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# Design and Evaluation of OFDM Based Optical Communication Network

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**Abstract:** With the advancement in communication technology and the introduction of the data center networks, cloud computing etc has triggered the growth of internet data traffic volume at an exponentially high rate. This has increased the demand for networks that provides higher data rates and larger bandwidth. To accommodate this huge demand, next generation Orthogonal Frequency Division Multiplexing (OFDM) based optical networks are considered as a promising solution. In this study, we have presented an OFDM based optical network that can accommodate higher data rates and provides improved efficiency over traditional networks. The performance of the system is evaluated by measuring quality factor, Bit Error Rate (BER) and constellation diagrams using Optisys simulator.

**Key words:** Elastic Optical Networks (EON), Quadrature Amplitude Modulation (QAM), Mach-Zehnder Modulator (MZM), Fast Fourier Transform (FFT), communication

## INTRODUCTION

With the recent developments in mobile technologies and introduction of cloud computing, data center networks and various multimedia applications that include data, voices and video services have triggered the demand in bandwidth an exponentially increasing rate. With the use of traditional WDM based networks several independently modulated light sources, each emitting signals at a unique wavelength are combined using a multiplexer into a continuous spectrum of signals and are coupled onto a single fiber. At the receiving end, a demultiplexer separates the optical signal into appropriate detection channels for signal processing as shown in Fig. 1.

Although, WDM accommodates traffic demand into existing 50 GHz fixed grid spaces standardized by ITU, it is affected by fiber non-linearity and dispersion effects and becomes prone to interferences and thereby suffers a higher SNR (Signal-to-Noise Ratio) per bit and limits long distance transmissions. To accommodate heterogeneous traffic volume, recently EONs based upon OFDM have been proposed which makes the spectrum flexible and improves spectral efficiency as compared to WDM networks as shown in Fig. 2.

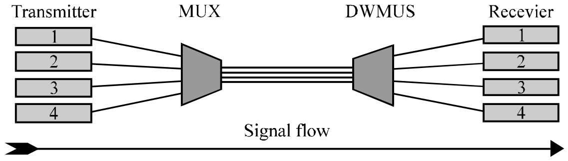

Fig. 1: Wavelength division multiplexing (Brodkin, 2012)

**OFDM based proposed system design:** The proposed design consists of an OFDM transmitter, optical link and the OFDM receiver. The OFDM transmitter consists of Pseudo-Random Bit Sequence (PRBS) generator, Non-Return to Zero (NRZ) pulse generator, QAM encoder, OFDM modulator and MZM modulator based I/Q modulator. The bit stream generated by PBRS are converted into electrical pulse using NRZ pulse generator. After encoding using a QAM encoder these are provided to an OFDM modulator which modulates these symbols on different orthogonal subcarriers (Meng *et al*., 2016).

Figure 3 shows the block diagram of OFDM transmitter and receiver system. In transmitter the OFDM channels after IFFT are separated into In-phase (I) and Quadrature (Q) phase are individually converted into optical analog signals by I/Q modulator using a pair of MZM modulators, then multiplexed on a single channel and are transmitted over the optical fiber and the receiver the signal is detected, demodulated and analyzed. Figure 4 shows the optical modulation using a pair of MZM modulators (Zaier1, 2011; Chen *et al*., 2013). The

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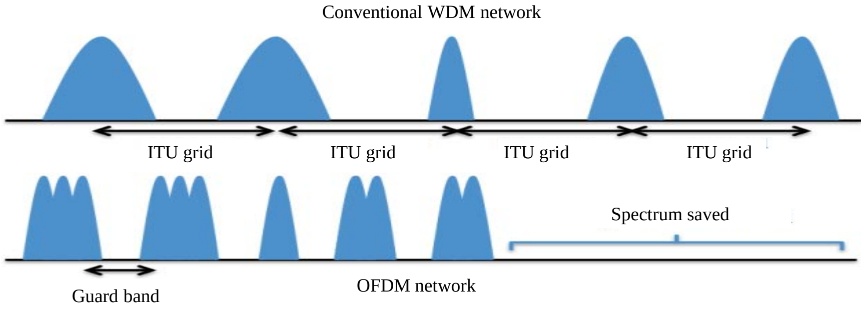

