Performance Analysis of Long Reaches WDM Optical Access Network for Different Modulation Formats

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ABSTRACT

In last decade or so, due to the emergence of various high bandwidth applications, there was a strong completion between various access networks. As the bandwidth is increasing day by day and in the present scenario various data intensive applications have led to the introduction of optical fiber as means of communication as a typical access network. As the optical access network provides a huge bandwidth and can be considered for long distance communication. The exceptionally high bandwidth of optical fiber can be explored by employing WDM technique in long reach optical access networks as WDM provides high bandwidth efficiency. In this paper, we have proposed a WDM access network for long reach networks. This proposed scheme evaluates physical layer parameters in terms of eye diagram, quality factor for NRZ and RZ modulation formats across variable optical fiber lengths that can be varied upto 200 kms for optimum solution and results. It is a flexible Solution to be used in next-generation access networks. Further, the bandwidth can also be utilized by using advanced modulation techniques e.g. Orthogonal Frequency Division Multiplexing (OFDM), hybrid WDM/TDM technique and Orthogonal Code Division multiplexing.

General Terms

Passive Optical network, wavelength division multiplexing, NRZ, RZ

Keywords

PON: Passive Optical network WDM: Wavelength division multiplexing.

1. INTRODUCTION

In the last decade or so, there was a considerable need and requirement of data usage for smart users. As the bandwidth requirement was increasing at a tremendous pace in technologies that are being used nowadays by the tech savvy users. Different access technologies are being used for such a huge requirement in data access networks [7][11]. The various access networks are being deployed and used to provide access to different bandwidth match scales provided by different access technologies. The various access technologies that showed some competition in the last decade that are being used until now for various tradeoffs are wireless access network and the optical access network. As we know the wireless access network provides mobility at the expense of low data rate but for high data rate usage we require a huge bandwidth media called optical access network so that it can provide access to different match scales that are being used by the tech savvy users. The optical access network provides huge bandwidth at the expense of lesser penetration at the end user. Hence we can say there is a trade off between the wireless access network and the optical access network in terms of mobility support and the data rate. The bandwidth requirement is increasing day by day, in various applications like Video on Demand (VoD), high definition television (HDTV), two way video conferencing [11].

The best and the novel solution for the optical access network is the passive optical network. It is used for high capacity wired access networks. The bandwidth intensive applications have led to the emergence of passive optical networks (PON), which provides high data rate at low cost. PON was initially introduced in 1980s and was used in long haul networks .The major step which led to PON was the development of Full Service Access Network (FSAN) consortium in 1995[13]. A PON consists of a central office (CO) which connects several optical network units (ONUs) in the customer premises by passive 1: N power splitter where N varies from 4 to 64 and the typical maximum distance in PON between the OLT and ONU is 20km [14][15]. PON provides huge bandwidth and instigates higher stability for data access across the optical access network. Fig.1 depicts the basic PON structure. The high bandwidth applications have explicitly led to deeper penetration of optical fiber into the access network resulting in *fiber to the* x (FTTx) where x stands for home, curb, neighbourhood, office, business organisation and premises [16][17]. PON is still taken as the novel solution in broadband access networks due to the emergence of huge bandwidth and low transmission loss and better immunity for the interference across the wired optical access network. PON consists of the active elements at the user end and source end only. There is no active element between the source and the user end that indicates that there is no active component in the channel between the central office and the user premises. HFC (Hybrid fiber coax) involve legacy modulation formats and network elements which makes it inefficient than FTTx. It may take any of the forms depending upon the fiber termination and interface. PON can be used for Point to point (P2P) or Point to multi-point (P2MP) configurations. Depending upon the nature of the device being used, FTTx can be implemented by active optical network (AON) or passive optical network (PON) [4]. The limitation of a passive optical network is that it only leads to the effective access only upto few KMs usually 20 KMs.

