

Long Reach and High Capacity Hybrid Passive Optical Network

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ABSTRACT

A number of applications are growing day by day and so the traffic. The need for bandwidth is also increasing at a rapid rate. The bandwidth and speed with which data can be transferred is very less when compared to core networks. The access network which was once a bottleneck is no longer so because of use of optic fiber (FTTH networks). A number of variants of Passive Optical Network (PON) have been proposed like the WDM PON and the Hybrid PON. Hybrid PON is a combination of TDM PON and WDM PON and is advantageous over WDM PON. This paper focuses on high capacity networks that can provide high data rate and long reach in the access part of the network. NRZ modulation format is normally used for transmission. We consider the advantages provided by the advanced modulation formats like DPSK. This modulation format is used here and its benefits are evaluated in Hybrid PON network to increase the capacity and the reach of the network. Parameters like the BER and the Q factors are analysed using Optisystem Software. Distortion and the phenomena of dispersion can limit the performance of such a system. Hence a Dispersion compensation mechanism like the Dispersion Compensation Fiber (DCF) is used in the system to transmit data over large distance.

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1. INTRODUCTION

A number of applications are growing day by day. There is an enormous amount of bandwidth requirement and a need for greater speed with which data should be transmitted [1]. Optical fibers are used in the core network which provides enormous amount of bandwidth and large speed. The bottleneck was only the access network which connects the core network to the subscribers. Since then optical fibers were used in the access part of the network, called the Fiber to the Home (FTTH) networks, this problem seems to be dwindling [2]. The access part of the network contains an Optical Line Terminal (OLT), an Optical Distribution Network (ODN) and the Optical Networking Units (ONU) or the subscribers. The OLT is housed in the Central office (CO). If the Optical Distribution network contains only passive elements then the access network is called the Passive Optical Network (PON). The elements in the Central Office are shared by the subscribers of the network [3]. Figure 1 shows a Passive optical Network.

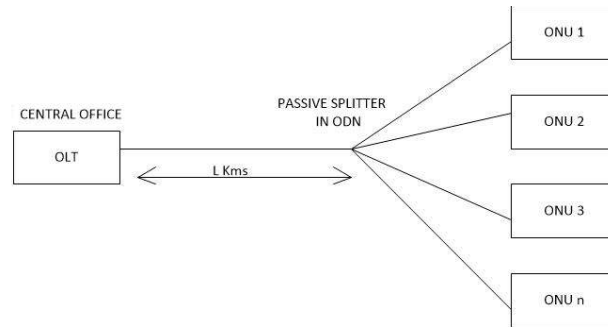


Figure 1. Passive Optical Network

There are a number of variants of PON called the EPON, WDM PON and the Hybrid PON [3-7]. EPON uses Ethernet packets for its transmission. It uses 1310nm for its downstream transmission and 1490nm for its downstream transmission. When data is transmitted downstream, the Ethernet frames reach all the ONUs. The ONUs discard the frames irrelevant to them and retrieve the information pertaining to that ONU. While transmitting in the upstream direction, if all the ONUs transmit at the same time, it may result in collision. Therefore, Time Division Multiple Access (TDMA) is used to gain access for the upstream transmission bandwidth [8]. For this a number of Dynamic Bandwidth allocation algorithms (DBA) are proposed in the literature and is used [9-11].

In the second variant called the WDM PON, there are a number of transmitters in the OLT. Each subscriber is assigned a specific wavelength for its upstream and downstream transmission. This provides enormous bandwidth as a number of wavelengths are used. But the bandwidth provided is not completely utilised by the subscribers and the cost of the equipment is also high [12].

To provide the advantages of WDM PON and at the same time to increase the utilisation of the bandwidth and to reduce the cost for the customer, Hybrid PON was proposed [13]. It combines both TDM PON and WDM PON and is shown in Figure 2. As in WDM a number of wavelengths are used for upstream and downstream transmission. A group of ONUs share a single upstream and downstream wavelength. When a subscriber doesn't have enough data to transmit, the wavelength is utilised by another subscriber of the same group to transmit its data. Thus the bandwidth is highly utilised. Also the data rate is more when compared to EPON networks [14].

The role of Modulation formats, optical components, optical amplifiers and optical fibers have been proved to be the key players to provide high spectral efficiency in optical networks. Modulation format specifies how the bit stream is converted from electrical to optical domain. The information is carried either in amplitude, Phase or polarisation of the signal [15]. Usually, NRZ modulation format is used for transmission in such networks [16]. More research is underway here for hybrid PON. This paper focuses on increasing the data rate and extending the reach of Hybrid PON networks by utilising advanced modulation formats like the DPSK format.

