Available online at www.elixirpublishers.com (Elixir International Journal)

Electrical Engineering

Elixir Elec. Engg. 89 (2015) 36808-36813

ISSN: 2229-712X

Investigation of 8 Channel WDM and ODTM PON for different Modulation Formats

Umer Ashraf[1,*] and Rakesh kumar jha[2]
Shri Mata Vaishno Devi university Katra , J&K 182320

ARTICLE INFO

Article history:
Received: 24 October 2015;
Received in revised form:
28 November 2015;
Accepted: 04 December 2015;

Keywords
Wavelength Division Multiplexing (WDM),
Passive Optical Network (PON),
Optical Time Division Multiplexing (OTDM),
Non Return to Zero (NRZ),
Return to Zero (RZ),
Max Quality Factor (Q),
Next Generation Passive Optical Networks (NG PON).

ABSTRACT
To support higher data rate optical networks play a vital role. The high bandwidth potential of optical fiber can be explored by exploiting multiplexing techniques like wavelength division multiplexing (WDM) and Optical time division multiplexing techniques (OTDM).This paper evaluates the performance of 8 channel WDM and OTDM passive optical network (PON) for 150 km using PIN and APD(avalanche photo diode) receivers. It is found that WDM passive optical network (PON) yields better performance. Hence, it is further investigated for different data rates and modulation formats. It is found that RZ modulation format provides better Max quality factor (Q) than NRZ modulation format up to a distance of 100km.Beyond 100km the Max quality(Q) factor decreases due to dispersion and nonlinearities. The current access networks and next generation passive optical networks (NG PON) has also been reviewed.

Introduction

The current triple play services (video, voice and data), high definition (HDTV) and online gaming which require high bandwidth [1, 2] has changed the physical medium of networks from copper to fiber [3] .In order to secure future, service providers have introduced fiber as a means of communication because of its high information carrying capacity, low cost and long reach .Also fiber is immune to electrical interference, noise and chemical effects as compared to copper wire. Due to recent advancements in application specific integrated circuits (ASIC), the cost of optical components have reduced to a considerable extend [4]. In 1980 optical systems were introduced in to the back haul network which was operational in second window (1300nm), carrying 140Mb/s and 150Mb/s for a regeneration spacing of 52 and 42km**.** This span was much more than the existing cable transmission systems. Later due to shift of optical carrier (OC) to third window (1500nm) were attenuation was less (0.2dB/km), the regeneration reached to 90km. In 1988 optical links were used to connect different continents which include TAT (transatlantic cable) 8 and TAT9 with a capacity of 280Mb/s and 560Mb/s per fiber. Due to replacement of plesiochronous hierarchy by Synchronous digital hierarchy (SDH), the 140 Mb/s multiplex systems was replaced by 155Mb/s Synchronous Transports Module (STM-1) which became basic block for the new hierarchy. In 1990s optical systems were able to support 2.5Gbps data rate, using electrical time division multiplexing of 16STM1 [3].Hence optical fiber emerged as the best means of communication. This paper is organised as follows: section II discuses the various impairments in the fiber, section III presents the basic overview of current access networks and Next generation access networks. Performance of different optical amplifiers and receivers is presented in section V. Section VI deals with system performance and simulation of 8 channels WDM and OTDM. Finally in section VII results has been analysed and conclusion is drawn.

Impairments in the optical fiber

The signal transmission within the optical fiber is governed by the nonlinear Schrodinger equation. It is given as [5]

$$\frac{\partial A_j(z,t)}{\partial z} + \frac{1}{2} i\beta_2(\lambda_j) - \frac{\delta^2 A_j(z,t)}{\delta t^2} - i\gamma \left|A_j(z,t)\right|^2 A_j(z,t) + \frac{\alpha}{2} A_j(z,t) = 0$$

