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# DISPERSION COMPENSATION IN OPTICAL COMMUNICATION SYSTEM BY EMPLOYING 16-QAM MODULATION USING OFDM

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## ABSTRACT

Next generation communication network will be required to provide increased data rate efficiently along with the flexibility to adapt to various dynamic traffic patterns in a cost effective manner. The optical fiber communication system can do the same along with low losses and good quality of transmission. In the recent past, the enormous growth of network traffic on deployed optical communication networks forced the demand for a more constructive utilization of the channel capacity of the optical fiber communication channel. In near future, the next generation optical links are going to carry 10 / 40 Gbps per wavelength. The two windows at 1310 & 1550 nm provide low attenuation with transmission bandwidth of approximately 50 Tbps. Optical fiber communication system are primarily operated at wavelength near 1550 nm in order to match with the minimum loss point of silica fiber and hence maximize transmission distance. Unluckily, at this wavelength dispersion restricts the achievable transmission distance. As the data transmission rate increases the dispersion causing pulse broadening results in Inter-Symbol Interference (ISI).

The dispersion restricts the highest transmission data rate and longest transmission distances for the repeater less optical communication link [1]. Various endeavors have been inscribed for the advancement of dispersion compensating techniques and devises to recuperate the pulse broadening due to ISI. The OFDM is a highly spectral efficient, multiple sub-carrier modulation technique. It have dynamic tolerance to dispersion, thereby making it an excellent dispersion compensation scheme for using the exiting optical communication networks for next generation dynamic traffic pattern. It overcomes the problem of ISI due to dispersion, by simultaneously modulating and transmitting a number of orthogonal sub-carriers at a low symbol rate, which makes the symbols period much longer than the channel impulse response. This work investigates the use of OFDM as a technique to fulfil these needs for next generation optical communication system. These involve design, modelling, simulation and comparative performance analysis of the optical communication system with and without using OFDM for dispersion compensation. A novel scheme of tuneable dispersion compensation using OFDM is presented in this work. The system performance has been analyzed in terms of BER, constellation diagrams and OSNR. OFDM is shown to outperform in high data rate optical communications system for the long haul high data rate transmission with high bandwidth utilization efficiency. Therefore, the combination of optical system and OFDM is the highly efficient technique for the next generation long haul high capacity communication network.

**KEYWORDS:** OFDM, Dispersion, Optical Fiber, SSMF, PMD, GVD, IFFT, FFT

## INTRODUCTION

The main goal of communication system is to transmit the maximum number of data bits per second over the maximum possible distance with the fewest errors. Due to the introduction of various wide band applications, such as video conferencing, broadband wireless communication etc. the demand of transmission capacity is growing exponentially. These have motivated the researcher to device & employ different techniques to enhance the existing transmission capacity of optical terrestrial and wireless networks [10]. The need of the high data rate with good quality of service of the next generation communication network can be accomplish by utilizing the optical fiber communication system which operatesat high data rate along with low losses [9]. But at high data rate inter-symbol interference due to dispersion causes the signal distortion, which needs to be suitably compensated in cost effective manner.

Dispersion is severe limiting factors in long distance high data rate transmission system. It is simply the widening of pulse duration as it travels through a fiber. As the optical pulse propagates, it can be considerably broadened to interfere with the neighbouring pulses on the optical fiber communication system, leading to Inter-Symbol Interference (ISI). The dispersion restricts the highest transmission data rate and longest transmission distances for the repeater less optical communication link [1]. It has been noticed that dispersion of a conventional standard single mode fiber is low mostbut attenuation is higher at 1310 nm, however it has comparatively high dispersion but minimum attenuation at 1550. To use the previously installed optical fiber cables the main problem related with these optical fiber are that they present high values for chromatic and polarization mode dispersion. Dispersion was not thought as limiting factor when the bit rate was at or below 2.5 Gbps and the distance was about a few hundred kilometres. However, with the steady growth of bandwidth demand and the subsequent migration to 10-Gbps and beyond transmission system, dispersion has become quite problematic that needs to be overcome. Dispersion is one of the major obstacles in long haul transmission system of over 10 Gbps speed, to increase the transmission distance with better quality of transmission. One of the best things to speed up the optical communication networks would be to replace all the already installed optical cables with new ones. But, this is not an economical viable solution. Hence existing network has to compensate the positive dispersion of the existing single mode fiber at 1550 nm wavelength so as to make it suitable for long distance broadband communication.