Fig. 2: Spectrum allocation OFDM network and conventional WDM network (Christodoulopoulos *et al*., 2011)

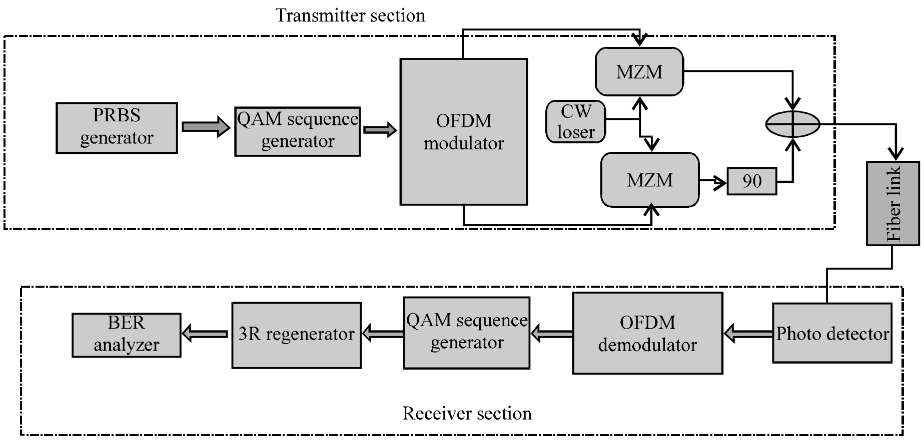

Fig. 3: Block diagram of OFDM based transmitter and receiver section (Zhang *et al*., 2013)

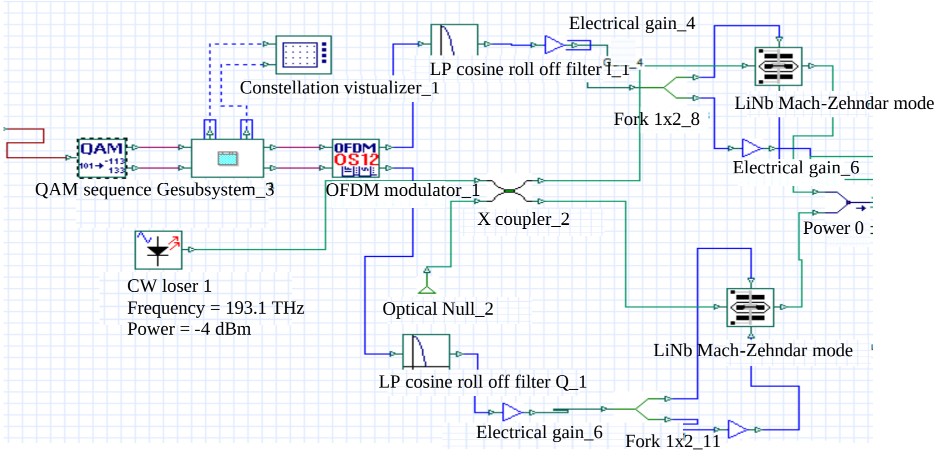

Fig. 4: OFDM transmission and Electrical to Optical (E/O) conversion using pair of MZM modulators in OptiSystem

optical link is consists of a single mode optical fiber along with Dispersion Compensation Fiber (DCF) and optical amplifiers. DCF is used to compensate the fiber dispersion. At the receiver end, the incoming optical signals are detected using coherent detection with a pair of balanced photo detectors and a local oscillator and then reverse I/Q operation is performed to convert optical signal into electrical signal as shown in Fig. 5. The signal after being OFDM demodulated is applied to a QAM decoder that converts the signal into bit streams.