$A_j(z,t)$ is the complex amplitude of the optical pulse in j channel, $\beta_2(\lambda_j)$ is the dispersion parameter of j channel, γ is the non linear coefficient and α represents loss coefficient .The channel residual dispersion after N section dispersion compensation can be expressed as

$$\Delta D(\lambda_j) = N L_{SMF}\left[(1-\mu_p) D_{SMF}(\lambda_p) + (j-p)\Delta\lambda \left(\frac{dD_{SMF}(\lambda)}{d\lambda} - \frac{\mu_p D_{SMF}(\lambda_p)}{D_{DCF}(\lambda)} \frac{dD_{DCF}(\lambda_p)}{d\lambda}\right)\right]$$

Where $\mu_p = \left|\frac{D_{DCF}(\lambda_p) L_{DCF}}{D_{SMF}(\lambda_p) L_{SMF}}\right|$. $L_{SMF}, D_{SMF}(\lambda_p)$

Represent the length and coefficient of single mode fiber at wavelength λ_p and while $L_{DCF}, D_{DCF}(\lambda_p)$ represent the length of

Tele: 7298286015
E-mail addresses: erumerashraf@gmail.com

aspersion and coefficient of dispersion compensated fiber at wavelengthλ_p. $\Delta\lambda$ is the channel spacing. Effects of dispersion can be reduced by employing dispersion compensating fibers (DCF) ,chirped fiber gratings(FBG) and higher order mode (HOM) fiber The quantities which limit the higher data rate within the fiber are dispersion, four wave mixing(FWM) stimulated Brillion scattering(SBS) and stimulated Raman scattering (SRS)[9].Bo-ning et.*al.* [5] found that for a system using Mach Zehnder modulator and G.655 optical fiber, the mixed dispersion compensation is the best one. The system was evaluated for a distance of 160km with the frequency range of laser varying from 192.6-194.01THz. SRS is more pronounced in dense wave division multiplexing(DWDM).In case of SRS the transmitted light interacts with the molecules of the fiber resulting in a shift of wavelengths know as Stokes shift. These waves now travel at higher wavelengths where they interact with the original waves resulting in undue amplification. This results in degradation of the optical signal to noise ratio [7] Another dominant nonlinear effect in fiber is FWM which is due to interaction of light with the dielectric of fiber. When more than three waves(v_i, v_j, v_k) are copropagating within a fiber it results in another wave with a frequency given as $v_{ijk} = v_i + v_j - v_k \text{ with } i, j \neq k$. This frequency leads to crosstalk.[8, 6]

An overview of access networks

The bandwidth intensive applications has led to the introduction of passive optical networks (PON),which provides high data rate ,long reach and low cost.PON was was initially(1980s) used in long haul networks .The major breakthrough which led to development of PON was the formation of Full Service Access Network (FSAN) consortium in 1995[10]. A PON consists of a central office(CO) which connects several optical networkunits (ONUs) in the customer premises by employing a passive 1: N power splitter where N varies from 4 to 64 and the maximum distance between the OLT and ONU is 20km [11, 12].Fig.1 depicts the basic PON structure. The high bandwidth applications led to deeper penetration of optical fiber in to the access network resulting in *fiber to the* x (FTTx) ,where x stands for home , curb, neighbourhood, office, business and premises[13,14]. It may take any of the forms depending upon the fiber termination and interface. Due to recent advancement in digital modulation techniques (DSP), multilevel modulation formats, coherent detection and fiber has led to 10Tbps capacity over 10,000km [15]

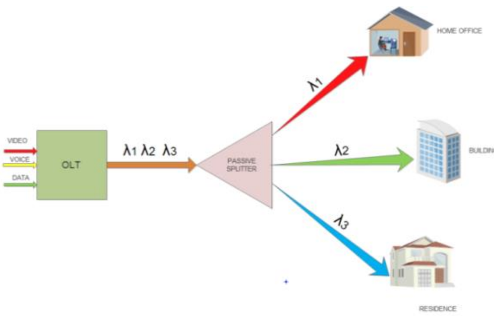

Fig 1. Basic PON structure

Depending upon the nature of the device being used, FTTx can be implemented by active optical network (AON) or passive optical network (PON)[16]. HFC (Hybrid fiber coax) involve legacy modulation formats and network elements which makes it inefficient than FTTx [16] .FTTx tends to reduces the overall cost of the system (capital expenditure and operational expenditure) [18], which lead to increased number of FTTx users. According to organisation for Economic Cooperation and Development (OECD) nations which include Sweden, Japan, Republic of South Korea, FTTH/B is the best option for local and industrial applications [6]. From the topological point of view PON can serve a single point or multiple numbers of points, hence two common configurations of PON are point to point (P2P)[9] or point to multi point (P2MP)[8]