**Optical Communication System (OCS) Review**

We are using different types of communication services, such as voice, video, images, and data communication, regularly. As needs for those services increase, demands for long haul high data rate networks also increase. In order to fulfilthese increasing demands for higher data rate, larger bandwidth light wave technology has been developed. The combination of photons and glass fibres provides a tremendous transmission capability improvement compared to transmission lines through electrons and copper wires. As a result, fiber optical transmission system is now widely deployed in the backbone of long distance high capacity communication networks. Clearly, fiber optic transmission technology will remain the key communication technology for the foreseeable future. Currently, it is extensively applied in different types of communication system, such as Internet and cable TV networks. This is due to the continuously increasing demand for more data in less time in transmission of voice, image, video, and so forth. The final termination for these services to subscriber terminals may be wireless or wired, but it is optical fiber that is depends on for the main distribution of the data between links. The idea of long distance communication through a glass fiber using the light pulses was originated by Kao and Hockman in 1966 [12]. Kapron show that single-mode waveguides can be constructed which have radiation losses of about 7 dB per km [13]. The proposal of information transmission using light through a glass fiber over long distance was materialized when low-loss glass optical fibers were first constructed by Coming in 1970, along with evolution of the semiconductor diode lasers by Bell Labs [14].

The basic optical communication link consists on following four basic components. The optical transmitter is used to generate light signal and modulate information on the signal; the optical fiber is the transmission media of light; the optical receiver receives the transmitted signal and converts it back to the carried information and the optical amplifier is used to extend the transmission distance. In advance optical communication link / system, in addition to the above four devices, more components are required.


**Figure 1: Optical Communication System**

The optical system can be noncomplex (i.e., local area network) to extremely complex and costly (i.e., long haul telephone or cable TV network) [16]. In the Single-Mode Fiber (SMF) the principal linear impairments are Group-Velocity Dispersion (GVD) i.e., different frequencies travel at different speeds and Polarization-Mode Dispersion (PMD) i.e., different polarizations arrive at the receiver with different delays. The two degenerate modes in the single mode fiber arrive at the receiver with different delays, due to random nature of the fiber birefringence [5]. The delay $\tau$ between the degenerate modes is also random and is Maxwellian distributed [5] is called PMD. The effect of chromatic dispersion becomes more and more critical at high data rate transmission, because the linear dispersion tolerance decreases with the square of the bit rate [15]. The GVD is comparatively stable and linear effect than the PMD, which makes dispersion compensation comparatively easy. [17].

**Dispersion Compensation Techniques**

In optical communication systemas the transmission rate goes from 2.5 Gbps to l0 Gbps or even 40 Gbps, the need for dispersion compensation will only become more critical for system performance. This is due to the widening of pulse duration as it propagates along the length of an optical fiber, leading to inter-symbol interference. Hence the transmittable distance limited by dispersion of the optical fiber and becomes shorter as the data transmission speed increases.A significant portion of the installed optical fiber in today's network comprises of conventional first generation Standard Single Mode Fiber (SSMF) exhibiting zero dispersion at 1310 nm but rather high dispersion at 1550 nm. At 1550 nm the theoretical minimum optical attenuation loss for SMF fiber is 0.2 dB per km, while at 1310 nm there is attenuation loss of about 0.5 dB per km for the same SSMF. Operation at 1310 nm thus leads to very low pulse broadening but the attenuation is higher than that at 1550 nm. Therefore to obtain a maximum transmission distance of a high capacity link, the dispersion null should be at the lowest attenuation value. This can be achieved if we can adjust the basic fiber parameters so that zero dispersion minimum could be shifted to longer wavelength.

The fiber behaviour can be altered by considering various ‘core’ and ‘cladding’ combination, i.e. the Dispersion Shifted Fiber (DSF), where the wavelength of zero dispersion is moved from the 1310 nm into the 1550 nm; Dispersion Flattened Fiber (DFF) in which low dispersion is made to occur over an extended wavelength range. The use of DSF and DFF are some of the common solutions for compensation [7]. DSF differs from standard SMF in that the zero dispersion point is shifted from 1310 nm to 1550 nm by constructing a single-mode fiber with a triangular-shaped refractive index variation (instead of a step / graded-index variation) [7]. The installed 1310 nm optimized SSMF optical fiber links may be upgraded for operation at 1550 nm. However, these are not always cost saving, especially for conventional fiber networks that are previously installed. In our country and all over the world, there installed tens of millions of kilometres of standard single mode optical fiber operating at 1310 nm. To replace the whole existing optical fiber network with the new optical fiber network is not economical viable. Hence existing network has to compensate the positive dispersion of the existing single mode fiber at 1550 nm wavelength so as to make it suitable for long distance high data rate communication. We may use different dispersion compensating schemes for compensating the relatively high value of dispersion Coefficient (D) of previously installed 1310 nm optimized fiber operating at 1550 nm.

