designing four-Channel High Rate TDM Passive Optical Network with NRZ Scheme for Wired Environment". International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 12746-12751

[4] A.B. Dar, F Zahoor, RK Jha, N Tripathi, M Sabraj, "An Analysis of 16 Channel 64 User Hybrid WDM/TDM Topology in the Optiwave Simulation Environment," International Journal of Computer Sciences and Engineering. VOL-4 Issue 5 pp(31-35). ISSN 2347-2693. 2016

[5] F. Effenberger *et al*., "An introduction to PON technologies [Topics in Optical Communications]," in *IEEE Communications Magazine*, vol. 45, no. 3, pp. S17-S25, March 2007. doi: 10.1109/MCOM.2007.344582

[6] P. P. Iannone *et al*., "Four Extended-Reach TDM PONs Sharing a Bidirectional Hybrid CWDM Amplifier," in Journal of Lightwave Technology, vol. 26, no. 1, pp. 138-143, Jan.1, 2008. doi: 10.1109/JLT.2007.913072

[7] K. Khairi, Z. A. Manaf, D. Adriyanto, M. S. Salleh, Z. Hamzah and R. Mohamad, "CWDM PON system: Next generation PON for access network," *2009* IEEE 9th Malaysia International Conference on Communications (MICC), Kuala Lumpur, 2009, pp. 765-768. doi: 10.1109/MICC.2009.5431392

[8] B. Zhu and D. Nesset, "GPON reach extension to 60 km with entirely passive fibre plant using Raman amplification," 2009 35th European Conference on Optical Communication, Vienna, 2009, pp. 1-2.

[9] C. Zhang, J. Huang, C. Chen, and K. Qiu, "All-optical virtual private network and ONUs communication in optical OFDM-based PON system," Opt. Express 19, 24816-24821 (2011).

[10] B. Chen, C. Gan, Qi, Y., et al. "A Novel Reliable WDM-PON System". *Journal of Optical Communications*, 32(4), pp. 247-250. (2011) doi:10.1515/JOC.2011.050

[11] B. Zhu, D. Au, F. Khan, and Y. Li, "Coexistence of 10G-PON and GPON Reach Extension to 50-km with Entirely Passive Fiber Plant," in 37th European Conference and Exposition on Optical Communications, OSA Technical Digest (CD) (Optical Society of America, 2011), paper Th.13.B.5.

[12] C. H. Yeh, C. W. Chow, H. Y. Chen and J. Y. Sung, "Hybrid OFDM-based multi-band wireless and baseband signal transmission in PON access," *in* Electronics Letters, vol. 48, no. 7, pp. 390-392, March 29 2012. doi: 10.1049/el.2011.3635

[13] T. Cevik, "A Hybrid OFDM-TDM Architecture with Decentralized Dynamic Bandwidth Allocation for PONs," The Scientific World Journal, vol. 2013, Article ID 561984, 9 pages, 2013. doi:10.1155/2013/561984

[14] Niazi, Shahab & Zhang, Xiaoguang & Xi, Lixia & Munir, Abid & Afridi, Muhammad & Khan, Dr.Yousaf. (2013). "A Viable Passive Optical Network Design for Ultrahigh Definition TV Distribution." Advances in Opto-Electronics. 2013. 10.1155/2013/219271.

[15] Chen, H., Gan, C., Gong, Y., et al. "Novel Colorless WDM-PON Featuring Optional Broadcast Service and High Reliability". *Journal of Optical Communications*, 35(1), pp. 71-75. (2013). doi:10.1515/joc-2013-0155

[16] A Sharma, D. Dhawan, "Cost Effective Long Reach Hybrid WDM-TDM Passive Optical Network Using Bidirectional EDFA," International Journal of Scientific & Engineering Research, Volume 4, Issue 5, pp( 2126-2130) May-2013 ISSN 2229-5518

[17] K. Nyachionjeka and W. Makondo, "Effects of Modulation Techniques (Manchester Code, NRZ or RZ) on the Operation of Hybrid WDM/TDM Passive Optical Networks," International Scholarly Research Notices, vol. 2014, Article ID 984157, 8 pages, 2014. doi:10.1155/2014/984157

[18] Song, Y., Gan, C., Gong, Y., et al. "A Survivable WDM-PON Architecture Using Optical Carrier Suppression Technique". *J. Opt. Commun.*, 34(4), pp. 357-360. (2013) doi:10.1515/joc-2013-0041

[19] S. Chen, Wei Nai, F. Zhang, S. Wang, D Dong, and Yi Yu, "Mathematical Verification for Transmission Performance of Centralized Lightwave WDM-RoF-PON with Quintuple Services Integrated in Each Wavelength Channel," Advances in OptoElectronics, vol. 2015, Article ID 183675, 13 pages, 2015. doi:10.1155/2015/183675

[20] M Morant, J Pérez, and R Llorente, "Polarization Division Multiplexing of OFDM Radio-over-Fiber Signals in Passive Optical Networks," Advances in Optical Technologies, vol. 2014, Article ID 269524, 9 pages, 2014. doi:10.1155/2014/269524

[21] Li, L. & Zhao, D.. "Performance of Phase Modulation in WDM-PON Transmission System". *Journal of Optical Communications*, 36(1), pp. 57-65. (2015) doi:10.1515/joc-2014-0050.

[22] Payal, Rajbir Singh, Deepak Sharma, "Performance Comparison of Hybrid Optical Amplifiers with Different Modulation Formats". International Journal of Electronics Electrical and Computational Systems (IJEECS) ISSN: 2348 117X Vol. 6 Issue 11 , Nov- 2017 pp(315-320 ).

[23] Payal , S. Kumar, D. Sharma, "Performance Analysis of NRZ and RZ Modulation Schemes in Optical Fiber Link Using EDFA." International Journal of Computer Science and Software Engineering Vol. 7, Issue 8 ,pp(161-168) August 2017 ISSN. 2277-128. doi:10.23956/ijarcsse/V7I8/0102.


## Authors Profile

Mr. Deepak Sharma is a PhD Research Scholar in Department of Electronics and Communication Engineering, UIET, MDU Rohtak. His research Interest areas include Heterogeneous Wireless Networks, MANETs and Optical Networks. He has published 37 research papers in International journals and in International/National Conference proceedings in India and abroad.

*Ms Payal* pursed Bachelor of Technology and Master of Technology from MDU, Rohtak India in year 2015 and 2017.She is currently pursuing Ph.D. in ECE Department of MDU, Rohtak India since 2017. Her main research work focuses on Optical Communication, Amplifiers, Nonlinear impairments. . She has published 8 research papers in International journals and in International/National Conference proceedings in India and abroad.

*Mr Suresh Kumar* has served in Corps of Signals (Indian Army) After taking PMR, joined as teaching faculty in UIET, MDU Rohtak, in Department of ECE in October 2008.He did his B.Tech from CME Pune and MCTE Mhow in 1999 from JNU New Delhi in Electronics and Communication Engineering. He did his PhD. In

ECE in 2011 on the title "CONTROL SPILL OVER OF TRANSMITTED POWER IN CDMA CELLULAR COMMUNICATION NETWORKS IN BORDER AREAS FOR DEFENCE FORCES". His area of specialization is wireless and Optical communication. He has guided 06 PhD. Thesis ( 04 awarded and 02 pursuing) and 24 M.Tech students dissertations. He has published 90 papers in International Journals and international/national conf proceedings in India and abroad.