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Optimization of hybrid WDM/TDM (16×1024) PON for future access systems

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In recent years, hybrid systems have provided the solution for high bandwidth requirements of future access networks. In this paper, the architecture of hybrid WDM/TDM PON network with full system line rate of 240 Gbps with 16 optical line terminals and 1024 optical network units has been presented. The proposed system has been evaluated on the basis of Q factor and eye pattern. Hybrid optical networks are subjected to waveform spectrum analyzer. The Performance of the proposed system is analyzed for suitable receiver configuration. Access network is examined for optical detector and a comparative analysis is carried out. Also, the proposed network is evaluated for various electric filters like RC filter, Butterworth filter, Bessel filter, Gaussian filter, Chebyshev filter and Raised Cosine filter. Further, optical access network is optimized by employing Butterworth optical filter just before the photo detector so that the quality information signals are communicated with enhanced transmission span. The proposed architecture provides a practical way for growing demand of future access networks.

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Keywords: Hybrid WDM/TDM PON, Photo detector, Electric filters, Q-factor

1. Introduction

The ever growing demand for the data services offered on the Internet has resulted in higher bandwidth requirements from clients affecting access networks. Progression in services offered by the access systems for high transmission capacity requests has indicated congestion in the infrastructure near the client end. For the upcoming requirements optical fiber is considered as the most guaranteeing transmission medium for access systems [1-2]. Access networks employing optical fiber cables are called as optical access networks and are categorized into two classes, one of them uses active components called active optical network (AON) & the other employs passive components known as passive optical network (PON). In terms of quality transmission, power consumption and cost, PON outperforms AON [3]. PON comprises of an optical line terminal (OLT) at the access provider end and a substantial number of optical network units (ONUs) installed at the client's side. OLT is associated with the ONUs through an optical fiber cable which is further split utilizing a 1: N passive optical splitter equipping the clients to share the transmission medium and so sharing of hardware costs among a number of subscribers [4]. All the commercial available standards of PONs are time division multiplexed PONs (TDM-PONs), which depends on single wavelength transmission per fiber with allocation of carrier through splitter. Because of lower information rates & losses due to power split, TDM-PONs was not able to bear the requirements of Next Generation Access (NGA) systems. For NGA networks wavelength division multiplexing (WDMs) based access systems (WDM-PONs) provides a better solution in which the transmission limit of the system can be upgraded by distributing diverse wavelengths to every client and thereby enhancing the transmission rate of the network. WDM reduces the losses, but it has a drawback of serving a limited number of clients. Full service access network (FSAN) Group of world's leading telecommunication service providers, has selected time and wavelength division multiplexed network called hybrid WDM/TDM PON technology for stage 2 of next generation of passive optical access systems (NGPON2). It integrates the benefit of additional wavelengths offered by WDM-PONs and vast number of clients per wavelength given by TDM-PONs [5-6].

Researchers had analyzed WDM-PON system with channel spacing of 0.8 nm transmitting at a rate of 2.5 Gbps, network perform satisfactory for a distance of 25 Km over single mode fiber. The effect of attenuation and Inter symbol interference were evaluated for transmitting good quality information signals utilizing performance metrics like Q factor, bit error rate in [7-9]. Authors [10] presented, Time and Wavelength multiplexed passive optical network with 40 Gbps line rate for a distance of 20 Km. Hybrid WDM/TDM access network were investigated by utilizing cost effective components like reflective semiconductor optical amplifier (RSOA) and Optical add-drop multiplexer (OADM) for a line rate of 1.25 Gbps over a distance of 25 Km in [11]. Hybrid orthogonal frequency division multiplexing network was optimized for a length of 60 km with a reference BER of 10^{-12} by authors and reported in [5].

