High Capacity Optical Fiber Link Design For Telecommunication Backbone Network

Imran Khan, M. Jakub Oleszko

Abstract:- Telecommunication traffic (voice, data etc.) is increasing day by day. So to meet the capacity demand, in this paper we have designed and verified a high capacity optical fiber communication system through simulation. We simulated a 40 Gbps single optical fiber link for telecommunication traffic transmission which could be possible to implement in developing countries with few modifications in their existing optical fiber transmission link. We used Rsoft-OptSim commercial software to simulate it. Designed single optical fiber link length was 1000 km and the bit error rate found was 4.29e-10. Next, we used 8 channels WDM system in this link to get higher data transmission capacity which was 320 Gbps and the center channel i.e. 1550 nm, bit error rate found was 2.7362e-12.

Index Terms:- BER, Capacity, EDFA , Eye Diagram, Gbps, Optical Fiber, WDM.

1 Introduction

Now a day's high speed and high capacity are the two preconditions for telecommunication networks to provide good quality and huge support to the subscribers. Today's telecommunication network is mainly based on the optical fiber (OF). In many developing countries they have the optical fiber telecommunication network. But the speed and capacity both are low. The users of these telecommunication networks are increasing day by day. So it is necessary to upgrade the existing OF network to a high speedy and high capacity network. To do so we have designed and simulated a 40 Gbps single OF link which is easy and cost effective. For capacity increasing we also designed a WDM system with 8 channels which corresponds the total capacity of 320 Gbps data rate. We analyzed the design from the result of the simulation based on the BER and Eye Diagram. BER is defined as [1]-

$$BER = \frac{N_E}{N_T} \tag{1}$$

Where N_E is the number of bit errors occurring over a specific time interval and N_T is the total number of bits sent during that interval. The Eye Diagram measurement technique is a strong method for assessing the data-handling ability of a digital transmission system. This technique is made in time domain and allows the effects of waveform distortion to be shown immediately on the display screen of standard BER test equipment [1].

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2 Single Link Design

The basic elements used in the link are bit generator, Continuous Wave (CW) laser with peak power of 0.95 mW as a source, electrical signal generator, electrical modulator with MachZehnder modulation technique, optical fibers- Corning-SMF28-1550 & Corning Vascade-S1000, optical amplifier-EDFA with 15.8 dB gain and optical receiver with LPbessel type filter and the filter Band Width (BW) was 4*E10. This is shown in Fig. 1. The length of the link was 1000 km. 1550 nm wave length was used for this single link, as this is the common telecom wavelength. In Fig.1 the 'PRBS' is the digital bit generator for the link, 'CWLaser' is the continuous laser source, 'ElecGen' is the electrical generator, 'ExtMod' is the external modulator for the link. Next the 'Loop' indicates the 1000 km OF within which the combination of fiber is as 'SMF' (Corning-SMF28-1550) and 'DCF' (Corning Vascade-S1000) to compensate the dispersion in the link. Next element is the 'Edfa' the optical amplifier to amplify the signal and finally the 'Receiver' unit.

2.1 Result & Analysis

Here we used 1550 nm wave length to design the link because the loss is less at this wavelength and this is the typical telecommunication wavelength. For this design the CW laser was chosen because this type of laser is much noise free than the pulsed laser. The external modulator was used instead of internal modulator to avoid the jitter noise. The two types of commercial fiber Corning-SMF28-1550 & Corning Vascade-S1000 were used in a particular combination to compensate the dispersion. The first one is the common telecommunication fiber and the second one is used to compensate the dispersion. As the loss is negligible at 1550 nm wavelength the main concern goes to fiber dispersion. Different spectral components of the pulse travel at slightly different group velocities in the fiber this phenomenon is known as fiber dispersion or intramodal dispersion [2]. There are two types of intramodal dispersion- material dispersion & waveguide dispersion. Material dispersion occurs because of the refractive index change of silica. This refractive index change depends on the material used for fiber fabrication which changes with optical wavelength. Waveguide dispersion occurs because single-mode fiber confines only 80% of the optical power to the core. Dispersion thus arises, since the 20% of light propagating in the cladding travels faster than the light confined to the core. Typical dispersion at telecom wavelength 1550 nm region is 15-18 ps/(km-nm).