The material peculiarity of dispersion & the resulting inter-symbol interference have been deciphered comprehensively and various schemes to compensate the dispersion have been published. There are a number of schemes that can be used for the dispersion compensation, inclusive of Dispersion Compensating Fiber (DCF) [18-21], Optical Phase Conjugator (OPC) [19-21], all-pass optical filters [16-19], chirped Bragg Gratings (CBG) [22–24], Reverse Dispersion Fiber (RDF) and Negative Dispersion Fiber (NDF) are some of the evident solutions. Out of various dispersion compensating schemes, DCF having high negative dispersion at 1550 nm is commonly inserted at regular intervals along the optical fiber link [8].In order to realize the high data speed communication system, a specific DCF having large negative dispersion for cancelling the dispersion of a transmission channel is currently installed in a repeater or a transceiver.

This specific fiber is expensive and an advanced design is required. Also, these factors drive up the price of the optical communication system. The DCF inverts the impact of the dispersion caused by 1550 nm wavelength signals that propagate through the standard single-mode fiber. It is shown that error free transmission is possible for a 16 channel 10Gbps DWDM system designed for transmission over 100 Km of NDF [37-38] using DCF.However, it has various disadvantages like, high implementation expenditure, large physical size, signal delay and difficulty in adaption. The attenuation due to the DCF requires additional EDFAs, which enters extra optical noise in the system [6, 36]. However, DCF is not an optimal dispersion compensating solution for the system, because it is efficient for only single wavelength. Also, it only provides a partial solution to the dynamically changing dispersion situation. A better solution able to provide tuneabledispersion compensation is highly demanded for advanced fiber optic communications. FBG has become a very vital scheme for the construction of tunable dispersion compensators. Ken-ichi Kitayama et al. in 2002 has analyzed the dispersion effect of FBG, which is extensively used in wavelength filtering [25] and smart sensing devices [26] on DWDM millimeter-wave optical signal transmissions [2]. Electronic Dispersion Compensation (EDC) can be used to enhance the data carrying capacity of optical fiber system without any modification in the internal architecture of the system. This scheme gives valuable saving of the reinstallation expenses of dispersion compensators in the system, since only external alteration is needed [27]. Electronic pre-distortion [27-28] is a contemporaneous development of EDC, but this scheme requires a reverse response from receiving end [4].

**Orthogonal Frequency Division Multiplexing (OFDM)**

OFDM is a multi-carrier transmission scheme that is well-recognized for its potential for attaining high data rate transmission and high spectral efficiency over frequency selective channels. It is decided modulation scheme for dispersive wireless channels. It permits high data rates with sufficient robustness to dispersive channel losses [14]. The introductoryidea forutilization of orthogonal frequencies for data transmission was proposed in 1966 by Chang at Bell Labs [31, 36]. The succeeding important step in the evolution of OFDM was proposed by Weinstein et al. in 1969 and 1971 [32], they suggested an efficient scheme by using the Fast Fourier Transform (FFT) for thegenerationof orthogonal subcarriers frequency, making OFDM feasible for electronic communications at that time. From 1990 onwards only, the OFDM was introduced into important consumer utility, the wireline protocol ADSL.The use of Discrete Multi-Tone (DMT), principally identical to OFDM, for DSL system [33-34] was proposed by Cioffi et al. at Stanford University, in which they featured to its provision of relatively higher data rates and efficiency [35]. It was patented in 1970, but because of the practical constraints and hardware requirement it was not implements. Even though appeared in early 1970, the key cause that the practical OFDM system could not be produced because of the implementation problems. Earlier, it was very problematic in the communication system to generate, transmit and receive OFDM signals, for multiplexing and transmitting parallel data in several modulated sub-carriers simultaneously. In the recent past, the hardware implementation for the generation of a number of sub-carrier was complex and costlier. However, now we can define and generateorthogonal sub-carriers of OFDM signal in time and frequency domain by using the digital signal processing building a feasible OFDM communication system.