Table 1. comparison of current access networks[17]

Configuration of PON	A PON	B PON	E PON	G PON
Framing	ATM	ATM	Ethernet	GEM
Maximum bandwidth	155Mb/s(↓↑)	622Mbs(↓↑)	1.25Gb/s (↓↑)	2.5Gb/s(↓) 1.5Gb/s(↑)
User per PON	16-32	16-32	16-32	32-64
Bandwidth per user	10-20Mb/s	20-40Mb/s	30-60Mb/s	40-80Mb/s
video	RF/IP	RF/IF	RF/IF	RF/IP
cost	low	low	Low	medium

In case of P2P PON large numbers of fibers need to be terminated in the CO which requires higher fiber management than P2MPHowever security is better in P2P PON. Due to restricted power budget of PONs the range is limited to 10-20km, its range can be increased to tens of kilometres by introducing active switch(Ethernet) between the CO and OLT[4] as shown in the fig.2 .The uplink transmission of PON is based on Multi-point control protocol (MPCP) while downlink transmission is broadcasted from OLT to ONU

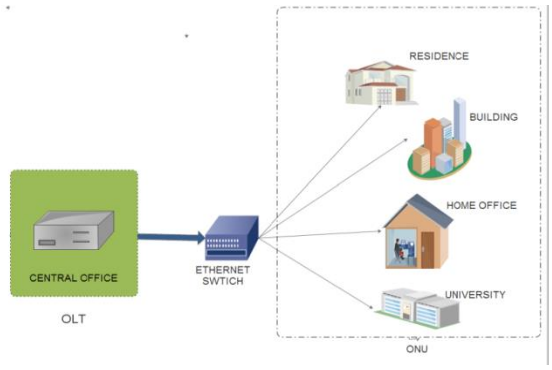

Fig 2. Active optical network

Overview of current and next generation passive optical networks (NGPON)

To support higher capacity various forms of current generation PONs based on time division multiplexing (TDM) include Asynchronous transfer mode (ATM) based passive optical network (A PON) ,Broadband passive optical network (B PON)[11]. The comparison of various current generation PON in terms of standard framing pulse and bandwidth is shown in the table 1. Ethernet passive optical network (EPON) and Giga passive optical network(GPON).APON was chosen as a country wide solution by Nippon telegraph and telephone (NTT)[16] however it needs up gradation which lead to B PON(ITU-T G.984) .Giga bit PON has been deployed in north America and Europe whereas Giga bit Ethernet PON is mostly used in Asia[14]. To support higher bandwidth the current PONs are upgraded to XG PON, where X stands for 10. The XG PON1 is cost efficient since they are backward compatible with the existing G PONs infrastructure. The XG PON1 aims to offer higher bandwidth so that large no of users can be can be supported. However .due to advent of new services, FSAN in 2011 has come forward with NG PON2, which aims to provide higher bandwidth, less cost, higher split ratio (1:256) and flexible architecture. The present capacity carrying target of NG PON2 is 40/10Gbps and 160/80Gbps for future downstream and upstream[17].the various technologies that support NG PON2 are time division multiplexing (TDM) PON, wavelength division multiplexing PON, optical code division multiplexing (OCDM) PON and optical frequency division multiplexing (OFDM) PON .Due to nonlinear effects and limited power budget NG PON1 based on TDM are not sufficient to meet the future demands .WDM PON clubs the information of different channels and transmits them over a single channel, hence it utilizes bandwidth of fiber efficiently. Since WDM PON provides P2P connectivity to the ONUs in the customer premises it is difficult to upgrade users from TDM PON to WDM PON Architectures based on WDM PON can be implemented using arrayed wave guide grating (AWG) or power splitter. Fig. 3 represents the basic WDM PON setup. The WDM PON based on AWG routes a unique wavelength to each ONU, while power splitter based architecture broadcasts the entire wavelengths to the each ONU in the PON. Such ONUs which are tuned to specific wavelength forms broadcast and select architecture of WDM PON[12].OCDMA can also be utilised by as NG PON2 requires encoders and decoders for each ONU.As the no. of users increase the noise from the adjacent channels limits its use. In case of OFDM each user is assigned a time slot, hence the flexibility and capacity of the network is increased .OFDM has not been considered as a good option for NG PON2 because the components are not matured yet[17].