In literature, the effect of different modulation format in the transmitter of WDM PON has been studied. A bi-directional passive optical network was investigated with different modulation formats such as NRZ, RZ and OOK in [17]. The downstream (10Gbps) and upstream (2.5Gbps) traffic data was successfully transmitted up to a distance of 150 km. It was observed that NRZ modulation format has an edge over RZ and OOK modulation formats. In order to meet the future network needs and reduce dispersion and non-linear signal degradation, A.Garcia-Perez et.al [18] studied the different modulation format for a high speed optical transmission system for a channel rate of 40Gbps and compared their performance in long reach systems for a distance of 80Kms. The study included the RZ, NRZ, and DPSK systems for a single channel. The results showed that DPSK based formats was the best due to its simple transmitter configuration and receiver cost effectiveness.

In [19], the authors analysed different types of modulation formats like NRZ, RZ, DB and DPSK for WDM-PON network. The Q factor and BER were studied for various data rates up to 10Gbps by varying the distance between the transmitter and the receiver. It was seen that more stable values of Q-factor were achieved for DB and CSRZ-DPSK when compared to the commonly used intensity modulation format, NRZ. In [20], authors analysed the various modulation formats, Non-return-to-zero (NRZ) on-off keying, return-to-zero (RZ) OOK, carrier suppressed RZ (CSRZ) OOK, Duobinary (DB), NRZ differential phase shift keying (NRZ-DPSK), RZ-DPSK and CSRZ-DPSK formats and compared the maximal reach which could be achieved with a lesser BER for a data rate of 10Gbps. With DCF used in the system, the longest transmission

distance was achieved with RZ-DPSK modulation format. In [21], a wavelength-division-multiplexing passive optical network (WDM-PON) is demonstrated using symmetric differential phase-shift keying (DPSK) signals and on-off keying (OOK) signals, in the downstream and upstream directions respectively at 10 Gbit/s. A reflective semiconductor optical amplifier (RSOA) as an intensity modulator at the optical network unit (ONU). The authors showed that an error free transmission could be achieved for a distance of over 25-km with low power penalty.

DPSK modulation has been proved to be quite successful for a transmission rate of 10Gbps in WDM networks. This paper experiments the use of DPSK modulation format at a data rate of 40Gbps with necessary dispersion compensation mechanisms to exploit its maximum use in Hybrid PON network [22].

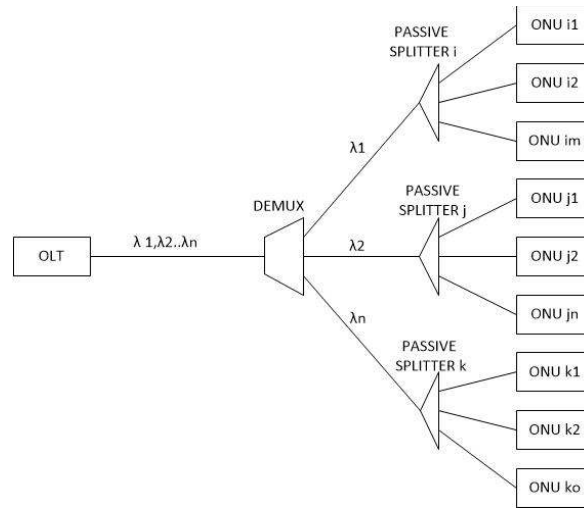


Figure 2. Hybrid PON Network

2. SIMULATION SETUP

The simulation is carried out using Optisystem. Four transmitters are used with 192.1THz, 192.3THz, 192.5 THz and 192.7 THz in which DPSK modulation is carried out. The data rate of the signals transmitted is set at 40Gbps. The four wavelengths are multiplexed by a WDM multiplexer and are transmitted over an optic fiber. In the optical distribution network, the signals are demultiplexed using a demultiplexer. All the four wavelengths are obtained at the output of the demultiplexer. Each of these wavelengths is connected to a passive splitter consisting of 128 ports with a loss of 21dB. Therefore, every wavelength can cater to 128 subscribers. When 4 wavelengths are used, the total number of subscribers reaches 512 numbers. The block diagram representation of the simulation setup is shown on Figure 3.