The performance of optical access network is affected by a number of network components like optical detector at receiver converts incoming optical signal back to electrical. Comparison of various optical detectors for longer wavelengths of 1300-1550 nm in an optical communication network was carried out in [12] utilizing performance metrics like Q factor, bit error rate (BER). Also, access networks are influenced by optical and electrical filters. An optical filter is employed in WDM optical network to filter out the transmitted wavelengths prior to the information signal is detected at receiver terminal. Electrical filter is utilized at receiver terminal to remove the unwanted signals added with the information signal. Authors in [13] analyzed the effect of different electric filters on WDM-PON. Different filters utilized were Integrator filter, Bessel filter, Butterworth filter, Chebyshev filter, Inverse Chebyshev filter, Elliptic filter, Gaussian filter and Rectangular filter. The transfer rate of 10 Gbps/channel and channel spacing of 100 GHz was used for investigation. On the basis of obtained Q-factor and BER, Bessel filter was considered to have better performance among considered filters. GPON system was examined for a separation of 60 km and a transfer rate of 2.5 Gbps. Band pass filter was employed before the transmitted signal is passed on to the detector. It was reported that Q-factor was improved which helped in improving the reach of the network in [14].

In literature, diverse works on optical access networks have been presented. Considering the work demonstrated in [7-8], WDM PON transmits 25 channels for a transmission distance of 20 km and optical network were evaluated for effects of attenuation and ISI. Similarly in [10], authors reported a time and wavelength multiplexed passive optical network for a distance of 20 km. Hybrid WDM/TDM access network was investigated for a network rate of 1.25 Gbps [11] Hybrid OFDM optical access system with four channels having an optimized length of 60 Km and reference BER of 10^{-12} as reported in [5]. Performance of APD and PIN Photodiodes was evaluated for a wavelength of 1300-1500nm in [12]. Performance of various electric filters was examined for a WDM-PON system in [13]. Further in [14], GPON system was designed for a length of 60 km. It employed an optical filter between power splitter and photodiode at ONU. By going through literature, we observe that hybrid access system was designed with less number of channels and ONUs for a short separation between the central office and ONUs. Also, configuration of receiver terminal is not presented for a hybrid WDM/TDM access system. Work can also be done for the evaluation of Photo diodes in hybrid PON system. Similarly, performance of electric filters like Raised cosine and RC filter has not been evaluated for a hybrid optical access network. Further, optimization of the hybrid network needs an attention and improvement can be done in this aspect.

In this paper, the work given in literature is expanded by improving the number of ONUs with a long reach and investigated hybrid WDM/TDM PON system. We have simulated the proposed architecture for 16 channels and 1024 client ONUs with a variable transfer rate of 10 Gbps and 15 Gbps for a separation of 130 km. A comparative analysis for receiver terminal is carried out to find the better photodiode and electric filter for the hybrid PON system. Further, the system is optimized for Quality of service by utilizing Butterworth filter between the splitter and receiver terminal.

The remaining part of the paper is structured as follows: the architecture of the proposed system is presented in section 2. In section 3, performance analysis of proposed network and results are reported. Finally, in section 4, conclusions are made.

2. Proposed system Architecture

In this section, the proposed architecture for the better performance of hybrid WDM/TDM PON system has been described. The architecture is proposed so that it provides high transmission capacity and sustains numerous clients with long reach. Undoubtedly, the work completed in this paper permits to make an examination between hybrid WDM/TDM PONs with similar qualities, the distinction is in transmission rate. The architecture is as shown in Fig. 1.