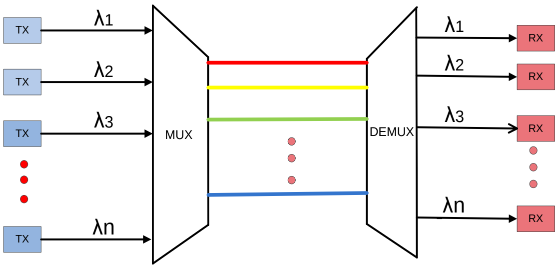

Fig 3. Basic WDM architecture

Optical Amplifiers

To compensate the various losses occurring in the optical fiber, different optical amplifiers were introduced in the optical channel which include Erbium doped amplifier(EDFA),Raman amplifier(RA) and semiconductor amplifier(SA).Earlier electronic repeaters were used which require two conversions first optical to electrical then to electrical optical conversion .Such conversions make the system complex and bulky .Optical amplifiers provide amplification in the optical domain without any conversion. Hence the complexity and reach of the system is increased.[19] EDFA which is operational in the C band is pumped using a laser at a wavelength of 980 nm or 1490nm can amplify multiple channels of different wavelengths. Low noise figure and high gain bandwidth of EDFA made it an optimum choice for amplifying multiple channels .Raman amplifier is used for long distance transmission since it reduces the noise accumulation. Semiconductor amplifier provides low power consumption and cost. To increase the performance of the system hybrid combination of above amplifiers is used[20]. Simranjit *et.al*[21] evaluates the performance evaluation of various amplifiers using different modulation formats for 160 × 10 Gbps and 96×10 Gbps DWDM. .It was found that return to zero (RZ) has better quality factor (13.88dB and 15.93 dB for 64 and 96 channels) than non return to zero (NRZ).Also the span achieved using RZ was higher than NRZ (180km and 175km for 64 and 96channels).

The gain equation of EDFA [22] is given as

$$G_{EDFA} = \frac{\sigma.n_t(W_p - \Gamma)}{2.\sigma.c.p + \Gamma + W_p} \quad (1)$$

where σ, c, Γ, p , n_t and W_p are the cross section for the induced emission ,velocity of light, reciprocal of lifetime of charge carrier, total population density of Er Ions and photon density. W_P is the pump rate of particles. The noise figure (NF) of EDFA is given as

$$\frac{P_{ASE}}{h.v.\Delta v.G} + \frac{1}{G} \quad (2)$$

Where v is the velocity of light, Δv is the bandwidth, G is the gain of the EDFA and h is the plank's constant. P_{ASE} , represents the amplified spontaneous emission power given as

$$P_{ASE} = 2n_{sp}\, h.vh.v(G-1) \quad (3)$$

Where n_{sp} represents the inversion factor which depends on the energy levels of the of erbium ions.