The PON usually consists of splitters, combiners, couplers and splitters. As it can use only passive components across its network. It basically contains a feeder fiber from source to the splitter. Due to the lesser installation cost and maintenance cost the feeder optical channel is used by all the users in the traditional passive optical access network. The splitter provides access to the users through the individual distributed fibers [8]. The topology for the Passive optical network is tree topology starting from source (central office) and ends at user premises [7]. The limitation of passive optical networks has led to long reach optical access networks that can be used upto 100s of KMs. In this paper the optical access network is deployed by using Wavelength division multiplexing. WDM is considered as the major option in case of optical access networks as it provides huge bandwidth performance and it also can be implemented for wide area networks. The WDM is implemented by using arrayed waveguide grating at the remote node as it only multiplexes or demultiplex optical signals on the basis of wavelengths. While as in Time division multiplexing it uses splitter at the remote node as it splits the incoming optical signal on the basis of power. WDM provides different wavelength channel for each user on the same feeder fiber channel, hence we can say it leads to better immunity and provides huge bandwidth for various applications in terms of huge data access needed by the tech savvy users which ultimately requires huge bandwidth for the latest and updated technologies in the internet access across the various access [6] [9][10] [12] networks. Thus the WDM technology can be considered as the best and the novel solution in terms of huge bandwidth capacity requirement.

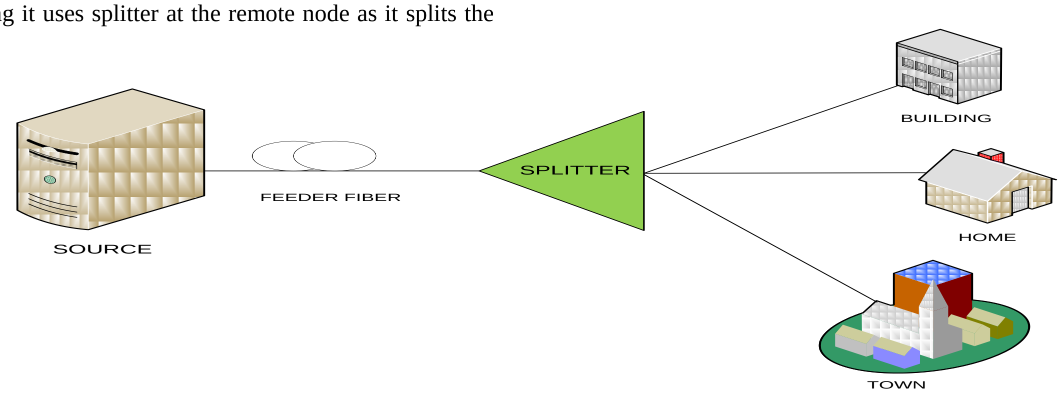


Figure 1 Basic PON architecture

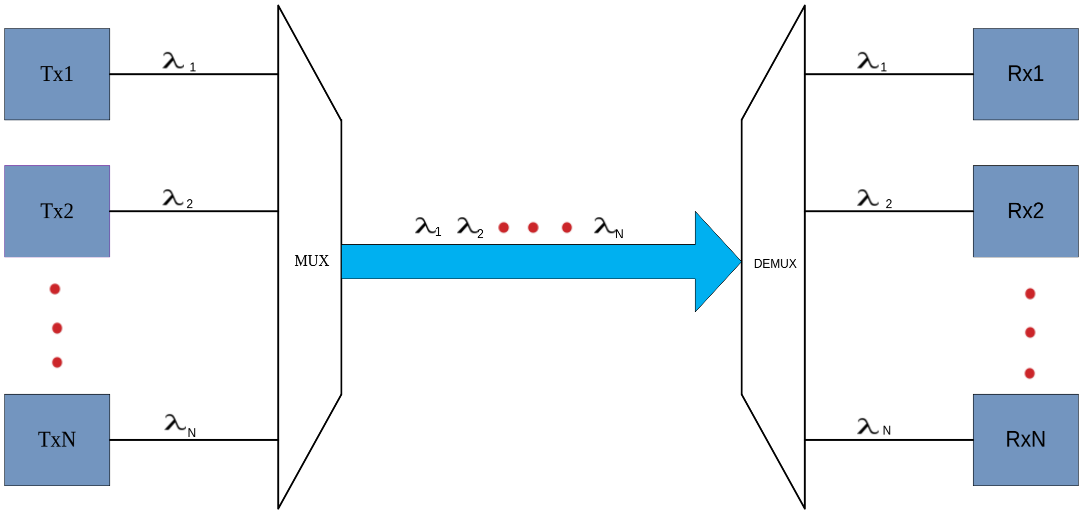
It provides point to point (P2P) communication. It can be the best idea and solution to be used for the Next generation (NG) access networks. Hence we can say, PON instigates better stability and provides huge bandwidth [7] but it fails to provide access for the mobile users. Thus it can be realized only for wired or static users. In this paper, we have investigated the optical access network for WDM access technique for various modulation formats (NRZ, RZ). We have analysed the proposed system for various physical layer parameters in terms of Quality factor, eye diagram across the various optical link fibers of variable lengths and data rates. This paper can be organised as: section 2 explains the architecture of basic WDM optical access network and explains how the basic WDM can be implemented across the various access networks. Section 3 explains the simulation design of the basic WDM access network from the central office towards the end user, section 4 explains the results and discussions and section 5 concludes the paper.