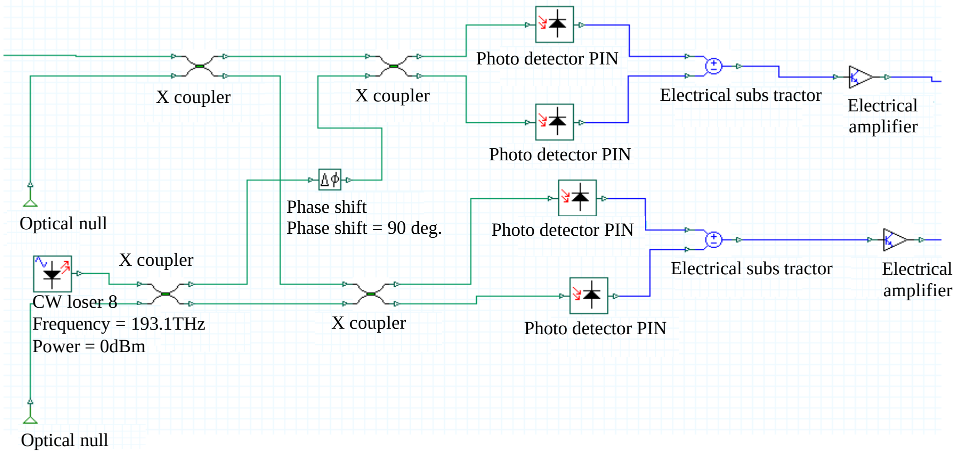

Fig. 5: Coherent detection using balanced modulator in OptiSystem

## MATERIALS AND METHODS

**Qualitative parameters used**

**Quality factor (Q-factor):** The Q-factor provides a qualitative description of the receiver performance because it is a function of the Optical Signal to Noise Ratio (OSNR). The Q-factor suggests the minimum OSNR required to obtain a specific BER for a given signal (Oyetunji and Akinninranye, 2013). Equation shows the definition of the Q-factor:

$$Q = \frac{\mu_1 - \mu_2}{\sigma_0 - \sigma_1}$$

Where:

$\sigma_0, \sigma_1$ = The noise variances

$\mu_1, \mu_2$ = The mean values of the marks/spaces voltages or currents

BER-BER is the number of bit errors per unit time. BER is the number of bit errors divided by the total number of transferred bits during a studied time interval. Bit error ratio is a unit less performance measure (Hodzic, 2007; Geetu and Singh, 2012):

$$\text{BER} = \frac{\text{Errors}}{\text{Sequence length-}2\times\text{Guard bit}}$$

**Constellation diagram:** It is a two dimensional representation of a digitally modulated signal using M Ary digital modulation schemes such as: PSK or QAM. After modulation the symbols are mapped as points in a complex plane in which the y and x-axis represents the imaginary part and the real part of the signal (Sharma *et al.*, 2010). Constellation diagrams can be used to identify the distortion that occurs in the signal and determine the type of interference.

## RESULTS AND DISCUSSION

In this proposed research, we have designed and analyzed a four channel OFDM communication system using OPTISYS simulator. The various parameters used for simulation are given in Table 1.

We have analyzed the designed layout for Channel 1 and 4 and we obtained values for Q-factor and BER at 240, 480, 720 and 960 km at 40 and 80 Gbps data rate. The variation of Q factor with distance at 40 and 80 Gbps is shown in Fig. 6 and 7.

The values of Q-factor obtained for Channel 1 are 87.6071, 15.3509, 8.16527 and 5.52261 for 40 Gbps and 3.69343, 2.35362, 2.26514 and 1.9346 at 80 Gbps for 240, 480, 720 and 960 km, respectively. The values of Q-factor obtained for Channel 4 are 43.8207, 7.6933, 3.54224 and 2.19834 for 40 Gbps and 3.07433, 2.18841, 2.12994 and 1.8836 at 80 Gbps for 240, 480, 720 and 960 km, respectively. These values of Q-factor obtained at different fiber length for different data rate are from Fig. 6 and 7 and from Table 2, it is observed that the Q-factor for both channels at 40 and 80 Gbps decreases with increase in distance of communication. The value of Q-factor for both channels is higher at lower data rate and it decreaseswith increase in data rate. Figure 8 and 9 shows the variation of BER with increase in fiber length at 40 and 80 Gbps data rate.

The values of BER obtained for Channel 1 are 6.5099e-005, 0.0011067, 0.0037107 and 0.0080079 for 40 Gbps and 0481544, 0488224, 0489335 and 0.50624 at 80 Gbps for 240, 480, 720 and 960 km, respectively. The values of BER obtained for Channel 4 are 0.0002604, 0.004231, 0.0189441 and 0.0452445 for 40 Gbps and 0.484669, 0.489448, 0.490093 and 0.516320 at 80 Gbps for 240, 480, 720 and 960 km, respectively. These values of BER at different fiber length with different data rate are given in Table 2.