Receivers

The common photo detectors are p-n, p-i-n .and avalanche photo diodes (APD). For the simulation of 8 channels WDM and TDM, PIN and APD have been analysed for different data rates and distances (20-150km). For light wave applications the i region in PIN photo diode uses InGaAs while p and n layers uses InP. [23] .Quantum efficiency and response speed depends upon the operating wavelength ,band gap and material used for the p, i and n regions .The quantum efficiency of PIN photodiode varies from 30 to 90 percent. To have little noise and large carrier multiplication Reach-through avalanche photodiode (RAPD) is used. The responsivity of APD in the wavelength range of 1100-1700 for InGaAs is 10- 40 which is much higher than PIN photodiode (0.75-0.95).The responsivity of APD is given as[24]

$$\mathcal{R}_{APD} = \frac{\eta q}{hv} M = M\mathcal{R}_{PIN}\,. \quad (4)$$

the quantum efficiency, q is represents the charge of electron and hv is the photonic energy. Hence the responsivity of APD is M times the responsivity of PIN photodiode. M is the multiplication factor which depends upon the ratio of total unmultiplied output current and primary current photocurrent.

System Performance

The performance of the system can be calculated by analysing BER and Q factor .BER is defined as ratio of no. of bit errors detected in the receiver to the total no bits transmitted. It is given as[25]

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \quad (5)$$

The Q factor is defined as[26

$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 - \sigma_0} \quad (6)$$

Here the subscripts "1"and "0" represents the signal. "μ" represents the received power while " σ" represents the standard deviation.

Simulation of 8 channel WDM and OTDM PON

Fig. 4&5 represents the simulation window for WDM AND OTDM to compare the performance of 40. 8 channel WDM and OTDM PON for 2.5Gbps data rate using PIN and APD receiver for NRZ modulation format.

Table 2. comparison of 8 channel WDM and TDM

Analysis	8 channel TDM for 150km		8 channel WDM for 150km	
Receiver	PIN	APD	PIN	APD
Max.Quality factor	9.2243	9.4554	27.0698	27.8061
Min BER	1.08604e-020	1.1938e-021	9.175e-162	1.20753e-170
Eye height	7.28077e-005	0.00022112	8.979e-005	0.000270445
Threshold	2.1621e-005	5.9965e-005	2.1967e-005	2.95212e-005

At the transmitting end of OTDM a single CW laser (193.1THz) is used. Both WDM and OTDM PONs are evaluated for a length of 150km using optical amplifier. Table no 2 depicts the analysis of WDM and OTDM. It is found that the performance of WDM PON is better than TDM PON .hence WDM PON is further investigated for different data rates and distances .The continuous wave (CW) laser whose frequency varies from 193.1 to 193.8THz is modulated using PRBS generator at 2.5Gbps. with PIN/APD at the receiver end for a distance of 150km .The maximum quality factor of WDM PON (27dB) is much greater than TDM PON (9dB).In both the cases APD provides better Max quality factor than PIN photodiode.

