Performance investigation of bidirectional Hybrid (wavelength-division multiplexing/time-division multiplexing) passive optical network

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We propose abidirectional hybrid wavelength division multiplexing/time division multiplexing passive optical network (WDM/TDM PON) for 128 optical network units (ONU's) and investigate for different data rates i.e. 1.25, 2.5, 5 and 10 Gbps. To realize bidirectional transmission in single fiber, a circulator is used to isolate the uplink signals from downlink signals. The effect of crosstalk between uplink and downlink signals is alleviated by using different wavelengths i.e. 1300 nm and 1550 nm wavelengths respectively. It is found that the downlink and uplink signals can be transmitted with acceptable BER upto 118 and 107 km reach without any inline amplification respectively.

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1. Introduction

Today the researchers are concentrated on hybrid wavelength division multiplexing/ time division multiplexing passive optical networks (WDM/TDM-PONs) to execute the obligation in next-generation of high-bandwidth optical access networks for cost-effective user-shared facilities [1]. This technology is well thought-out to be one of the most promising solutions for next broadband commitment. In WDM-PONs each user is assigned dedicated channel [2].The considerable enlargement in today's necessity i.e. demand for audio, internet data, video online, cloud and data center services and venture connectivity etc. can be carried out by this technology [1,3]. Designing of PONs architectures depends upon many parameters like ONU design, amplifiers, lasers, modulators, effect of non linearity (cross phase modulation (XPM), four wave mixing (FWM) etc.), topology, routing algorithm, location, allocation, capacity planning and cost. Various researchers have described the various optimization techniques based upon these parameters [4].

Fady I. et al. [5] proposed and demonstrated a bidirectional SCM–WDM PON using a reflective filter and cyclic AWG where up/downlink data was provided using a single optical source. The signal for downstream was modulated by a single CW laser diode and remodulated in the optical networkunit as an upstream. 1 Gbps signal both for up and downstream was demonstrated in 10 km bidirectional optical fiber link.L. Xu et al. [6] proposed and demonstrated a bidirectional transmission, hybrid wired and wireless access network based on subcarrier modulation (SCM) techniques. Error-free transmissions through a 25km length of single mode fiber (SMF) for both the downstream baseband and the remodulated upstream signals were confirmed by bit-error-rate (BER) measurements. Chien Hung Yeh et al. [7] proposed and experimentally demonstrated the remodulation technique using DPSK format in both downlink and uplink traffics with high extinction ratio (ER) in colorless WDM-PON. Error free operation was achieved in a 20kmreach 10-Gb/s WDM-PON without dispersion compensation. R. Kaler et al. [8] employed a fiber communication system using Giga Ethernet Passive Optical Network (GE-PON) architecture. The architecture had been investigated for different lengths from a Central Office to the PON in terms of BER. For 10 Gbps system, the BER versus transmission distance graph up to 15 km was plotted.R. Goyal et al. [9] analyzed the performance and feasibility of a hybrid wavelength division multiplexing/ time division multiplexing passive optical network (WDM/TDM) PON system with 128 optical network units (ONUs). The triple play services (video, voice and data) were successfully transmitted to a distance of 28 km to all ONUs.

In literature, various works on hybrid passive optical networks have been reported. Considering [5], a bidirectional SCM–WDM PON using a reflective filter and cyclic AWG is proposed and only 1Gbps data signal both for up and downstream is demonstrated in 10 km bidirectional optical fiber link. In [6], a bidirectional transmission hybrid wired and wireless access network based on subcarrier modulation (SCM) techniques is proposed and demonstrated upto a distance of 25 km only. In [7], 10-Gbps WDM-PON is proposed till 20 km distance. In [8], GE-PON investigated for a distance of 15 km and in [9], hybrid PON is proposed for distance of28 km only.Till now, we observe that the proposed hybrid passive optical networks are limited to lesser data rate and less number of ONU's, up to short distance and comparison of hybrid PON for different data rates is not done yet. Most of the papers are based upon downlink transmission only. In this paper, we extended our previous work [9] by investigating bidirectional hybrid PONs for different data rates at different distanceswith 128 ONUs.