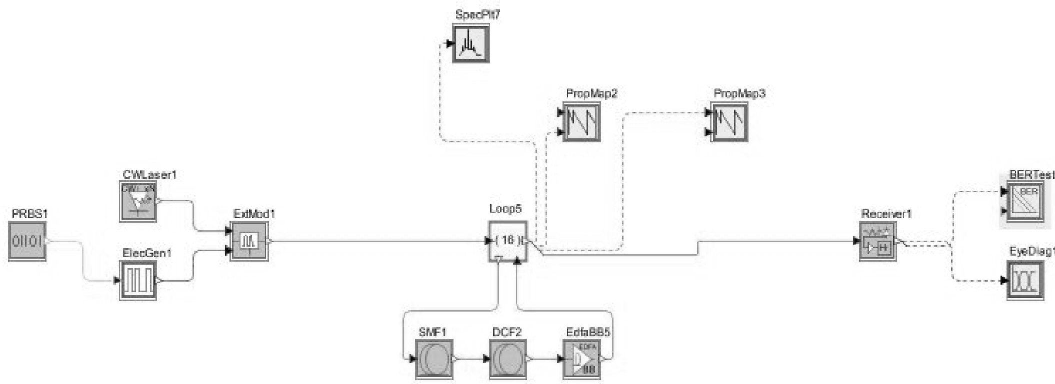

Fig. 1. 40 Gbps 1000 km single optical fiber link (Rsoft-OptSim). Solid lines are the OF link components and dashed lines indicates the measuring equipments.

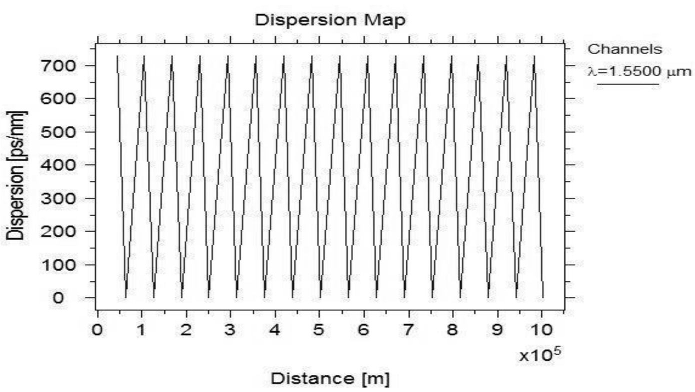

Fig. 2. Dispersion compensation using Dispersion Compensated Fiber (DCF).

To compensate the dispersion, we used SMF-28 common telecom fiber for certain distance and then used Vascade-S1000 Dispersion Compensated Fiber (DCF) for next calculated distance. So for the SMF-28 fiber there is positive dispersion and for the Vascade-S1000 fiber there is negative dispersion as a result the total dispersion for that certain distance is approximately zero which is shown in Fig. 2. As a result the total dispersion in the 1000 km optical fiber link is negligible as shown in Fig. 3. Another important parameter for the optical fiber link is the optical amplifier gain. Used optical amplifier is the Erbium Doped Fiber Amplifier (EDFA). The gain of this inline amplifier should be carefully chosen otherwise the nonlinearity effect will be so high. In this design we have chosen the gain as 15.8 dB. This value is not causing too much of non-linear effect noise and at the same time is sufficient to keep power peak close to 0dBm as the input was 0.95mW ehich is shown in Fig. 4. We achieved the average Bit Error Rate (BER) for the link as $4.29 * 10^{-10}$ (Fig. 5) which is error free. Because for error free transmission the BER should be at least 10^{-9} and our BER is less than this.

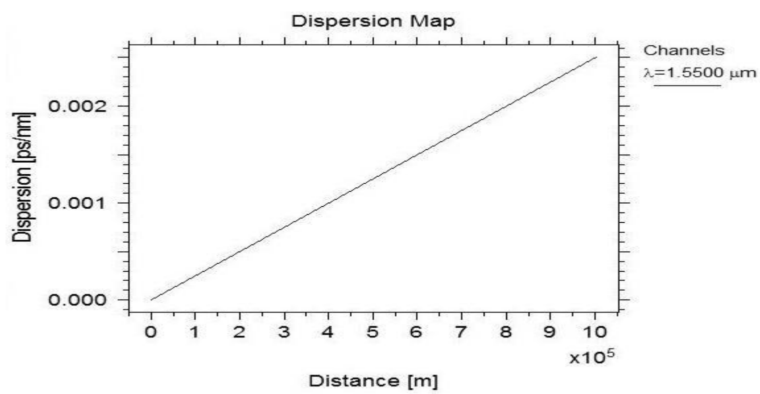

Fig. 3. Total dispersion for the whole 1000 km optical fiber link.