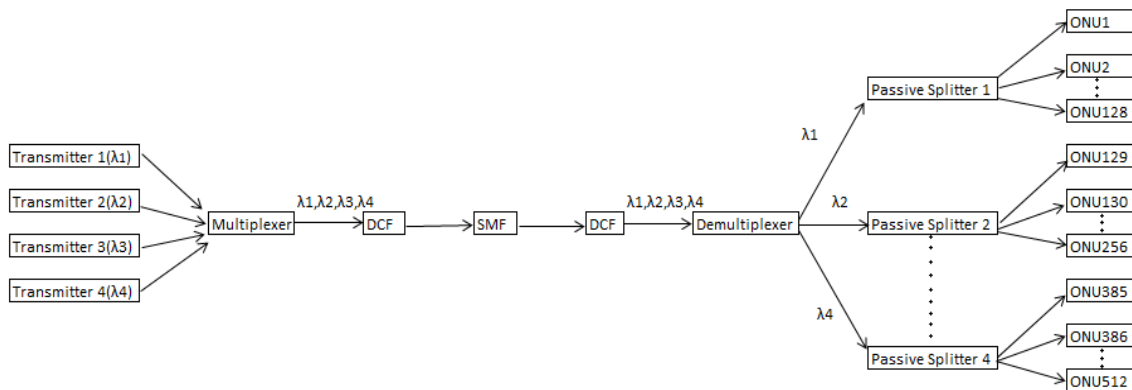


Figure 3. Simulation Setup of Dispersion Compensated Hybrid PON with DPSK Modulation

In the transmitter section, data and voice signals are combined (voice over internet protocol) having 40Gbps data rate and is generated by PRBS signal generator and the signal pass through Non-return to Zero (NRZ) driver. Two concatenated modulators are used for DPSK Modulation. The phase modulated signal is generated by encoding the NRZ signal using a Duobinary precoder. It then drives a Lithium Niobate Mach-Zehnder Modulator and modulates the phase of the CW signal. The output of this modulator then drives a second modulator, which is driven by sinusoid of 20GHz frequency. Four such transmitters are connected to a WDM multiplexer and the multiplexed signal is sent through the optic fiber. The transmitter section is shown in Figure 4.

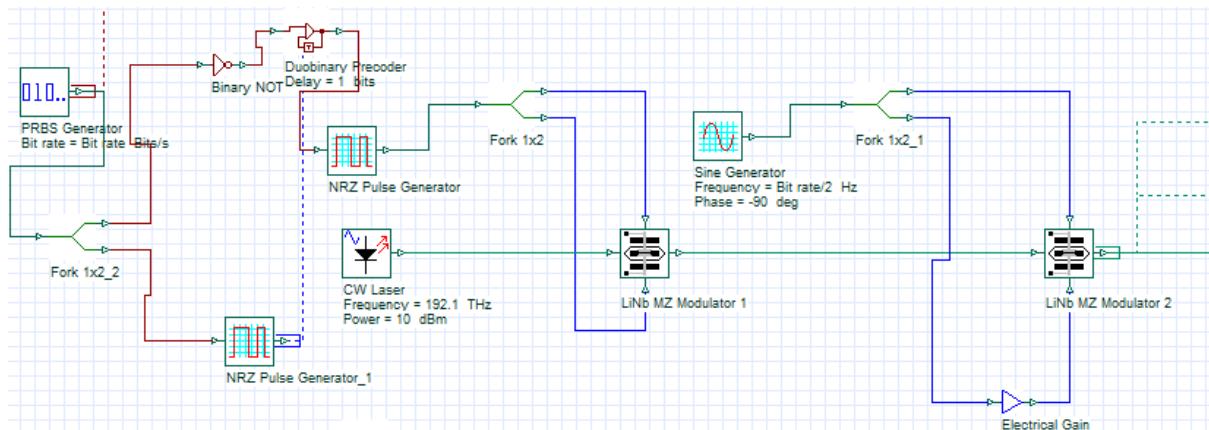


Figure 4. Transmitter section of Hybrid PON

When a number of wavelengths are sent through the fiber chromatic dispersion causes pulse broadening and hence the adjacent bit periods overlap leading to inter-symbol interference. Broadening of pulse depends both on the wavelength, distance and the dispersion parameter. The Dispersion parameter of the SMF is taken to be 17ps/nm/km in 1.55μm wavelength range. Using dispersion compensated fiber reduces the dispersion in fiber [23]. Out the three dispersion compensation schemes like the pre compensation, post compensation and the symmetrical compensation scheme, symmetrical compensation has proved to be a better technique and hence is adopted here [24]. The symmetrical compensation applied to the fiber is shown in Figure 5.