This paper is organized into four sections. In section 1, introduction to hybrid PON is reported. The system setup for hybrid PON is described in section 2. In section 3, results have been discussed for the different data rates at different distances. Finally, in section 4, conclusion is made.

2. System setup

The block diagram of system setup for hybrid PON is shown in Fig. 1. In the proposed model, 128 ONUs can transmit and receive the data withvarious data rates. The central office(CO) is equipped with optical line terminal (OLT) devices. The transmitter consists of electrical signal generator with pseudo-random data generator (PRBS), modulation format coding, laser source and external modulator.

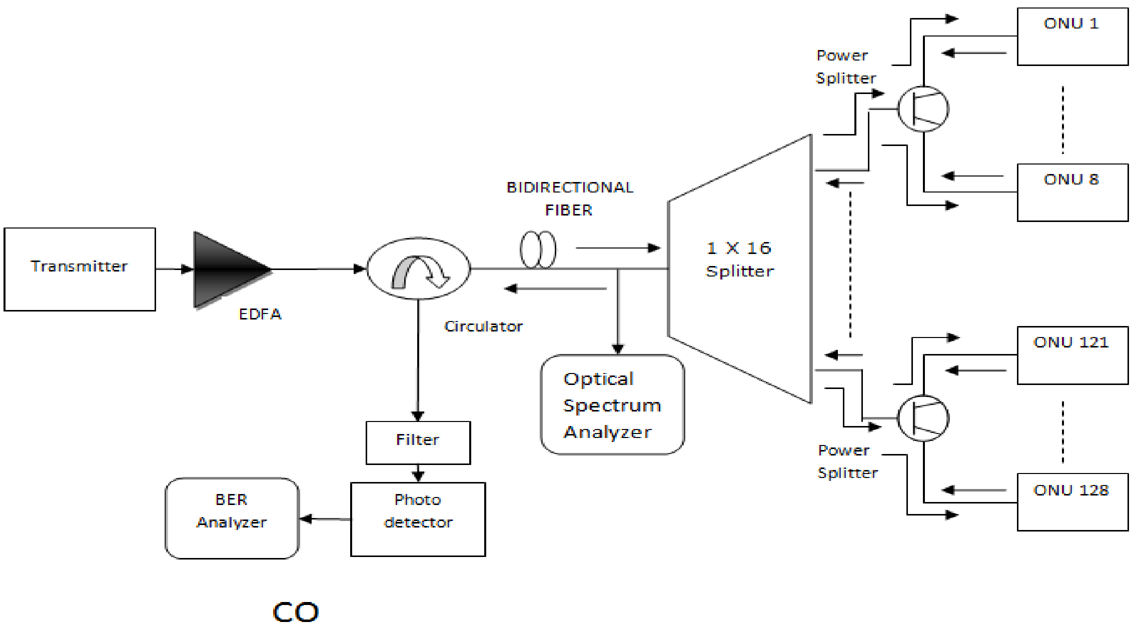

Fig. 1.Block diagram of system setup for hybrid PON.

The output signals from the transmitter are pre-amplified by a booster Erbium Doped Fiber Amplifier (EDFA). To realize bidirectional transmission in single fiber, a circulator with 3 dB insertion loss, 55 dB isolation and -100 dB noise power is inserted to isolate uplink optical signals from downlink.

The internal structure of the transmitter is shown in Fig. 2. PRBS generator is used to realize downstream data link with 1.25, 2.5, 5 and 10 Gbps speed. Non Return to Zero (NRZ) format is used for all input signals. An External Modulated Laser (EML) optical source is used to generate laser beam at 187.1 to 195.8 THz with 100 GHz channel spacing, -3 dBm power and 15 dB extinction ratio. The input signals from data sources are modulated through a carrier (optical signal from the laser source) by using the external Mach-Zehnder modulator.