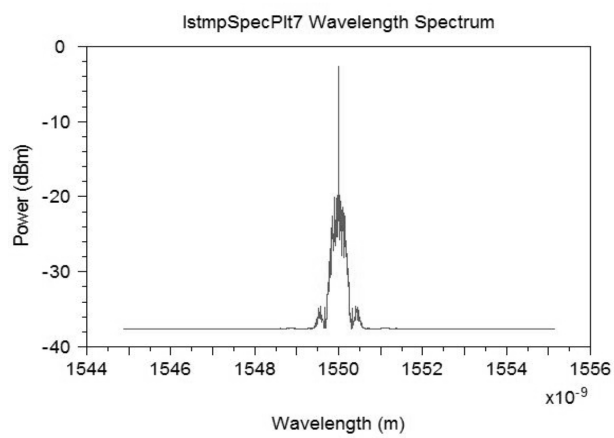

Fig. 4. Signal power after using EDFA with 15.8 dB gain.

In case of the eye diagram we got a clear open eye which implies that the transmission is error free and the optical fiber link can be used for error free transmission. We compare the eye diagram before transmission with the eye diagram after transmission (Fig.6).

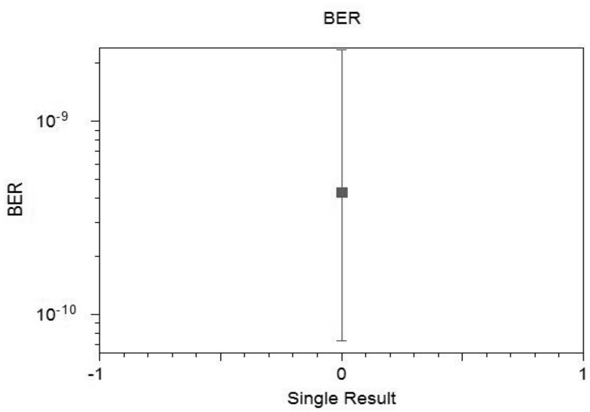

Fig. 5. Average BER for the single OF link.

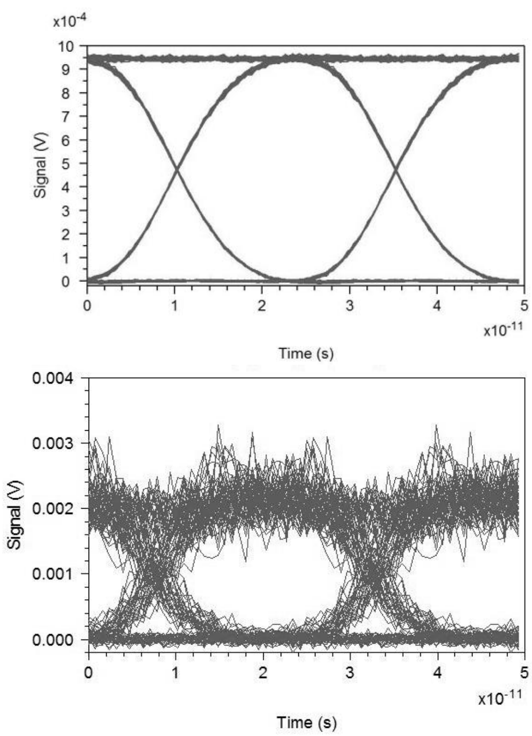

Fig. 6. Eye-diagram at source end before transmission (upper one) and at receiver end after transmission (lower one).

Final eye-diagram shows clear opening. So it is easy to distinguish between two decision levels. There is some noise in the upper level which is caused by some unavoidable non-linear effect.