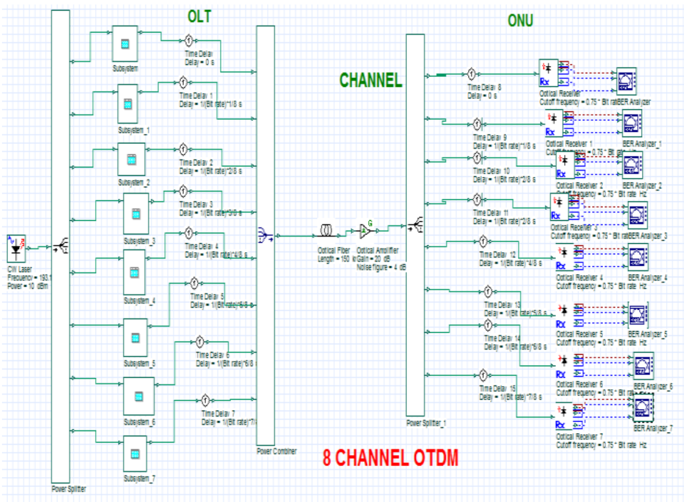

Fig 4. simulation window of 8 channel OTDM

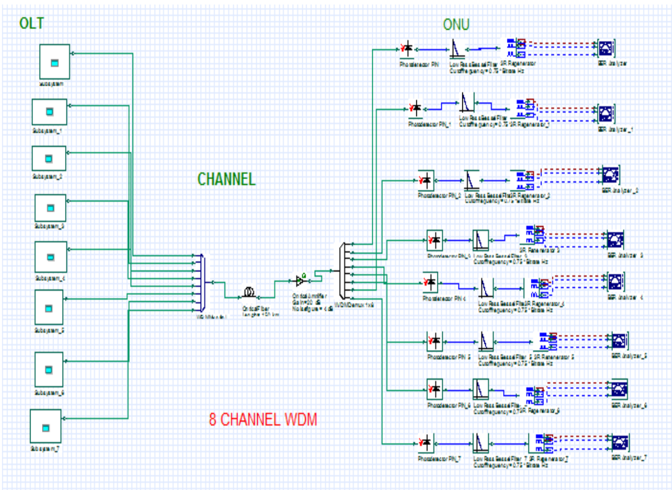

Fig 5. Simulation window of 8 channel OT

Table 3. simulation parameters of WDM

Parameters	Values	
Frequency of Laser	193.1THz	
Bit rate	1Gbps- 4Gbps	
Modulator	Mach Zehnder Modulator	
Modulation format	NRZ and RZ	
Insertion loss of 8x1 power combiner and 1X8 power splitter	0dB	
Distance	10km-150km	
Time delay	(1/Bit rate)*i/N	
Gain of Optical amplifier	20dB	
Detector	PIN	APD
Responsivity:	1A/W	1A/W
Dark current	10nA	10nA
Order of the Bessel filter	4	

I= time delay for ith path,N = no of channels in the system
I= time delay for ith path,N = no of channels in the system