Table 1: Simulation parameters

| Parameters | Values |
|---|---|
| Number of subcarriers | 512 |
| Number of FFT points | 1024 |
| Power of laser source | -5 dBm |
| Dispersion of SMF | 16 ps/nm/km |
| Number of samples per bit | 8 |
| Dispersion of DCF | -80 ps/nm/km |
| Symbol rate | 2.5e+009 symbols/sec |
| Local Oscillator (LO) frequency | 193.1 THz |
| LO line-width | 0.1 MHz |
| LO power | -2 dBm |

Table 2: Variation of Q-factor with distance

| | Q-factor | | | |
|---|---|---|---|---|
| | Channel 1 | | Channel 4 | |
| Distance (km) | 40 Gbps | 80 Gbps | 40 Gbps | 80 Gbps |
| 240 | 87.60710 | 3.69343 | 43.82070 | 3.07433 |
| 480 | 15.35090 | 2.35362 | 07.69330 | 2.18841 |
| 720 | 08.16527 | 2.26514 | 03.54224 | 2.12994 |
| 960 | 05.52261 | 1.93460 | 02.19834 | 1.88360 |

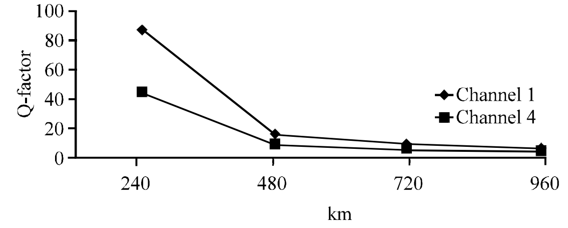

Fig. 6: Variation of Q-factor with distance for Channel 1 and 4 at 40 Gbps

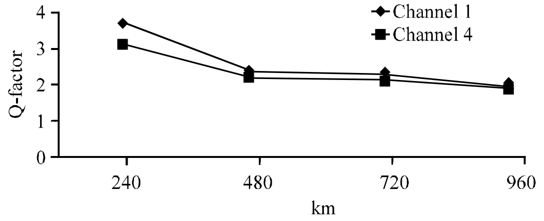

Fig. 7: Variation of Q-factor with distance for Channel 1 and 4 at 80 Gbps

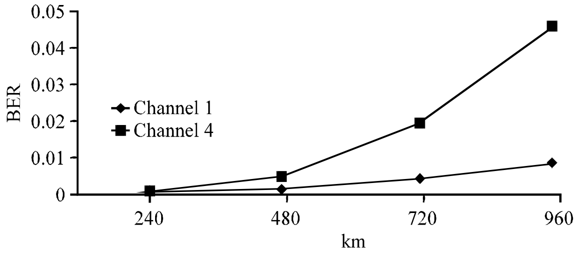

Fig. 8: Variation of BER with distance for Channel 1 and 4 at 40 Gbps

Table 3: Variation of BER with distance

| | Q-factor | | | |
|---|---|---|---|---|
| | Channel 1 | | Channel 4 | |
| Distance (km) | 40 Gbps | 80 Gbps | 40 Gbps | 80 Gbps |
| 240 | 6.5099e-005 | 0.481544 | 0.0002604 | 0.484669 |
| 480 | 0.0011067 | 0.488224 | 0.0042310 | 0.489448 |
| 720 | 0.0037107 | 0.489335 | 0.0189441 | 0.490093 |
| 960 | 0.0080079 | 0.506240 | 0.0452445 | 0.516320 |

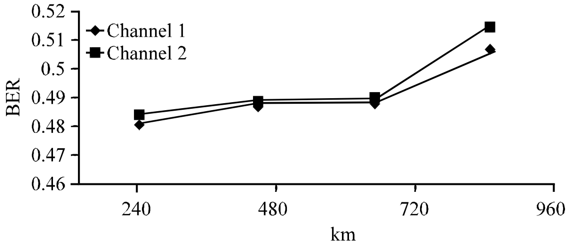

Fig. 9: Variation of BER with distance for Channel 1 and 4 at 80 Gbps

From Fig. 8, 9 and Table 3, the BER for both Channel 1 and 4 increases with increase in fiber length. The value of BER obtained are lower at lower data rates and it increases with increase in fiber length. The decrease in Q-factor and increase in BER are due to increase in attenuation, dispersion and other losses with increase in fiber length. In order to mitigate the losses due to dispersion we have used a DCF of 10 km length with a dispersion of -80 ps/nm/km and to remove attenuation losses we have employed an EDFA with a gain of 25 dB.