3 WDM SYSTEM DESIGN

For the high capacity transmission we designed the WDM system with 8 channels and 2 nm channel spacing. We used 1540 nm to 1560 nm wave length range for this WDM system design. This wavelength range was chosen because; firstly to use the low loss transmission window in optical fiber. Secondly, to enable the system this is compatible to use the EDFA [3]. Channel spacing 2 nm was used to avoid the inter symbol interference and other possible noise creation. For this system we added a multiplexer (MUX) after the sources and a demultiplexer (DEMUX) before the receivers with the single link and the EDFA gain was fixed as 16 dB. The filter used at the DEMUX level to separate the transmitted signal was Trapzoidal. The filter center frequency was set as the transmitted channel frequency or wavelength. In general the designed system can be represented as shown in Fig. 7.

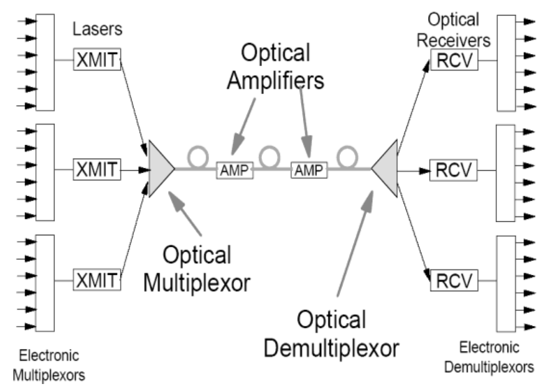

Fig. 7. WDM long distance fiber transmission system (only 3 channels are shown) [3]

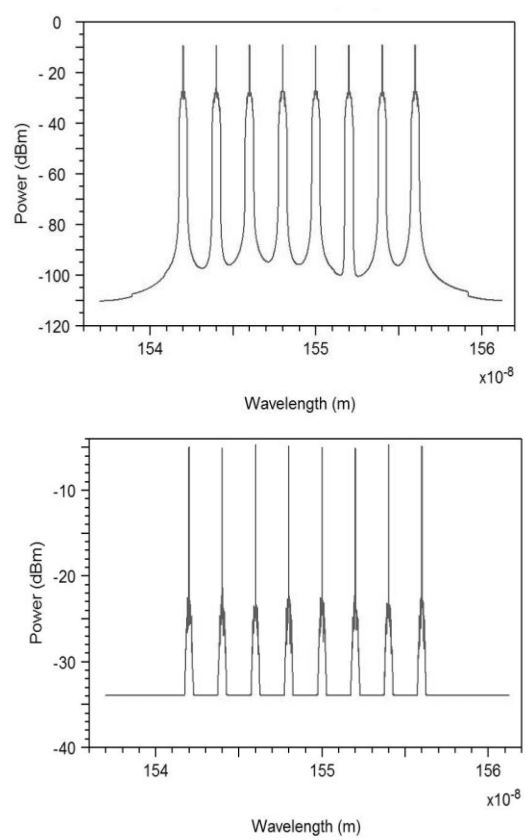

Fig. 8. 8-Channels with 2 nm spacing after the MUX (upper one) and 8-Channels after 1000 km.

In the WDM system the 8 channels were designed as- 1542 nm, 1544 nm, 1546 nm, 1548 nm, 1550 nm, 1552 nm, 1554 nm and 1556 nm as shown in Fig. 8 (upper one). Due to the typical fiber loss and attenuation and unavoidable dispersion effect after 1000 km at the receiver level the received affected signal power are shown in Fig. 8 (lower one).

3.1 Result & Analysis for WDM System

We checked the BER for the 8 channels and found the satisfactory result which is error free. The eye diagrams were open and the two levels of the each eye diagram were distinguishable. The BER for each channel are given in the Table 1.

TABLE 1
CHANNELS & THEIR CORRESPONDING BER AFTER 1000 KM

Channel Numbers	Channels (Wavelengths) nm	BER
01	1542	9.8221e-011
02	1544	1.1414e-011
03	1546	1.1089e-011
04	1548	3.6534e-012
05	1550	2.7362e-012
06	1552	4.2042e-012
07	1554	3.8943e-011
08	1556	6.2473e-010

From the Table 1 we can see that the BER obtained from each channel after 1000 km were error free. So the designed WDM system is capable for error free transmission over 1000 km through the optical fiber link. For individual WDM system channel output analysis, let us consider the 1st channel- 1542 nm.