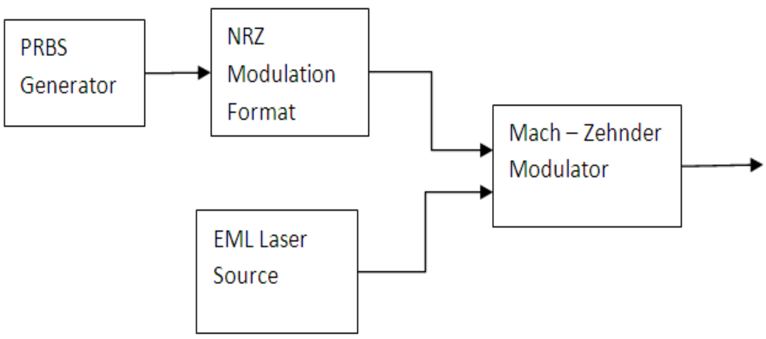

Fig. 2.Internal Structure of thetransmitter.

The uplink signals are converted into original signal with the help of Bessel filter and PIN photodiode.The wavelengths assigned to downlink and uplink signals are 1550nm and 1300nm respectively. Dispersion Shifted (DS) anomalous fiber distribution with 0.2 dB/km attenuation and 16.75 ps/nm/km dispersion is used in the channel.The input signals from CO send out through two remote nodes to ONUs. A 1: 16 optical wavelength splitter is installed at first remote node with a fiber link of varying length. At second remote node (which consists of pulse train generator, power splitter and delay blocks),a 1: 8 power splitter is used to feed these signals to 8 individual ONUs with different time delay parameters.10 ps time delay is given to each ONU to receive the signal i.e. the first ONU will receive the signal with zero time delay and the second ONU will receive after 10 ps delay and so on. The block diagram of ONU is shown in Fig.3.

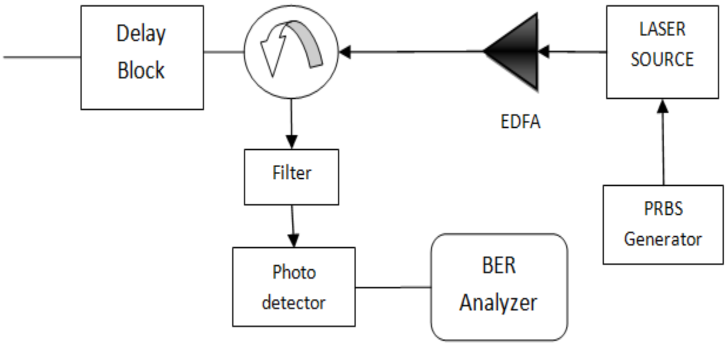

Fig.3. Block diagram of ONU.

At the ONU, the downlink signals are converted into original signal with the help of Bessel filters and PIN photodiode with 1 A/w response and 10 nA dark current. Different measurement components to analyze the results are also connected to the detector. For the uplink data, PRBS generator is used with EML optical source with 100 GHz channel spacing,-3 dBm power and 12 dB extinction ratio.The proposed architecture model of hybrid PON is designed for 128 subscribers with different data rates at different distances.The BER and Q factor are most commonly used performance parameters. The Q factor can be defined as [9]:

$$Q = \frac{m_1 - m_0}{\sigma_1 - \sigma_0} \quad (1)$$

Where $m_1, m_0, \sigma_1, \sigma_0$ are the mean and standard deviations of the received signal at the sampling instant when a logical 1 and 0 is transmitted respectively.
The bit error rate (BER) is measure of the probability that an error will occur in a given bit period. It can be estimated by the following inverting formula [9]:

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

In the system setup, a series of signals are received as upstream signals at the OLT side. So, we measured BER individually with the respective ONU.

3. Result and discussion

In order to observe the performance ofhybrid PONsystem is simulated for different data rates at different distances. Various result parameters like BER, Q factor and eye closure at different data rates for uplink and downlink by varying optical fiber length areobserved.

The BER versus transmission distance at 1.25, 2.5, 5 and 10 Gbps data rates for downlink graph is shown in Fig.4.