We have also analyzed constellation diagrams which represent a modulated signal into two dimensional scattered diagrams to validate our results. The constellation diagrams for received signal at different fiber length for Channel 1 and 4 at 40 Gbps data rate using 4-QAM encoder are shown in Fig. 10 and 11.

In the constellation diagrams, the blue color represents the noise; distortion and attenuation and the red color represent the original information content in the received signal. From Fig. 10 and 11, it is clearly visible that with increase in fiber length the fiber losses increases and a distorted signal is received at the receiver. This distortion increases with increase in fiber length as various spectral components overlap with each other and distort the signal. Hence with increase in fiber length and data rate, the distortion increases and therefore the Q-factor decreases and BER increases with fiber length.

We have also analyzed the designed OFDM system with 16-QAM modulation schemes and the result obtained and in synchronization with the results of 4-QAM modulation format. The value of Q-factor for Channel 1 with 16-QAM at 40 Gbps is obtained as 59.80707, 24.32786, 8.47853 and 2.77078 for 240, 480, 720

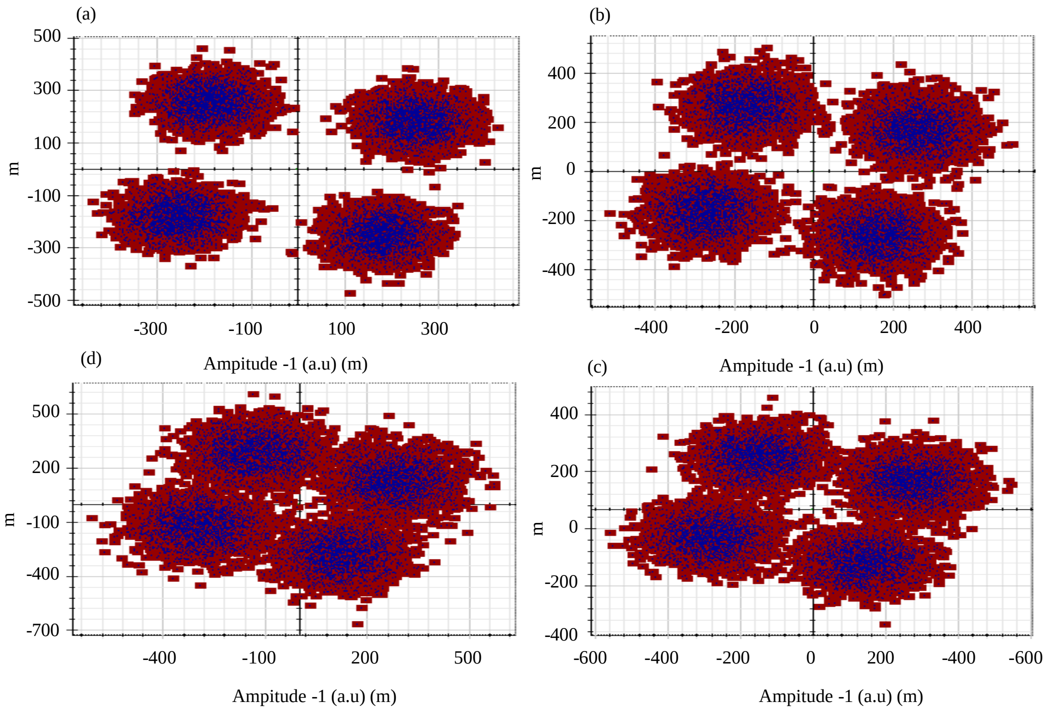

Fig. 10: Constellation diagram at different fiber lengths for Channel 1 at 40 Gbps: a) 240 km; b) 480 km; c) 720 km and d) 960 km