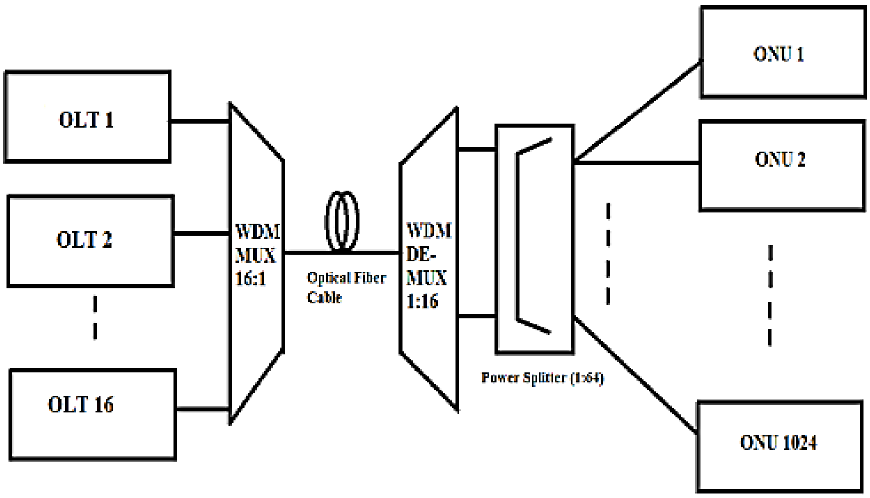


Fig. 1. Architecture of Hybrid WDM/TDM System

In this architecture, Information generated at various optical line terminals (OLT) which are generally represented as Central office (CO), is combined by WDM Multiplexer and transferred to Client ONUs through optical fiber cable. At Receiver, Information signals are separated by WDM (de)multiplexer and fed to ONUs through power splitters. Central office (CO) is configured for 16 OLTs, 1024 ONUs. In the proposed framework setup clients can access information without utilizing any reach extender like amplifier or repeater, thereby making the system economical. The frequency of 192.4 THz to 193.9 THz is employed for WDM channels which are segregated by 100 GHz (0.8 nm). Information is communicated by utilizing optical cable with a varying length of 50-130 km. The information is retrieved with the assistance of WDM de-multiplexer. The CO is associated with clients by dividing the information signal to 16×64 times. The signal is split by utilizing passive element: power splitter (PS) to split the signal before focusing on to the receiver ONU.

In proposed system, transmitter section consists of information source, non return-to-zero (NRZ) driver, continuous wave (CW) laser and outer Mach-Zehnder Modulator (MZM). OLT comprises of a data generator which delivers the information to be broadcasted at a desired transmission rate. Our system is designed for a transfer rate of 10 Gbps and 15 Gbps. At the recipient's side, information signal received from optical splitter is fed to the photo detector which is the primary component of receiver and generally PIN photodiodes are used due to its data transmission efficiencies and quick response. Also, avalanche photodiode (APD) can be employed for detection at receiver end. APD has the advantage over PIN in having good performance parameters. It can estimate and detect light even with low intensity. In proposed system a comparative evaluation is carried out to figure out a suitable detector for the system. In addition, performance of hybrid optical system is analyzed for various electric filters such as Bessel, Gaussian, Chebyshev, Butterworth, Raised Cosine & RC filter. We have investigated the proposed structure with/without employing Butterworth optical filter just before the photo detector.

The proposed system is examined using the common performance parameters such as Q factor and BER. The Q factor can be determined from the mean values η_0 and η_1 and the standard deviations σ_0 and σ_1 of the received information signal voltage levels 0 and 1respectively, as expressed in equation 1.

$$Q = \frac{\eta 1 - \eta 0}{\sigma 1 + \sigma 0} \tag{1}$$

The BER can be expressed in terms of Q factor as per equation 2 by using the decision-circuit method introduced [16] and enhanced in [17]

$$BER = \frac{1}{2} erfc(\frac{Q}{\sqrt{2}}) \tag{2}$$

where *erfc(x)* is the complementary error function (also called the Gauss error function) given by equation 3. Further, from the equation 1 and 2 we can express the value of BER in terms of σ_0 and σ_1 as per equation 4.

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \tag{3}$$

$$BER = \frac{1}{2} erfc\left(\frac{\frac{\eta 1 - \eta 0}{\sigma 1 + \sigma 0}}{\sqrt{2}}\right) \tag{4}$$

Equation 4 represents the analytical method for calculation of bit error rate.

3. Result and discussion

The results shown in Fig. 2 to 5 demonstrate the variation of quality factor vs. distance for various parameters. The curve shown in Fig. 2, measures Q factor for line rates of 10 Gbps and 15 Gbps. It is observed that, Q factor decreases with rise in data rate and distance. Quality-factor drops from 9.50336 to 3.49224 as the fiber length increases from 50 km to 130 km for line rate of 10 Gbps. The system performs better up to a transmission distance of 80 Km. However, the quality factor drops from 6.7166 to 1.10259 for the data rate of 15Gbps.