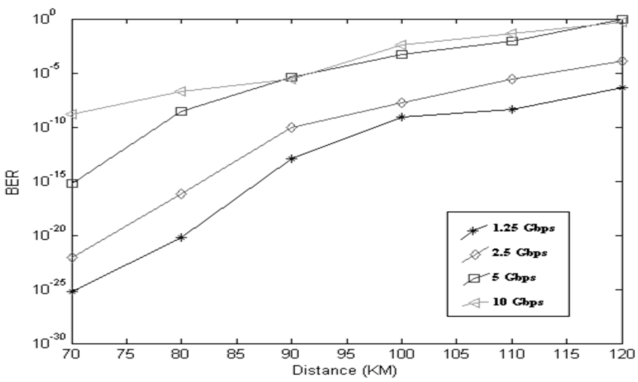

Fig.4. BER versus transmission distance at different data rates for downlink.

As shown in the above figure, the BER increases with respect to the transmission distance using 128 users. The distance of fiber link ranges from 70 km to 120 km in this graph. The most acceptable bit error rate isprovided by

1.25 Gbps is 3.8×10^{-9}at 118 km, by 2.5 Gbps is 1.9×10^{-8} at 102km, by 5 Gbps is 2.6×10^{-9} at 80 km and by 10 Gbps is 1.4×10^{-9} at 73km. If we further increase the fiber link length, then the BER increases and hence system is not sufficient to transmit the data.

The graphical representation of Q factor versus transmission distance at 1.25, 2.5, 5 and 10 Gbps data rates for downlink graphis shown in Fig.5. As we increase the distance, the Q-factor gets decreased due to the fibre non-linearity [10].

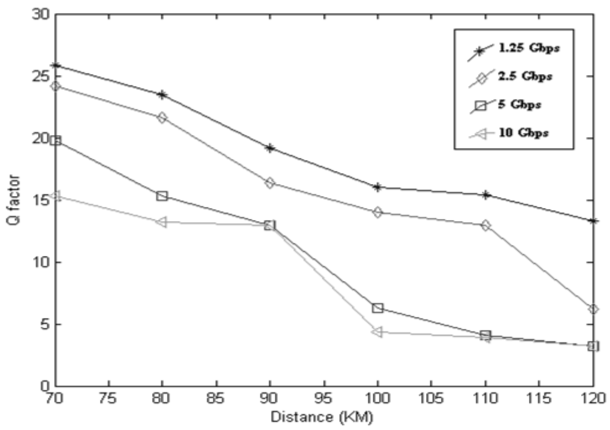

Fig.5. Q factor versus transmission distance at different data rates for downlink.

It is observed that the Q factor of 15 dB at 110 km by 1.25 Gbps, 16.4 dB at 90 km by 2.5 Gbps, 15.3 dB at 80 km by 5 Gbps and 15.1 dB at 70 km by 10 Gbps is achieved with 128 users.If we increased the fiber link length above thesedistance, then the Q factor decreases and hence system is not sufficient to transmit the data [11].

The optical output power of -22, -24, -29 and -33 dBm for downlink and -28, -36, -42 and -48 dBm for uplink are observed for 1.25, 2.5, 5 and 10 Gbps data rates respectively.We observed that the output power received is not same for all the channels while keeping the same or more than 15 dB quality factor for both uplink and downlink.

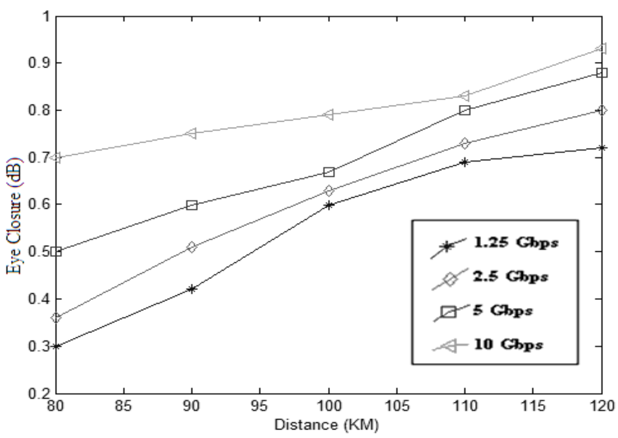

Fig.6. Eye Closure for HPON at (a) 1.25 (b) 2.5 (c) 5 and (d) 10 Gbps data rates for downlink.