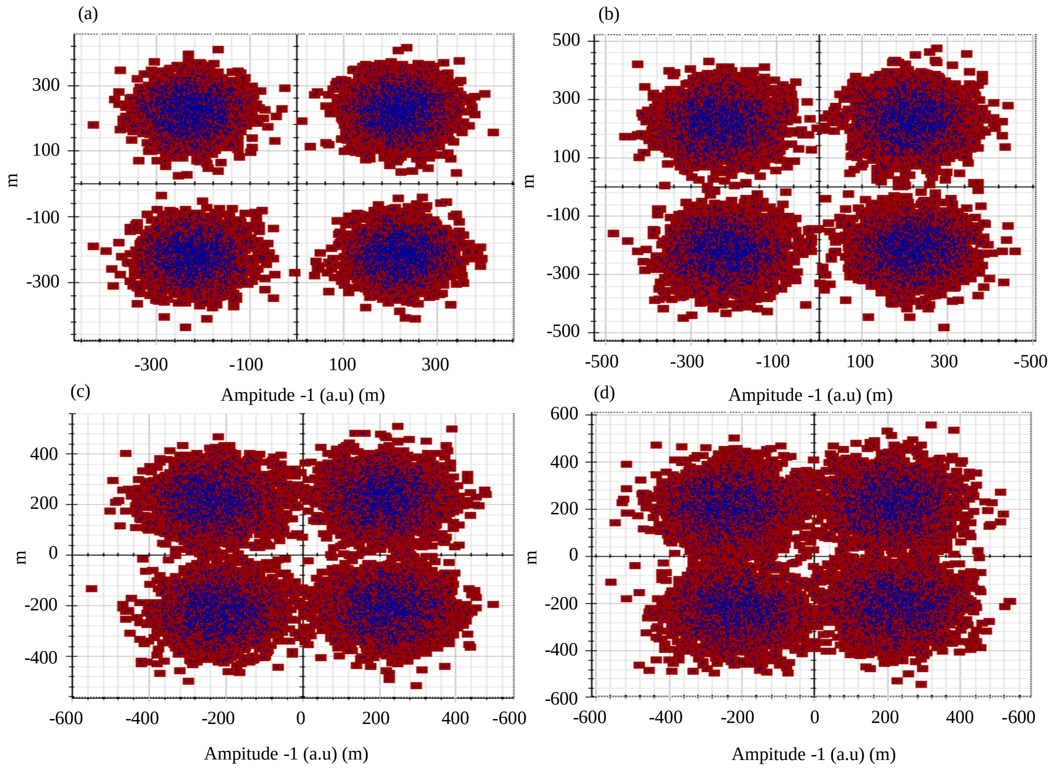

Fig. 11: Constellation diagram at different fiber lengths for Channel 4 at 40 Gbps: a) 240 km; b) 480 km; c) 720 km and d) 960 km

and 960 km, respectively. The value of BER obtained is 0.0000325, 0.0403889, 0.390868 and 0.488654 for 240, 480, 720 and 960 km, respectively. Figure 12 and 13 show the variation of Q-factor and BER with distance.

As seen from Fig. 12 and 13, the value of Q-factor decreases with increase in fiber length and the value of BER increases with increase in fiber length. The above variations in Q-factor and BER can be validated from the constellation diagram for the received signal at Channel 1 shown in Fig. 14. As observed from the constellation diagram in Fig. 14 with increase in fiber length, the attenuation and distortion increases which limits the Q-factor and increases the BER in transmission and affects the quality of transmission.

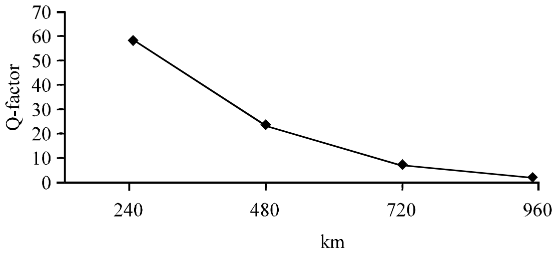

Fig. 12: Variation of Q-factor with distance for Channel 1 with 16-QAM at 40 Gbps