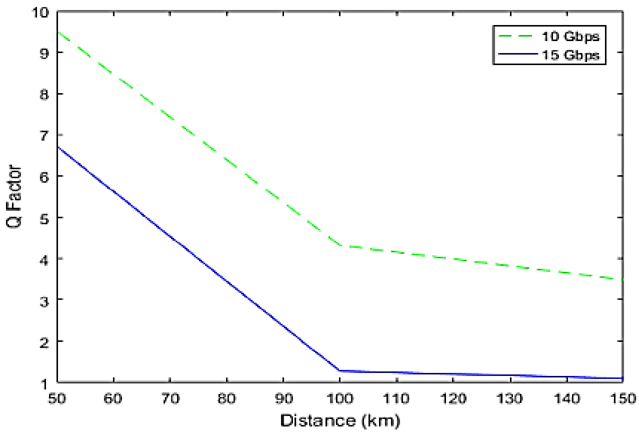
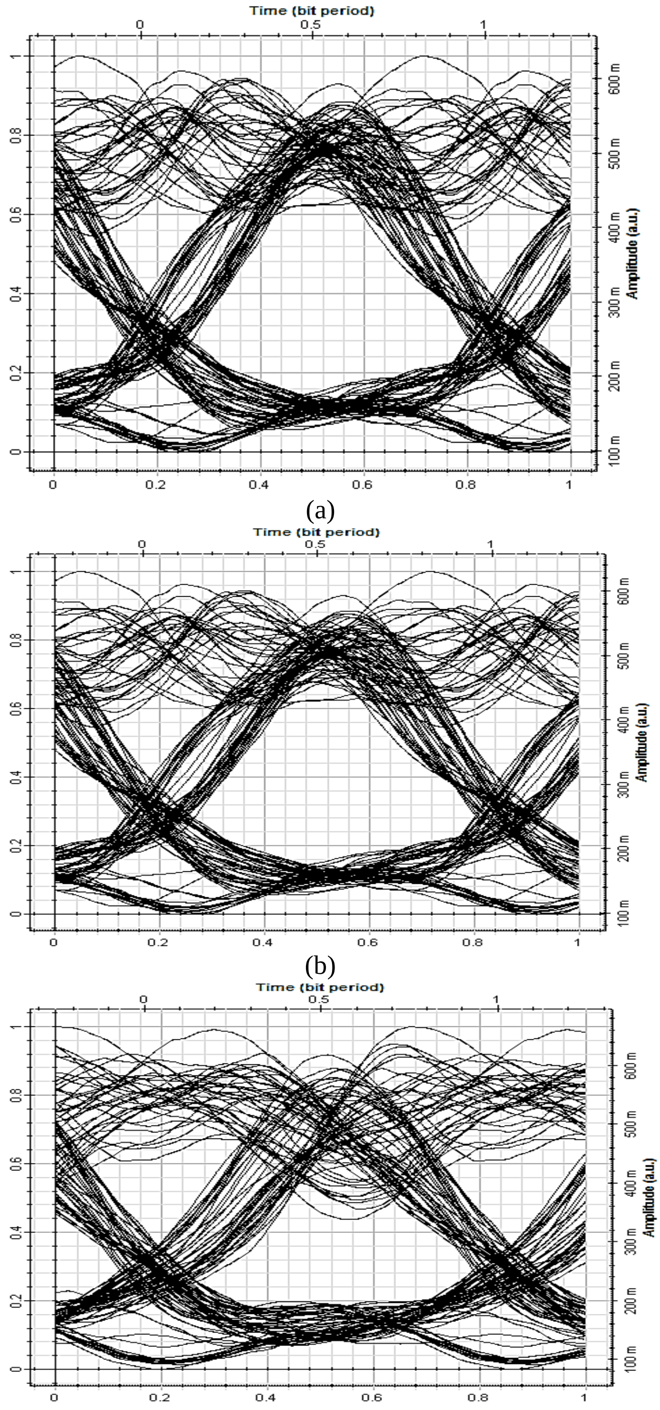


Fig. 2. Q Factor Vs Distance for varying data rate (color online)