The graphical representation of eye closure versus transmission distance at different data rates for downlink graph is shown in Fig.6. An eye closure of 0.6542 dB at 115 km by 1.25 Gbps, 0.6109 dB at 95 km by 2.5 Gbps, 0.5786 dB at 90 km by 5 Gbps and 0.7 dB at 80 km by 10 Gbps data rates is observed. As we increase the distance, the closure of eye is also increased due to the fibre non-linearity like XPM and FWM etc. [10].

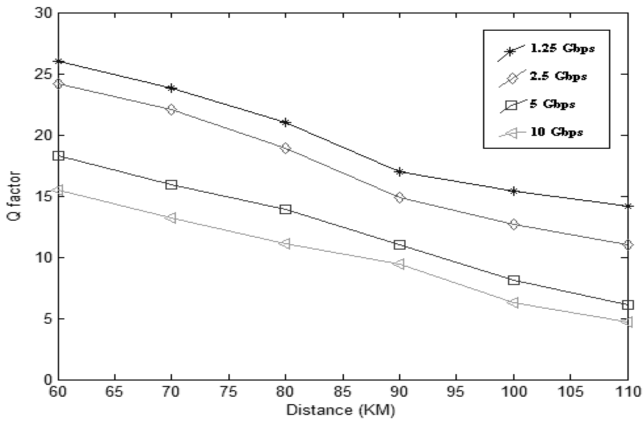

Fig.7. Q factor versus transmission distance at different data rates for uplink.

The graphical representation of Q value versus transmission distance at 1.25, 2.5, 5 and 10 Gbps data rates for uplink graph is shown in Fig.7. As we increase the distance, the Q-factor gets decreased due to the fibre non-linearity [10].

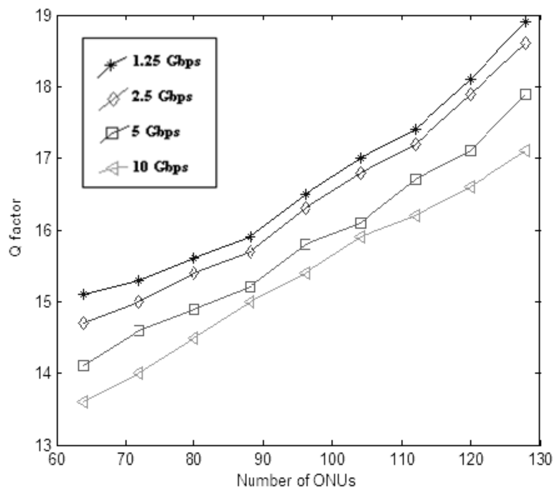

Fig.8. Q factor versus number of ONUs at 110 km for different data rates.

The graphical representation of Q value versus number of ONUs at 110 km for 1.25, 2.5, 5 and 10 Gbps data rates for downlink signal is shown in Fig.8. It is observed that the Q factor of 15.1 dB at1.25 Gbps, 14.7dB at2.5 Gbps, 14.1 dB at 5 Gbps and 13.6 dB at10 Gbpsdata rate is achieved for 128 ONUsat 110 km transmission distance.

4. Conclusion

In this paper, bidirectional hybrid passive optical networks for 128 end users are investigated. The users can transmit and receive the data through the same fiber. To enhance the performance of the system, the combination of WDM and TDM techniques is used in the system. The 1550 nm wavelength is usedfor downlink data and 1300 nm is used for uplink data transmission to reduce the effect of crosstalk. The results are carried out for different data rates i.e. 1.25, 2.5, 5 and 10 Gbpsat different distances. A transmission distance of 118, 98, 82 and 70 km for 1.25, 2.5, 5 and 10 Gbps data rates is achieved for downlink.We also successfully transmit uplink data traffic over 107, 88, 73 and 64 km distance for respective data rates without any inline amplification. If we further increase the distance (above 120 km) and/ or number of ONUs (more than 128), the BER will be increased. We expect further improvement in distance and/ or number of ONUs can be made by considering power level of lasers, spectral profile of the filters, performance of optical amplifiers, crosstalk,impact of non linearity, circulator and splitters devices, dispersion compensation in fibers etc. Also, the system can be enhanced with same number of users at the central office end.

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