2. ARCHITECTURE

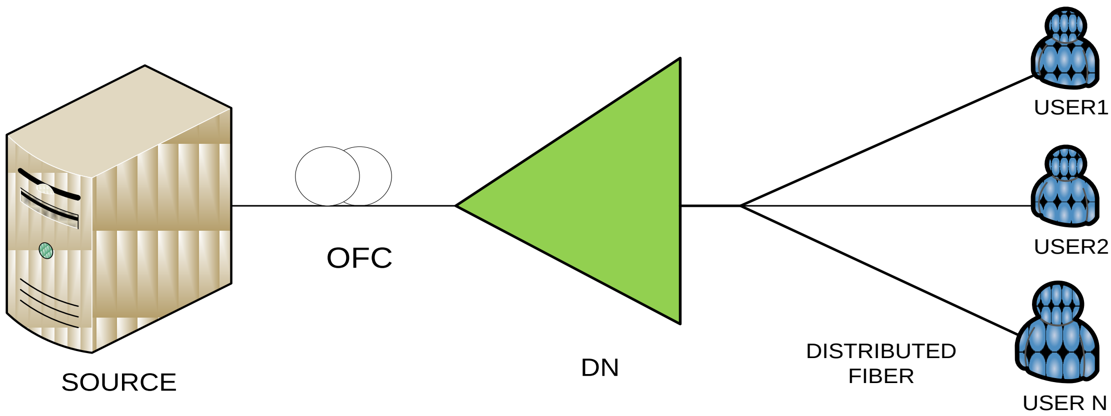
The basic architecture of WDM is shown in figure 2. It consists of N optical transmitters at the transmitting end. These optical transmitters generate signals at various optical wavelengths. These N wavelengths are selected with the help of WDM MUX and are added together to provide the signal to the feeder fiber. Then these signals are separated with the help Of WDM DEMUX at the receiver of WDM optical access network. This WDM access technique is realized into the various optical access networks as it provides huge bandwidth applications. It can be realized in an optical access network as the basic technique that can be implemented in order to provide access to the end users [6]. The architecture consists of the central office, feeder optical fiber, optical amplifier, distribution node and the customer/user premises. Since, the long reach optical access network is implemented by the active component in the optical access network at feeder fiber. It can be realized upto 200 km. The central office consists of optical transmitters and can be implemented by WDM multiplexer which transmits the various signals at different frequencies (193.1 -193.8) THz with wavelengths (λ1-λ8) across the feeder fiber channel, i.e. it transmits the optical signal across this feeder fiber. The feeder channel contains the optical amplifier and after providing this signal to optical amplifier it is provided to the WDM Demultiplexer which separates the different channels to provide the access to the different receivers [8].

The optical transmitters at the central office generate the signal at different frequencies and then these signals are transmitted across the feeder fiber channel and then processed in optical amplifier. Then after processing at the optical amplifier it is provided to the WDM Demultiplexer in order to separate the different channels in order to provide access to the end users.

WDM optical access networks are subjected to lesser constraints, that is why it is implemented in case of long reach optical access networks. The wavelength allocation is done at source (central office). The central office provides N wavelengths for N customers/users, these N wavelengths are combined at the source end by the WDM MUX and then transmitted across the feeder fiber with 100 GHz frequency spacing. These N wavelengths are separated before the receiver end at the distribution point with the help of WDM DEMUX. Then these wavelengths are provided to the various users with the help of different distributed fibers. These can be illustrated by the help of figure 3.



Tx: Transmitters, Rx: Receivers, MUX: Multiplexer, DEMUX: Demultiplexer.
Figure 2 Basic architecture for WDM access network.



OFC: Optical fiber cable/FEEDER, DN: Distributed node.
Figure 3 Basic architecture of long reach WDM optical access network.