Zou and Wu [29] described that in OFDM data loss on carriers situated about nulls in the channels frequency response can be recovered using Forward Error Correction (FEC) because the data on the other carriers remains intact. Since the subcarriers are densely packed in the frequency domain, a further advantage of OFDM is that it achieves its resilience to multipath fading without sacrificing bandwidth. In 2001 Dixon et al. proposed the use of OFDM to detract the effects of modal dispersion in a Multi-Mode Fibre (MMF) [8]. The permissiveness for the dispersion of the OFDM in an optical fiber channel has been accepted as one of the key quality for making OFDM the best precedent for exploitation in next generation optical fiber networks. Research on OFDM has accelerated because it is widely used in both wired and wireless communication, and has been specified for the different kinds of high data rate communications. At present OFDM has become the hot topic for the research teams for the optical communications system. In the world a number of research centres have the expert teams working on the OFDM for various applications.Because of the various advantages, OFDM is thus a promising candidate for mobile broadband wireless and has already been adopted in various high data capacity wireless communications standards such as mobile cellular phones, Digital Audio broadcasting (DAB), satellite communications, the wireless networking standard IEEE 802.11a/g Wi Fi for Wireless Local Area Networks (WLAN), IEEE 802.16 WiMAX for Wireless Metropolitan Area Networks (WMAN), Digital Video Broadcasting - Terrestrial (DVB-T) [11], General Switched Telephone Network (GSTN), Digital Subscriber Lines (DSL) and High Definition Digital Terrestrial Television Broadcasting, are also based on OFDM.

## DISPERSION COMPENSATION IN OPTICAL COMMUNICATION SYSTEM USING OFDM

Optical communication system technology has tremendously increased the transmission capacity of communication system to meet increasing demand for various services. It is well known that the optical signal attenuation loss and dispersion can degrade the optical signal; this makes it difficult to recovered signal at the receiver end. While using optical amplifier such as EDFA can compensate the reduced power for long distance link, the dispersion also needs to be compensated to avoid the ISI originated by the dispersion. Hence, In order to transmit more channels / data in a fiber or increase transmission speed in each channel, dispersion effects must be suppressed. OFDM deals with one of the most significant problem in communication system consisting of the dispersion in a very efficient way. It is an extensively used in broadband wired and wireless communication system. It is a modulation / multiplexing technique that permit digital data to be efficiently and reliably transmitted over multipath conditions, because of its natural tolerance to the multipath signal. OFDM is a process consists of efficiently multiplexing and simultaneously transmitting data by using a number of modulated orthogonal, overlapping, narrow band sub-subcarriers. It splits the original transmitted signal spreads over a wide bandwidth into narrow band results into many small band sub-carriers to conquer the effect of frequency selective fading. Also, by creating symbol duration comparatively longer than the channel impulse response and low rate modulation the effect of the inter-symbol interference detracts.

The separations of the OFDM sub-carriers are theoretically minimal and divide the available bandwidth such that all the sub-carriers are mathematically orthogonal, results in efficient spectral utilization. The term mathematically orthogonality normally stands for at $90^0$ to each other but in communication engineering it is quite generally means that each carrier is placed such that it take place at the null points of all the other carriers. The SINC = SinX/X has this property and is used as sub-carrier in the OFDM system. The orthogonality between the sub-carrier ensures that even though there are many carriers, but there is no interference among the carriers. The flatness observed by a narrow band channel defeats the fading. Out of these carriers only few carriers will be lost, because of the frequency selectivity. In OFDM system the symbol period is compel to have much longer than the optical channel impulse response to eliminate the effect of the ISI. By inserting a guard band between the two symbols the effect of ISI is further reduced. It will make the symbol period much longer than impulsive response of the channel.

The guard interval is selected in such a way that the maximum delay spread did not cause any two adjacent symbols to overlap. During guard interval a part of the symbol is transmitted, to avid the intercarrier interference. Hence, the pulse dispersion smaller than guard interval did not result in inter-symbol and inter-carrier interference.At the same time a large number of the sub-carriers are used,to overcome the loss in data rate. By using the Forward Error Correction (FEC) codes, along with interleaving in time & frequency domain, can then be used to detect and correct for the faulty subcarriers. Furthermore, more number of sub carriers, higher order modulation techniques and the usage of CP could lead into an overall better quality of transmission for long-haul optical communication system.The important benefit of using OFDM is that it allows trade off of the data rate as well as format depending on the transmission channel characteristics.Hence, the OFDM is a multiple sub-carrier modulation technique which is highly spectral efficient and have a dynamic tolerance to dispersion thereby making it an excellent dispersion compensation scheme for using the exiting optical communication networks for next generation dynamic traffic pattern. Therefore, the combination of the long haul high capacity optical communication system and OFDM is the highly efficient technique for the next generation network. This work investigates the use of OFDM as a technique to fulfil these needs for next generation optical communication system