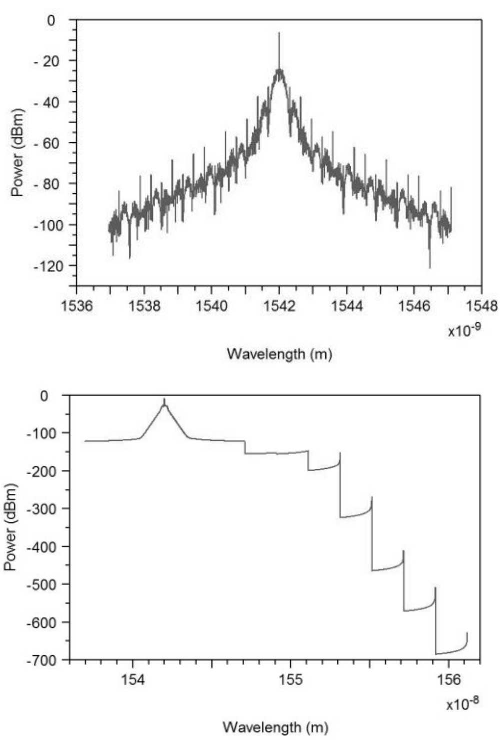

Fig. 9. For 1542 nm channel- spectrum after source (upper one) & spectrum after DEMUX (lower one).

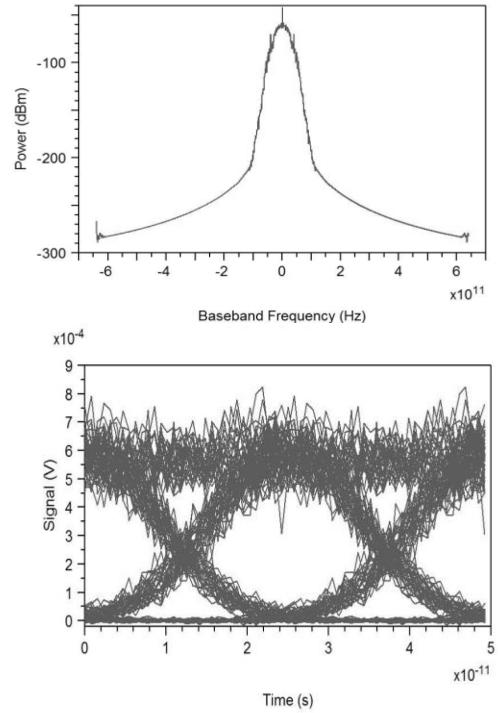

Fig. 10. For 1542 nm channel- received signal (upper one) & eye diagram (lower one).

From the Fig. 9 (lower one) we can see that after the transmission, at the DEMUX only 1542 nm channel exists and all others are dropped out. This was done by the internal filter inside the DEMUX which is designed only for the specific channel wavelength, here for 1542 nm. And from Fig. 10 (lower one) we see the eye diagram for this channel. The eye is open and the two decision levels are distinguishable and the corresponding BER for this 1542 nm channel was 9.8221e-011. The BER also implies the error free transmission through the optical fiber link over 1000 km.

4 CONCLUSION

From the design & simulation it is found that fiber dispersion as well as non-linearity effect of fiber affects the high bit rate (eg. 40 Gbps) transmission through OF. So an optimized design is done in this paper to compensate the fiber dispersion. The gain of EDFA also does a master role in the transmission. The gain of the EDFA should be well defined for error free transmission. Because if we choose too much gain then there will be non-linearity effect and if we choose less gain then the signal will be degraded. If the signal power is increased then there will also the non-linearity effect. That is why an optimization is required for the EDFA gain. So for this system design we checked the gain several times and found the optimized gain for EDFA as 15.8 dB & 16 dB for single link and WDM system respectively. The power budget has not mentioned here for any link, by observing these simulation result it is possible to make the power budget accordingly. Most of the developing countries existing telecommunication network has the single optical fiber link for voice and data transmission. With a few modifications of the element’s parameter in the link as mentioned here we can upgrade the single link up to 40 Gbps. And after that just applying the WDM system we can upgrade the transmission capacity up to 320 Gbps.

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