3. SIMULATION DESIGN

It consists of central office, optical fiber, distribution node, user premises or receivers. Central office consists of 8 continuous wave (CW) lasers generating various optical channels at different frequencies (193.1-193.8) for 1.6 nm channel. These channels are having a frequency spacing of 100 GHz. These optical channels can be viewed by optical spectrum analyser as shown in figure 4. These optical channels are then combined by using WDM MUX having bandwidth of 10 GHz. Then these signals are provided across the feeder fiber. The optical fiber length has been varied from 20 to 200 km having attenuation constant of 0.2 dB/Km and dispersion of 16.75 ps/nm/km. Then this signal is provided to the optical amplifier operating in gain control mode having gain of 20 dB with optical power as 10 dB. It has noise figure of 4 dB. These channels are then separated by the WDM DEMUX at the distribution node having bandwidth of 20 GHz. Then the distribution node provides the optical signal to the end users. End user premises consist of optical to electrical convertors followed by electrical filter and regenerators. The optical to electrical convertor used here is avalanche photodiode of responsivity 1 A/W and dark current of 10 nA, followed by low pass Bessel filter of order 4 with cut off frequency as 0.75 × data rate and 3R regenerator with no delay compensation. The simulation diagram for the WDM PON can be viewed in figure 5.

The gain equation of EDFA [3] 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, photon density total population density of Er. Ions and 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. 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 [1]

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

The Q factor is defined as [2]

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

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

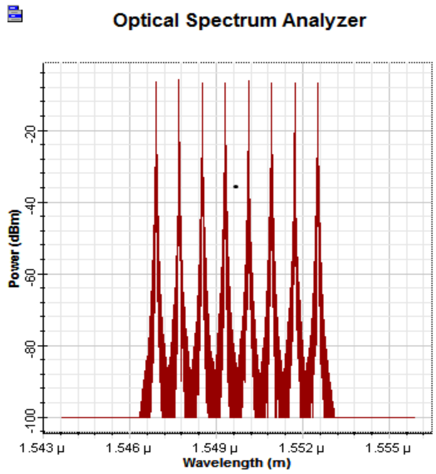
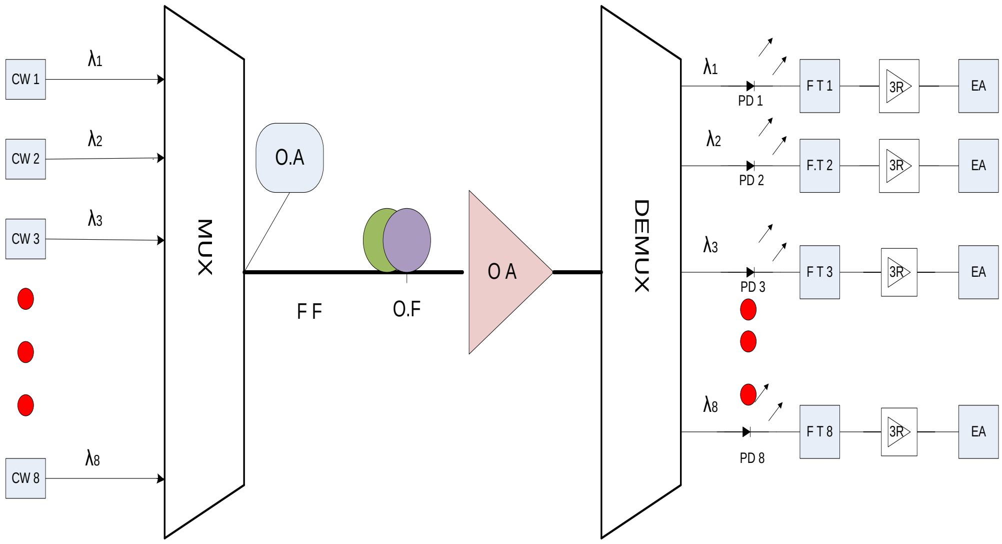


Figure 4 Allocated wavelengths for WDM optical access network



CW: Continuous Wave Laser, MUX: Multiplexer, O.A: Optical analyzer, FF: Feeder Fiber, OF: Optical Fiber, OA: Optical Amplifier, DEMUX: Demultiplexer, PD: Photodiode, FT: Filter, 3R: 3R Regenerator, EA: Electric Analyzer.
Figure 5 Simulation diagram

4. RESULTS AND DISCUSSION

The various physical layer parameters were evaluated for various conditions in terms of eye diagram, quality factor, and variable optical fiber cable length. The proposed system was analysed and the corresponding eye diagram evaluated for data rates at 2.5 Gbps for NRZ and RZ modulation formats as shown in figure 6 and figure 7 respectively. The eye diagrams show that RZ modulation format shows better results than NRZ modulation format at 2.5 Gbps.