## MODELING AND SIMULATION OF OPTICAL SYSTEM

The assessment of the optical system performance is critical for simulation, modelling as well as experimental setups. The performance of the optical communication system can be analysed by various parameters, such as eye opening, eye opening penalty, bit error rate, quality factor, optical signal to noise ratio etc. Nevertheless a number of performance parameters are present, but the proper selection of the parameters is very critical issue for the design of the long-haul high data rate optical communication transmission system. Here we have performed comparative investigation on optical communication systemwith and without using OFDM. The key problems of dispersion for the high speed long distance transmission have been addressed. Weanalysedthepracticabilityoftransmitting10Gbps andmoredataratethroughoptical communication system using OFDM.The major steps in modelling and simulation of optical communication system[3] consisting of modelling and design of OFDM modulator & demodulator, modelling and design of optical fiber system, Simulation of the Optical Communication system with and without using OFDM for dispersion Compensation.

Finally, for assessing the dispersion compensation tolerance of the system, the performance investigation of the optical communication system has been carried out through the various parameters computation of BER, Q factor, OSNR and constellation diagram etc. The systems are simulated by using the simulated software “Matlab and Opti-System” employed by numerous researchers for the investigation of the various nonlinearity and distortion due to dispersion in the optical fiber communication system[30, 39].Thevarious crucial parameters of the system are consideredin the simulation

**Simulation of the Optical Communication System using OFDM for dispersion Compensation**

The schematic of the optical fiber communication systemwith using OFDM for dispersion compensation in the long distance high data rate transmission is depicted in Figure 1 The different partsof optical fiber communication system with using OFDM includes OFDM modulator / transmitter, OPTICAL transmitter / up-converter, optical fiber channel, Optical receiver / down-converter, & OFDM demodulator / receiver. The system data rates are varying from 10–40 Gbps. The span of the fiber varying from 0 to 200 Km. the PRBS generated data are mapped by the 16-QAM encoder for the 16-QAM modulation..

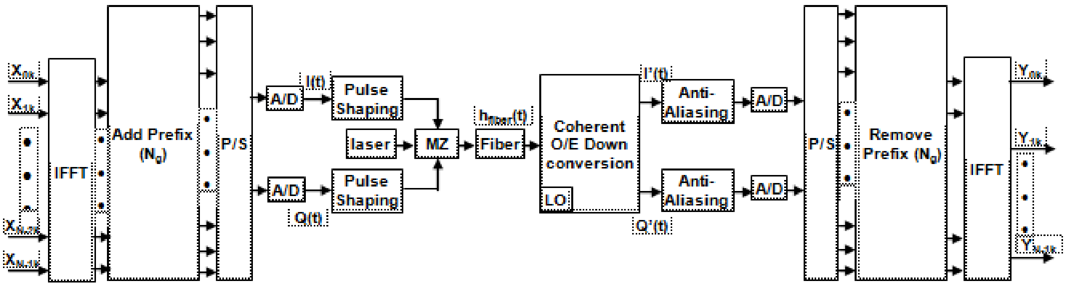


**Figure 2: Schematic for Optical System Using OFDM for Dispersion Compensation**

Subsequently these data stream is passed to 1024 sub-carriers and further processed by the IFFT. By inserting the CP comprising of the samples at the end part of the symbol in the initial part of the symbol we can furthermore reduce the impact of the dispersion causing the ISI. The information data are mapped and OFDM modulated digitally using IFFT. The Mach Zehndermodulator along with the continuous wavelaser is used for the electrical to optical conversion / modulation. For the coherent optical OFDM the real and imaginary parts of the OFDM modulatedsignal are used for the optical modulation of both the amplitude and phase of the continuous wave LASER optical carrier. The OFDM modulated optical signal composed of in-phase (I (t)) part and quadrature phase (Q (t)) part are then passing to the A/D converter followed by the low pass filter. The LASER line width isset at 0.15MHz. The systems operate at centre wavelength of 1550 nm. The different length of the standard single mode fiber having the attenuation constant of 0.2dB/km, dispersioncoefficient17 ps/nm/km and nonlinearity coefficient of 2.09 /w/km. The OFDM modulated signal after electrical to optical conversion are transmitted via optical fiber channel. The signal gets distorted because of the optical fiber channel dispersion and attenuation. The received optical OFDM modulated optical signals after filtering & amplification are converted in to electrical form by utilizing a coherent optical receiver having a local oscillator. For these the “I and Q” components of the OFDM modulated optical data signal are used. The local oscillator laser is also having the line width of 0.15 MHz and ideally aligned. OFDM modulated data signal after the down conversion in to “I and Q” components of the OFDM modulated data signal is sent to an OFDM demodulator comprising of the FFT. Subsequently the 16-QAM decoders are used for getting back the transmitted information for the performance evaluation of the system. The transmission information retrieved from the received information data and the transmitted information data are used for the computation of different transmissionperformances parameters (Constellation diagrams, BER and OSNR) for the system and compared. The four wave mixing and cross phase modulation are not producein the single channel optical fiber communication systemand need not to be consider herewith. The primary objective of this research work is the investigation of the performance of the OFDM to detract the impact of dispersion generating the ISI in optical communication system by linear effects.