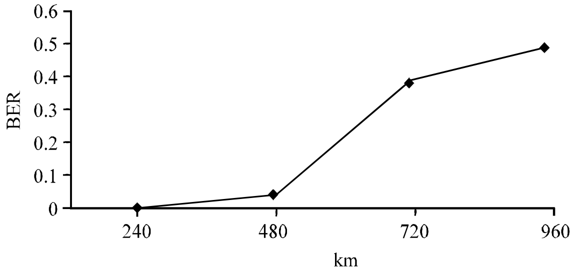

Fig. 13: Variation of BER with distance for Channel 1 with 16-QAM at 40 Gbps

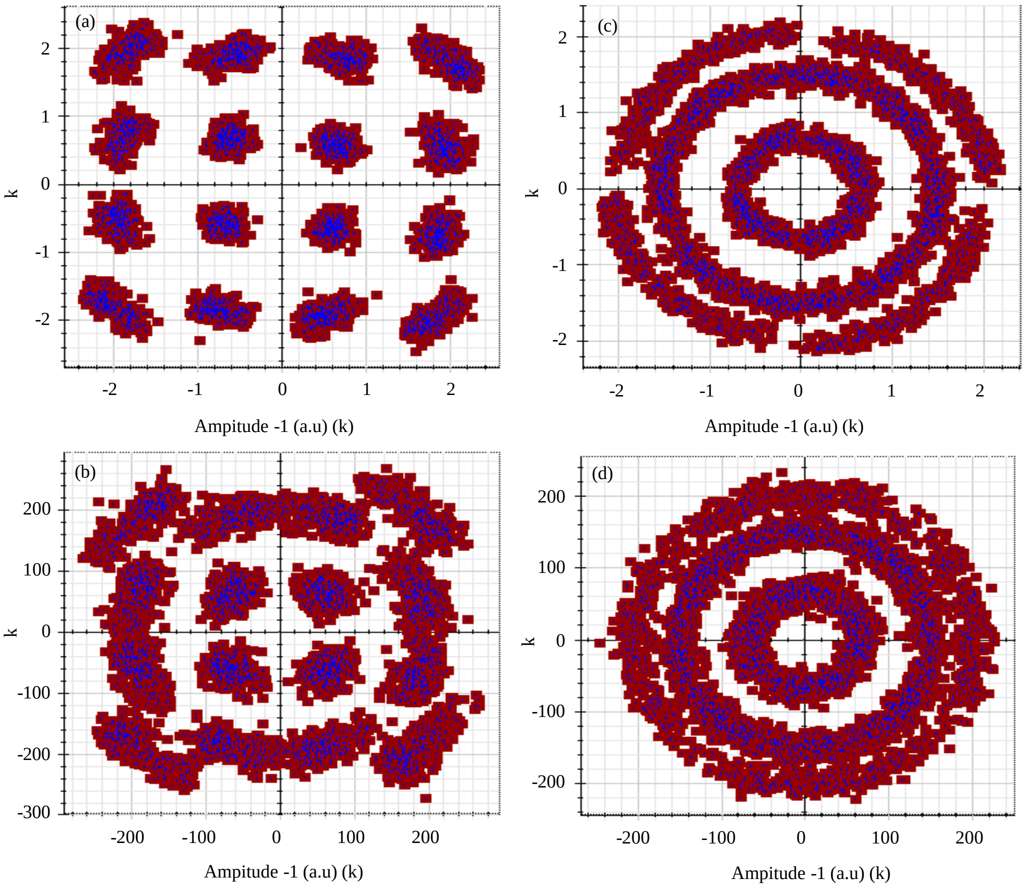

Fig. 14: Constellation diagram at different fiber lengths for Channel 1 with 16-QAM at 40 Gbps: a) 240 km; b) 480 km; c) 720 km and d) 960 km

## CONCLUSION

We have designed and simulated an OFDM based communication link using OPTISYS simulator and evaluated its performance for two channels based upon Q-factor and BER at 40 and 80 Gbps data rate at 240, 480, 720 and 960 km fiber length. We found that the designed link works satisfactorily and the value of Q-factor decreases and BER increases with increase in fiber length for both channels. The proposed design has shown significant improvement in Q-factor and BER as compared to traditional optical networks. We have also extended this system to 16-QAM higher modulation format and the system works in synchronization with 4-QAM modulation format.

## RECOMMENDATION

In future, this designed link may be extended to other higher order modulation formats such as 64-QAM and it can be used in designing next generation EONs.

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