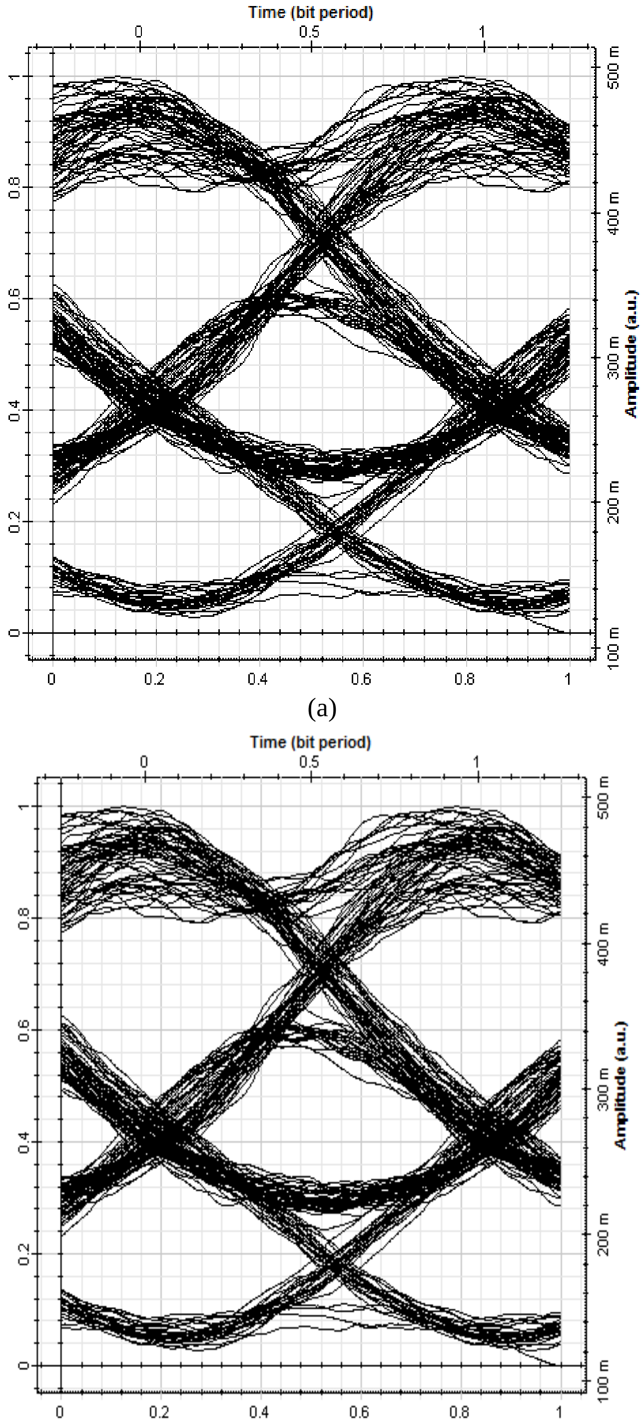
(a)

(b)

(c)

Fig. 3. Eye diagrams of optical access system with a data rate of 10 Gbps (a) 60 (b) 80 (c) 100 km distances respectively

Eye diagram analysis was carried out on proposed optical access network as shown in Fig. 3(a)-(c). An eye pattern is a typical barometer of the information quality received in optical networks. By utilizing an oscilloscope to generate eye patterns, the performance of the system can be analyzed as it helps in detecting the distortion of transmission channel. By carefully evaluating the eye opening, it is visible that the proposed access network can transmit information up to a span of 80 km, beyond this network separation the effect of noise increases sharply and data transmission is hampered.

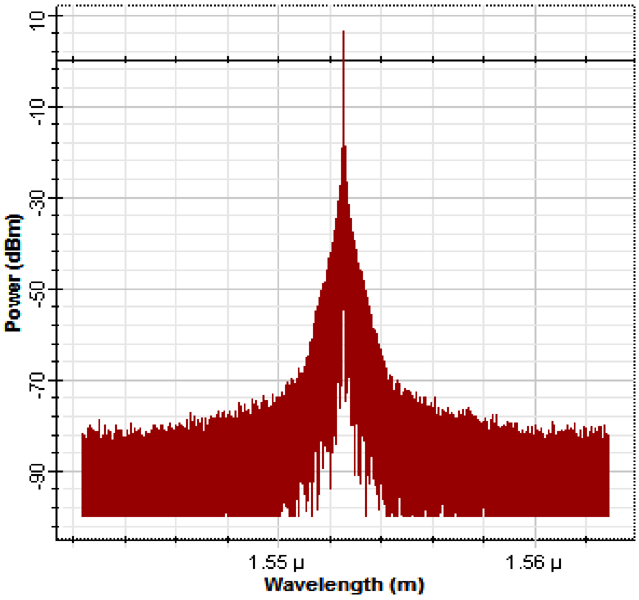


(a)