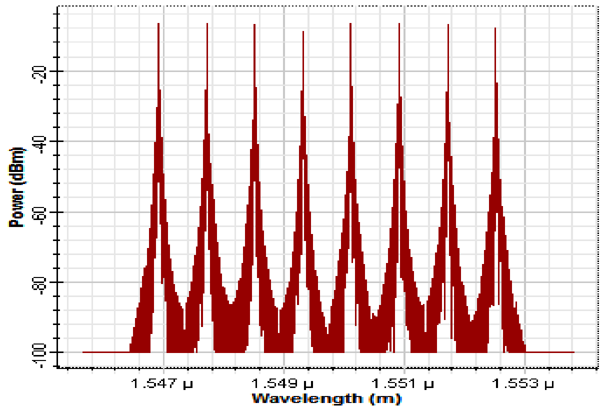

Fig 6. spectrum of 8 channels WDM

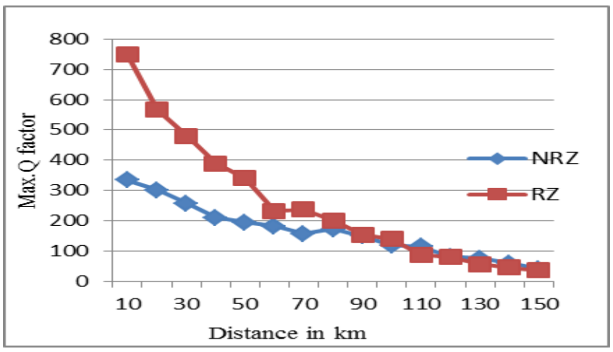

Fig 7. Max Quality factor vs distance for 1Gbps data rate

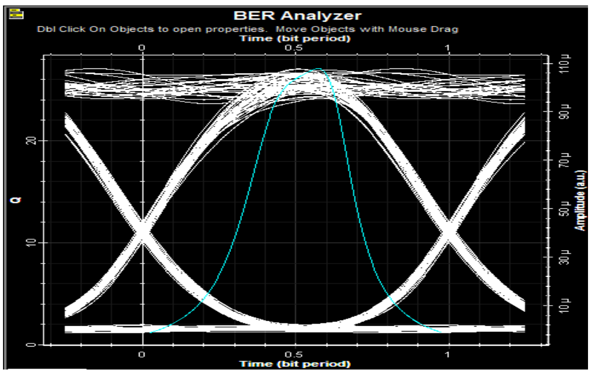

Fig 8. Eye diagram of 8 channel WDM at 2.5 Gps data rate

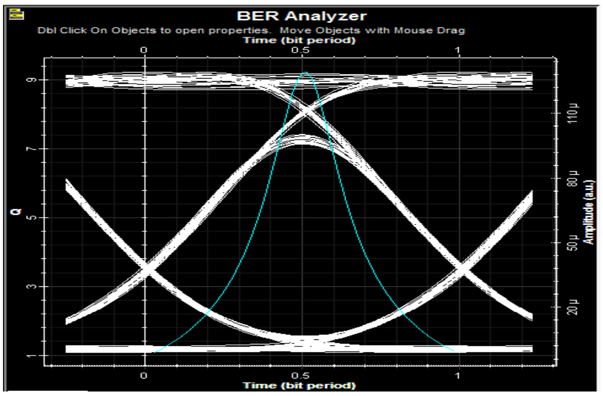

Fig 9. Max. Quality factor vs distance for 2.5Gbps data rate

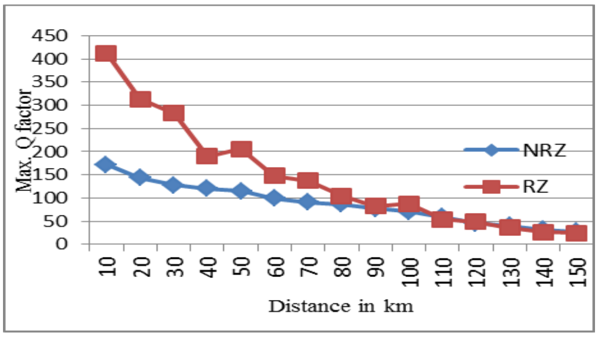

Fig 10. Max. Quality factor vs distance for 4 Gbps data rate

Results and Analysis

The performance of 8 channel WDM PON in terms of quality factor vs. distance for different data rates using NRZ and RZ modulation formats is analysed. Figure represents the variation of maximum quality factor vs distance at 1Gbps, 2.5Gbp and 4Gbps for RZ and NRZ modulation formats. Eye diagram is a novel way of representing the performance of the syterm.It is observed that RZ modulation format provides high quality factor than NRZ for different data rates.(1Gbps,2.5Gbps and 4Gpbs).Due to dispersion and nonlinearities Max quality factor decreases with distance .After 100km the performane of RZ and NRZ for different data rates is fairly same.

Conclusion

Multiplexing techniques have explored the high bandwidth potential of optical fiber**.** The quality factor of a system at a particular data rate depends upon the modulation format. Effects which limit the data rate can be overcomed using dispersion compensation techniques and suppression of four wave mixing problem ,self phase modulation and cross phase modulation.This work can be extended by using hybrid combination of WDM/OTDM.

References

[1]. De Paiva, G. E. R., et al. "80 km extended gigabit passive optical network." Microwave & Optoelectronics Conference (IMOC), 2011 SBMO/IEEE MTT-S International. IEEE, 2011.

[2]. Guo, Chen, and Teng Tiow Tay. "On scalability, migratability and cost-effectiveness of next-generation WDM passive optical network architectures." Signal Processing and Communication Systems (ICSPCS), 2012 6th International Conference on. IEEE, 2012.

[3]. Joindot, Michel, and Stéphane Gosselin. "Optical fiber transport systems and networks: fundamentals and prospects." Comptes Rendus Physique 9.9 (2008): 914-934.

[4]. Kaiser, W., et al. "Integrated circuits for coherent transceivers for 100G and beyond." Optical Fiber Technology 17.5 (2011): 456-463.

[5]. Hu, Bo-ning, et al. "Analysis on Dispersion Compensation with DCF based on Optisystem." Industrial and Information Systems (IIS), 2010 2nd International Conference on. Vol. 2. IEEE, 2010.