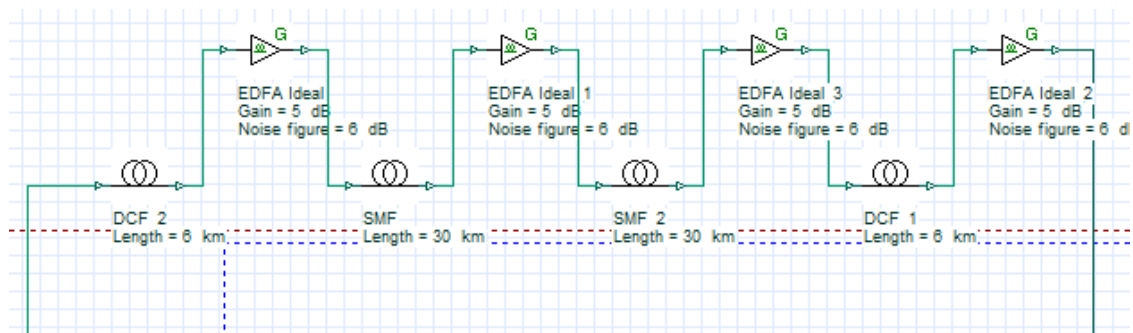


Figure 5. Symmetric compensation DCF

At the receiver end, a de-multiplexer is used to separate the different wavelengths. Each of the output ports of the de-multiplexer is then connected to a passive splitter/combiner. The splitter helps in connecting the subscribers to the access network. A group of users connected to the same passive splitter shares a single wavelength. Demodulation of the received signal is carried out by Mach-Zehnder interferometer and balanced photodiodes at the receiver. The receiver section is shown in Figure 6.

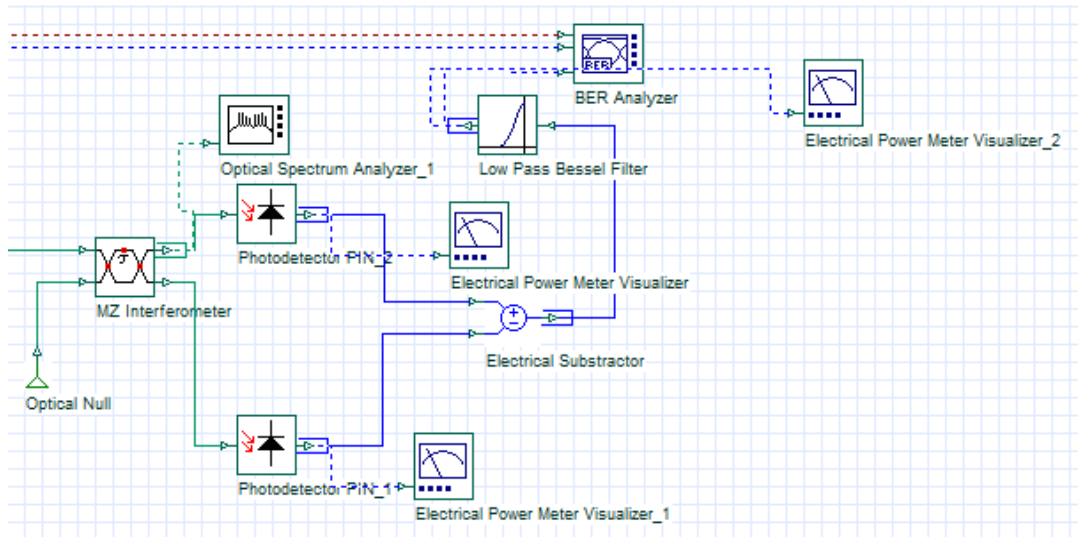


Figure 6. Receiver Section of Hybrid PON

3. RESULTS AND DISCUSSION

The optical spectrum at the output of the modulator for the light wave for 1560 nm is shown in Figure 7 for an input consisting of data and voice. The optical spectrum has enough Single Mode Suppression Ratio (SMSR) which enables transmission of signals over long distance through the Single Mode Fiber. The eye diagram for the transmission of data/voice in the downstream link at 60Km is shown in Figure 8. The received signal’s quality is estimated from the eye diagram. The height and width of the eye opening specifies the effect of inter symbol interference and noise. The noise margin of the signal is specified by the vertical eye opening and the horizontal eye opening defines the interval of time over which sampling of the received signal can be done without the effect of noise. A large eye opening indicates a low BER in the system. The Q factor is measured using

$$Q = \frac{\mu_1 - \mu_0}{\delta_1 + \delta_0}$$

Where μ_1, μ_2 are the mean of the received signal at the sampling instant when a logical 1 and 0 is transmitted and δ_1, δ_2 are the standard deviations of the intensities around the levels of “1” and “0”. The dependency of Q factor on the transmission length is given by

$$Q \propto (P_i e^{-\alpha L})$$

where L is length of transmission and α is the coefficient of attenuation. The maximum length for which transmission can take place is given by L.

$$L = (4DBS_\lambda)^{-1}$$

Where B is the rate at which data is transmitted, D is the coefficient of dispersion and S_λ denotes the rms value of the spectrum width.