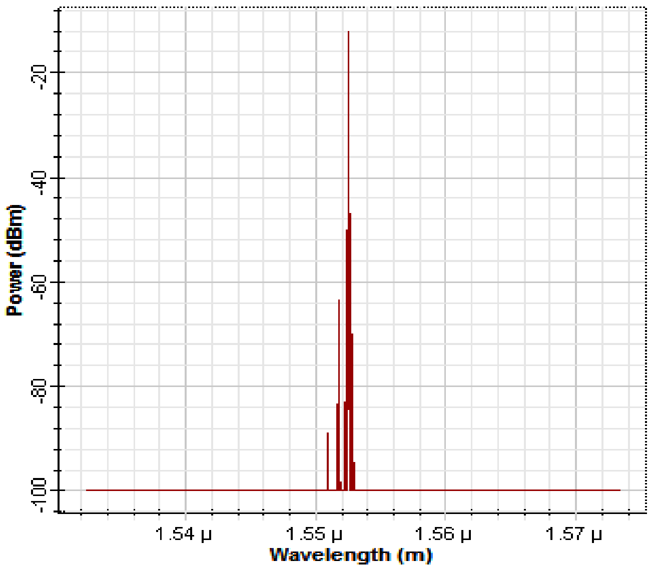
(b)

Fig. 4. Eye diagrams of optical access system for a network span of 50 km (a) 10 Gbps (b) 15 Gbps line rates respectively

Further, the performance of proposed network is evaluated using eye pattern for a network separation of 50 km with signals transferred with a data rate of 10 Gbps and 15 Gbps. It is indicated from the eye diagrams shown in Fig. 4 (a)-(b), quality of the information signal gets degraded as the line rate increased from 19 Gbps to 15 Gbps.



(a)



(b)

Fig. 5.(a) and (b).Wavelength spectrum of transmitted and received signals respectively

Fig. 5(a) and (b) displays wavelength spectrum of transmitted and received information signals. Due to the effect of Inter symbol Interference (ISI) data signals may encounter dispersion as information is communicated over the fiber. Dispersion may cause deformations because of the impact of noise in the transmitted information signals. Wavelength range analyzer looks at over various wavelengths and exhibits the power of data at each wavelength. The waveforms are captured for a hybrid WDM/TDM passive optical system with a transfer rate of 10 Gbps at a distance of 50 Km. Information signal is transferred at a input power level of 10 dBm. At receiver, information signal is detected with the help of APD detector. It is observed from the spectrum of transmitter that the data has a power of about 6 dBm which drops to -12 dBm as it is received at ONU. This drop is due to the effect of noise.

Also, system performance for various optical detectors has been examined. The Q-factor is measured for a transmission rate of 15 Gbps. At receiver when the information signal is detected using APD photo detector, the system gives a Q factor of 6.7166 and BER of 8×10^{-12}. For the same distance of 50 Km, PIN photo detector gives a Q factor value of 5.36128 with BER of 3.92×10^{-12} as depicted in Table 1. It shows that the proposed architecture works better when the signal is detected with APD photo detector.