**Simulation of the Optical Communication System without Using OFDM**

The schematic diagram for the optical communication system without using OFDM is shown in Figure 2. The optical communication system is configured &analysed for assessing the performance. The system consists of the optical modulator / transmitter, the optical fiber channel, and the optical demodulator / receiver. For the evaluation of the performance of the optical system without using OFDM, the different parameters (i.e., BER, OSNR and constellation diagram)are evaluated and compare with the optical communication system with OFDM. The PRBS sequence generator output is mapped by the 16 QAM encoder followed by conversion into optical signals by using Mach Zehnder Modulator, which modulates optical carrier from CW laser. Subsequently the optical modulated signals are fed to the optical fiber channel at the wavelength cantered at 1550nm and EDFA are used to overcome the signal attenuation. The output optical modulated signal after passing through the optical fiber channel are fed into PIN diode photo detector / receiver, for the optical to electrical conversion. For the noise reduction and filtering of the electrical time domain signal the Low Pass Bessel filter used.

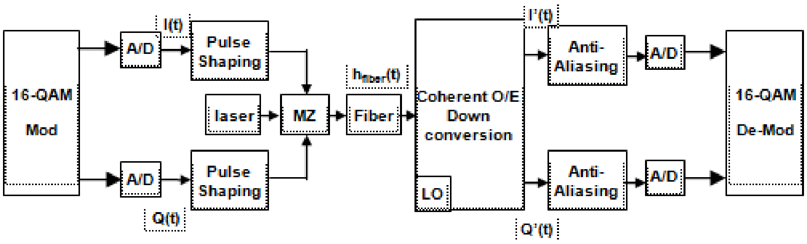


**Figure 3: Schematic for Optical Fiber Communication System without Using OFDM**

## RESULTS AND DISCUSSIONS

The optical communication system is configured &analysed for assessing the performance. The system with OFDM at the data rate 1.0 – 40 Gbps is simulated for the fiber span ranging from 0 – 170 Km. the constellation diagram for 16-QAM system at the transmitter side is shown in the Figure 4.1

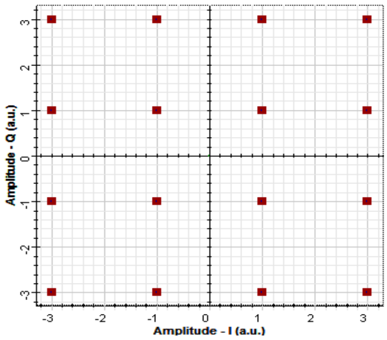


**Figure 4: Input Signal Constellations of 16-Qam Encoders**

The 16 QAM encoder maps the PRBS sequence generator output. The OFDM modulated data feed to the MZ modulator. The output of the Mach-Zehnder modulator is fed to the optical fiber channel followed by the optical receiver for the performance evaluation of the system. The transmission performance characteristics of the optical system is analysed by examining the various parameters of the received signal i.e., by the Signal Constellation / BER / OSNR at the receiving end for different fiber span, data rate etc

**Performance Analysis of Optical Communication System with using OFDM by Employing QAM Modulation**

**OFDM 16-QAM 1024 Sub Carriers 10Gbps**

From the various constellation diagramsdepicted in Figure 5 we notice that for the fiber length up to 160 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference.Figure 6 shows that the OSNR are function of the length of fiber and decreases linearly with its length, also the bit error rate deteriorates as fiber span increases beyond 160 Km. it approaches to a negligible value at approximately 170 Km. Therefore from the performance analysis evaluation of the various parameters (i.e., constellation diagrams, BER and OSNR) it can be notice that the comprehensive performance of the introduced optical communication system with using OFDM for 10 Gbps data rate with 1024 sub carriers is reasonably good up to transmitted distance of 160 Km only and subsequently the performance is highly degraded.