The results of our work are shown in Figure 9 where the Q factor versus length of the fiber for 64,128 and 256 users are plotted. We use DPSK Modulation format at 40Gbps with Symmetric Dispersion Compensation techniques.

Though NRZ Modulation format is widely used in PON Network, due to its simplicity in implementation, considering the higher data rate requirement of future generation networks, we evaluated the performance of DPSK Modulation format at 40Gbps transmission rate in the Hybrid PON Network. The influence of the transmission link distance on the factor and the influence of number of users in the network is studied for the given data rate and is shown in Figure 9.

A Q factor of 40.75, 31.9 and 17.28 is observed for 64, 128 and 256 users respectively at 40Gbps data rate for an optical fiber of length 10 Km. The Q factor decreases to 8.899, 6.29 and 3.04 for 64, 128 and 256 users respectively at the same data rate for a fiber length of 60 Km. It is seen from the graph that the Q factor is decreasing for increase in the length of fiber. This is due to factors like chromatic dispersion and fiber attenuation etc. Also the Q factor reduces when the number of users sharing the same wavelength increases. This is because of the splitter losses in the Hybrid PON. It is seen from the graph that the Hybrid PON network employing symmetrical dispersion compensation which utilises DPSK modulation can be used for long reach with larger number of users accessing the same wavelength. It can be seen from the graph that 128 users can use the same wavelength up to a distance of 60kms with a Q factor of 6.29 and 256 users can use the network for a distance of up to 40kms. When 4 such wavelengths are used in the network, the number of users increases to 512 users at a distance of 60kms from the CO and 1024 users for a distance of 4kms.

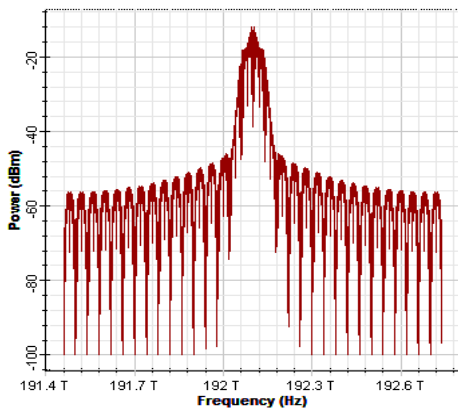


Figure 7. Optical Spectrum at the Output of the Modulator

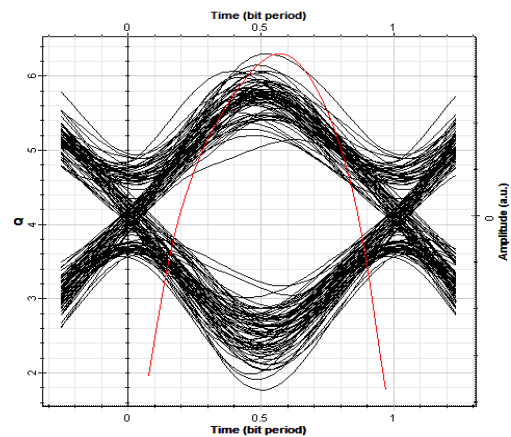


Figure 8. Eye Diagram for the Transmission of Data/Voice in the Downstream Link at 60Km

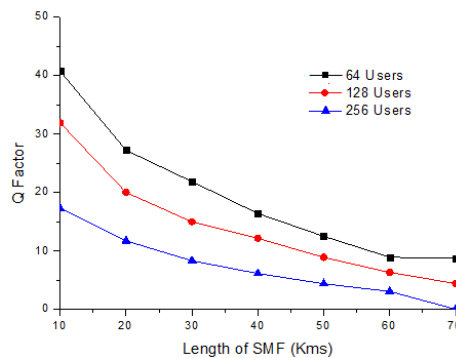


Figure 9. Q Factor vs. Length of Fiber

4. CONCLUSION

An hybrid WDM/TDM-PON access network has been proposed and simulated to provide network services for business and residential subscribers. 40Gbps data and voice signals are successfully transmitted over a distance of 60km using DPSK Modulation. Dispersion compensated Single Mode Fiber with 128 users per wavelength and over 40kms with 256 users per wavelength. The Q factor of 6.29 is obtained for 128 users up to 60 km of transmission distance with a bit rate 40 Gbps, which is an acceptable value. Eye diagrams with sufficient eye openings are also seen. Therefore, DPSK with symmetrical dispersion compensation is preferred for Hybrid PON Networks for a distance of up to 60kms with 128 users per wavelength.

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