Table 1. Q factor and BER value for various photo detectors at 50 km

Photo Diode	Q Factor	BER
APD	6.7166	8×10^{-12}
PIN	5.36128	3.92×10^{-12}

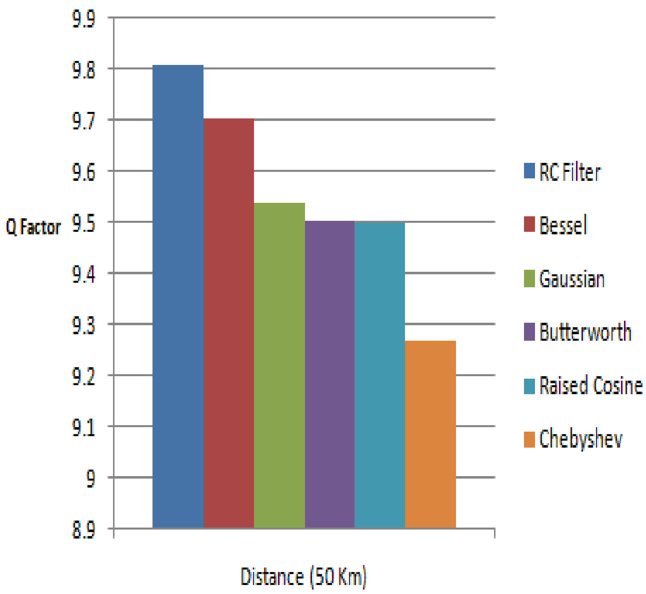


Fig. 6. Q-Factor Vs. Distance for different electrical filters (color online)

In [13], the WDM-PON was evaluated for various electrical filters. We have analyzed the performance of proposed system for different electrical filters namely Butterworth filter, Bessel filter, Gaussian filter, Chebyshev filter, RC filter, Raised Cosine filters with the help of Q-factor. Fig. 6 shows the variation of Q-factor versus distance for various filters at receiver. RC filter gives Q-factor value of 9.80852 for a transmission distance of 50 km; whereas, Bessel filter gives a value of 9.70584. It is observed that RC filter gives better result as compared to other filters.

Band stop optical filter was employed for reach extendibility of passive optical system by author in [17]. We have extended the work by using a Butterworth optical filter after the optical splitter and before the ONUs at receiver. The investigation is carried out for a transmission rate of 15 Gbps at a variable distance of 50 km to 130 km.

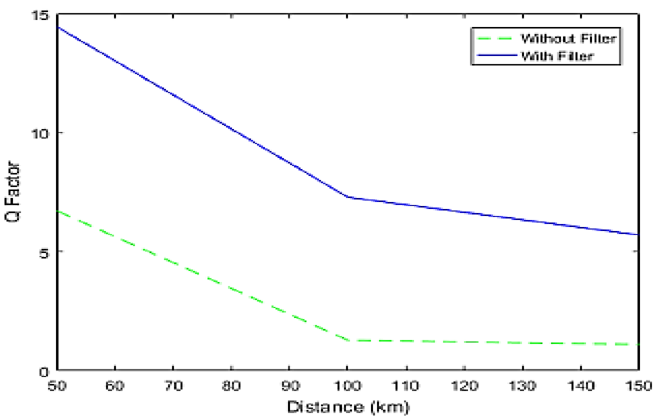


Fig. 7. Q Factor Vs. Distance with/without optical filter (color online)

It is observed from plot of Fig. 7, that the Q factor improves from 6.7166 to a value of 14.4516 with the use of optical filter for a distance of 50 km. The proposed system transmits data with an acceptable Q factor of 7.28639 at a transmission distance of 100 km.

4. Conclusion

In this paper, hybrid WDM/TDM PON system for 1024 end users is presented. Information is transmitted through the optical fiber cable over a frequency range of 192.4 THz to 193.9 THz and network separation of up to130 km. It is observed that when the information is transmitted at a rate of 10Gbps/line, the network gives acceptable Q factor for 80 Km. The proposed system gives a higher transmission distance of around 10 km with higher number of clients when compared with the system proposed in [5]. Also, when the line rate is enhanced to 15 Gbps, the system works well up to around 50 km. The above observations are verified by eye pattern and waveform spectrum analysis. The proposed network is evaluated for receiver configuration and found that the better quality is received if the information is detected with the help of Avalanche Photo Diode. A comparative analysis of various electric filters is done and RC filter gives highest Q factor of 9.80852 and Chebyshev filter have the lowest Q factor of 9.26744 for a network span of 50 km. The performance of the network further improves if an optical filter is installed just prior to the ONU. Q factor of 14.4516 is achieved in comparison with a Q factor of 6.7166 for a data rate of 15 Gbps/line and a full system line arte of 240 Gbps for 50 km. Further the proposed system gives an acceptable Q factor of 7.28639 for 100 km as defined as defined by ITU-T for next generation access network. Hence by installing an optical filter just prior to receiver optimizes the performance of the optical access networks and more number of clients is served with long reach and the system becomes cost effective. The investigated hybrid system is an ideal choice for future access networks.

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