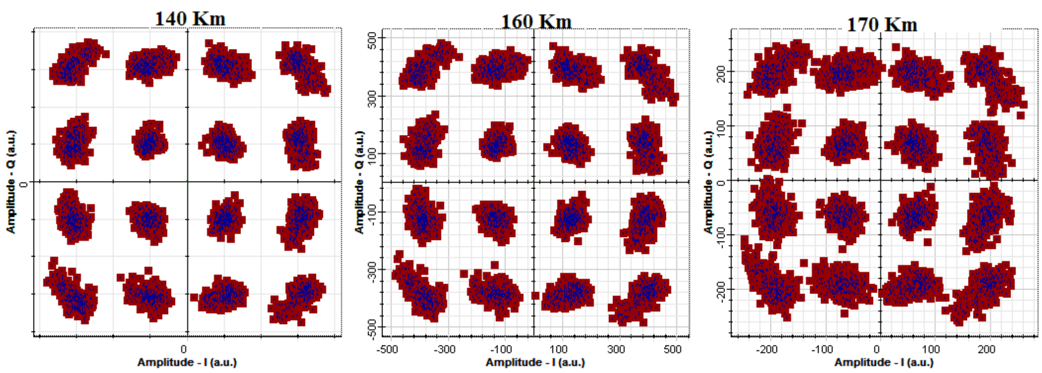


**Figure 5: Constellation Diagram for the Received Data for OFDM 16-QAM 1024 Sub-Carriers at 10 Gbps**

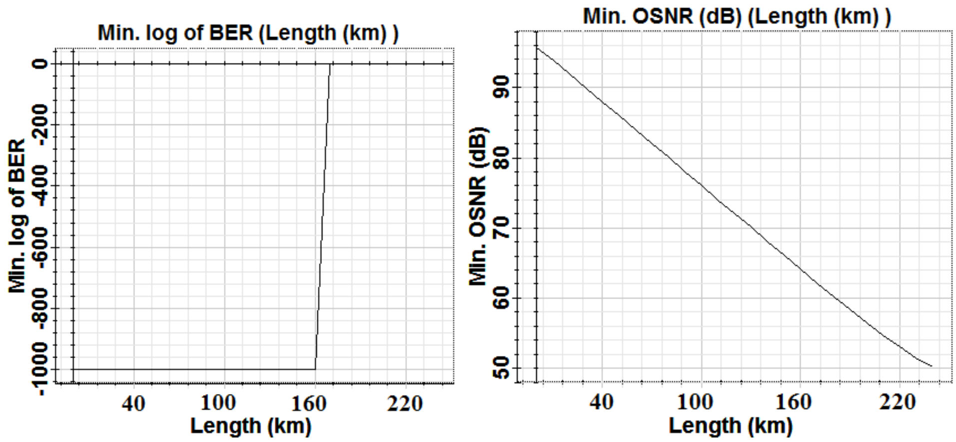


**Figure 6: Evaluation of OSNR / BER v/s Length Obtained for OFDM 16-QAM 1024 Sub-Carriers at 10 GBPS**

**OFDM 16-QAM 1024 Sub Carriers 20Gbps**

From the various constellation diagrams depicted in Figure 7 we notice that for the fiber length up to 100 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference. Figure 8 shows that the OSNR are function of the length of fiber and decreases linearly with its length, also the bit error rate deteriorates as fiber span increases beyond 100 Km. it approaches to a negligible value at approximately 110 Km.