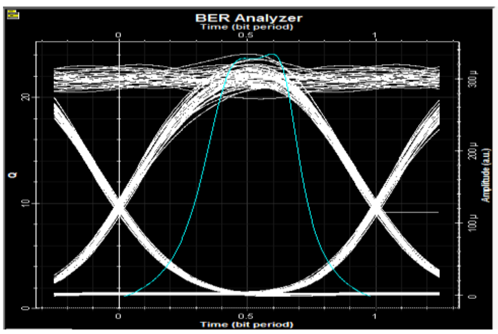


Figure 6 Eye diagram for NRZ scheme at 2.5 Gbps

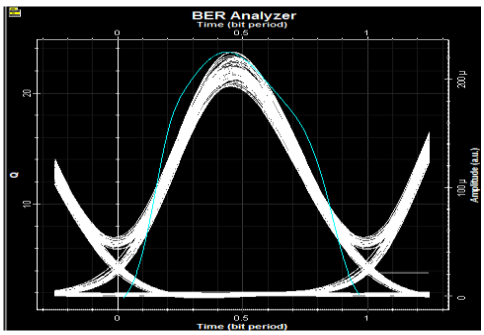


Figure 7 Eye diagram for RZ scheme at 2.5 Gbps

We have also evaluated quality factor for NRZ and RZ modulation format in terms of variable length of optical feeder fiber neglecting the length of distributed feedback fibers. The maximum quality factor for NRZ and RZ modulation format is 137 and 298 respectively at 2.5 Gbps and the maximum quality factor for NRZ and RZ modulation format is 74 and 187 respectively at 4 bps. It can be shown by the curves in Figure 8 and Figure 9.

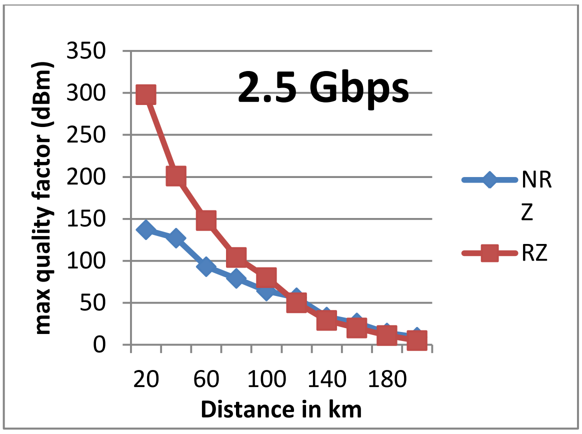


Figure 8 Quality factor Vs Distance (in KMS).

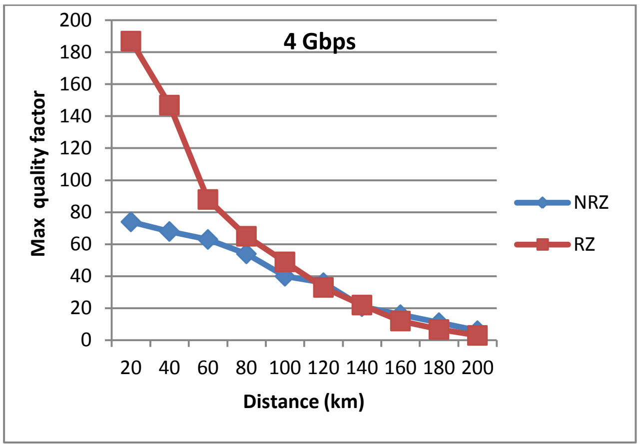


Figure 9 Quality Factor Vs Distance (in KMS)

5. CONCLUSION

In this paper the performance of an 8 channel WDM system is analysed in terms of quality factor and eye diagram for different modulation formats up to 200km optical fiber length. It is found that the quality factor of RZ is better than NRZ modulation format. Apart from accommodating various channels, Optical amplifier also compensate various losses occurring in the optical fiber. Due to dispersion and non linearity affects the Quality factor of both the modulation formats decreases with distance. The system performance can be increased by employing dispersion compensation techniques and the reach range of the system can also be increased. The capacity at the user end of this system can be further increased by clubbing the various advanced multiplexing techniques. These advanced techniques include hybrid WDM/TDM, WDM/OCDM and WDM/OFDM.

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