[6]. Kaur, Gurmeet, and M. L. Singh. "Effect of four-wave mixing in WDM optical fibre systems." Optik-International Journal for Light and Electron Optics 120.6 (2009): 268-273.

[7]. Kaur, Gurmeet, M. L. Singh, and M. S. Patterh. "Effect of fibre nonlinearities in a WDM transmission system." Optik-International Journal for Light and Electron Optics 121.10 (2010): 889-896.

[8]. Abed, H. J., et al. "Recent four-wave mixing suppression methods." Optik-International Journal for Light and Electron Optics 124.15 (2013): 2214-2218.

[9]. He, Jun, et al. "A survey on recent advances in optical communications." *Computers & Electrical Engineering* 40.1 (2014): 216-240.

[10]. Luo, Yuanqiu, et al. "Time-and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation PON stage 2 (NG-PON2)." Journal of Lightwave Technology 31.4 (2013): 587-593.

[11]. Ahmed, Maha, Daryoush Habibi, and Iftekhar Ahmad. "An improved architecture for integrating fourth generation wireless and passive optical networks." (2012).

[12]. Kramer, Glen, et al. "Evolution of optical access networks: architectures and capacity upgrades." Proceedings of the IEEE 100.5 (2012): 1188-1196.

[13]. Kazovsky, Leonid G., et al. "Next-generation optical access networks." *Journal of Lightwave Technology* 25.11 (2007): 3428-3442.

[14]. Wong, Elaine. "Next-generation broadband access networks and technologies." Lightwave Technology, Journal of 30.4 (2012): 597-608.

[15]. Sillard, Pierre. "New fibers for ultra-high capacity transport." Optical Fiber Technology 17.5 (2011): 495-502.

[16]. Effenberger, Frank, and Tarek S. El-Bawab. "Passive optical networks (PONs): past, present, and future." Optical Switching and Networking 6.3 (2009): 143-150.

[17]. Bindhaiq, Salem, et al. "Recent development on time and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation passive optical network stage 2 (NG-PON2)." Optical Switching and Networking 15 (2015): 53-66.

[18]. Tanji, Hisashi. "Optical fiber cabling technologies for flexible access network." Optical Fiber Technology 14.3 (2008): 177-184.

[19]. Singh, Simranjit, and R. S. Kaler. "Performance evaluation of 64× 10Gbps and 96× 10Gbps DWDM system with hybrid optical amplifier for different modulation formats." Optik-International Journal for Light and Electron Optics 123.24 (2012): 2199-2203.

[20]. Kaler, R. S. "Simulation of 16× 10Gb/s WDM system based on optical amplifiers at different transmission distance and dispersion." Optik-International Journal for Light and Electron Optics 123.18 (2012): 1654-1658.

[21]. Padwal, Soniya N., and Manisha Chattopaddhyay. "Performance Analysis of Hybrid Optical Amplifier in C and L Band over EDFA and RFA." International Journal of Advanced Research in Electronics and Communication Engineering 2.1 (2013): pp-040.

[22]. Padwal, Soniya N., and Manisha Chattopaddhyay. "Performance Analysis of Hybrid Optical Amplifier in C and L Band over EDFA and RFA." International Journal of Advanced

Research in Electronics and Communication Engineering 2.1 (2013): pp-040.
[23]. Agrawal, Govind P. Fiber-optic communication systems. Vol. 1. 1997.
[24]. Keiser, Gerd. Optical communications essentials. McGraw-Hill, 2003.
[25]. Jaiswal, A. K., et al. "To Study the Effect of BER and Q-factor in Intersatellite Optical Wireless Communication System." *IOSR Journal of Electronics and Communication Engineering* 3.4 (2012): 19.
[26]. Huang, Jing, and Jianquan Yao. "Performance comparison between 160Gb/s WDM and TDM systems." Optik-International Journal for Light and Electron Optics 123.24 (2012): 2254-2259.