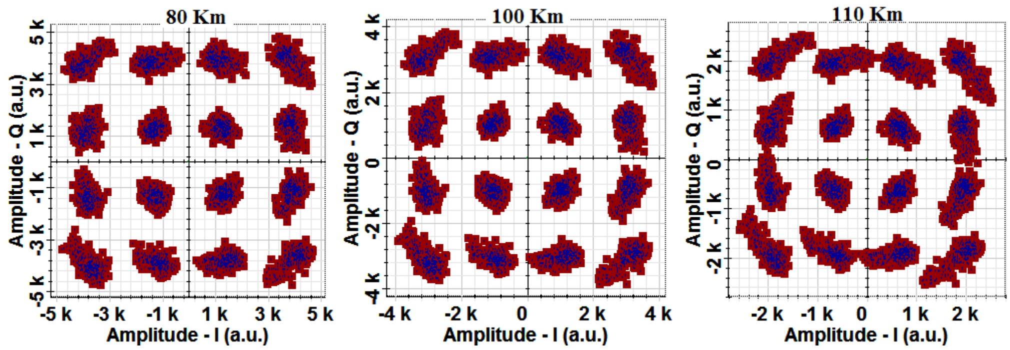


**Figure 7: Constellation for the Received Data for OFDM 16-QAM 1024 Sub-Carriers at 20 Gbps**

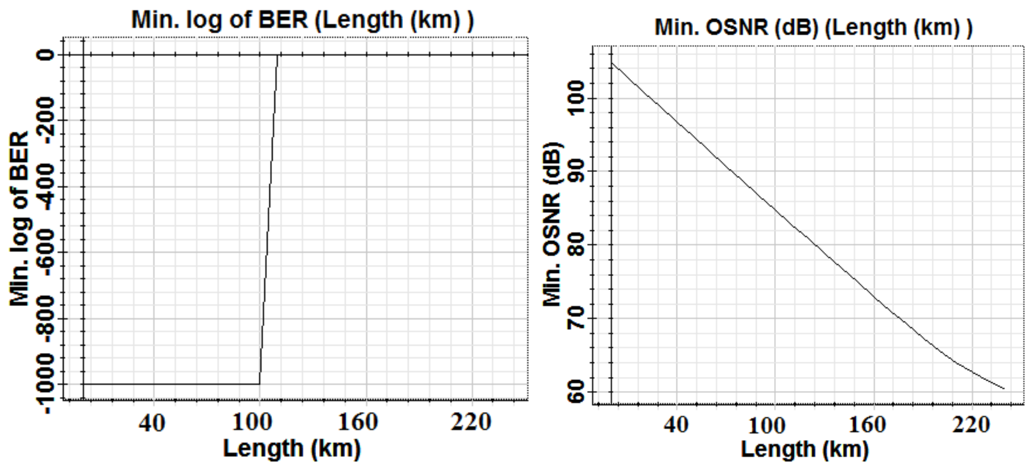


**Figure 8: Evaluation of OSNR / BER v/s Length Obtained for OFDM 16-QAM 1024 Sub-Carriers at 20 Gbps**

Therefore from the performance analysis of the various parameters (i.e., constellation diagrams, BER and OSNR) it can be notice that the comprehensive performance of the introduced optical communication system with using OFDM for 20 Gbps data rate with 1024 sub carriers is reasonably good up to transmitted distance of 100 Km only and subsequently the performance is highly degraded

**OFDM 16-QAM 1024 Sub Carriers 30Gbps**

From the various constellation diagrams depicted in Figure 9 we notice that for the fiber length up to 70 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference. Figure 10 shows that the OSNR are function of the length of fiber and decreases linearly with its length, also the bit error rate deteriorates as fiber span increases beyond 70 Km. it approaches to a negligible value at approximately 80 Km.Therefore from the performance analysis of the various parameters (i.e., constellation diagrams, BER and OSNR) it can be notice that the comprehensive performance of the introduced optical communication system with using OFDM for 30 Gbps data rate with 1024 sub carriers is reasonably good up to transmitted distance of 70 Km only and subsequently the performance is highly degraded.

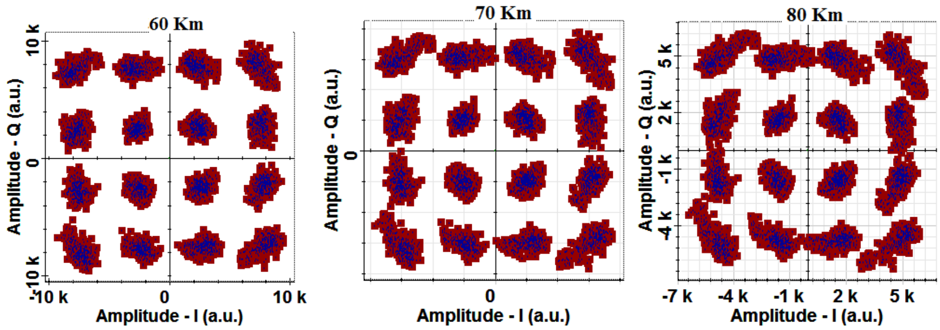


**Figure 9: Constellation Diagram for the Received Data for OFDM 16-QAM 1024 Sub-Carriers at 30 Gbps**

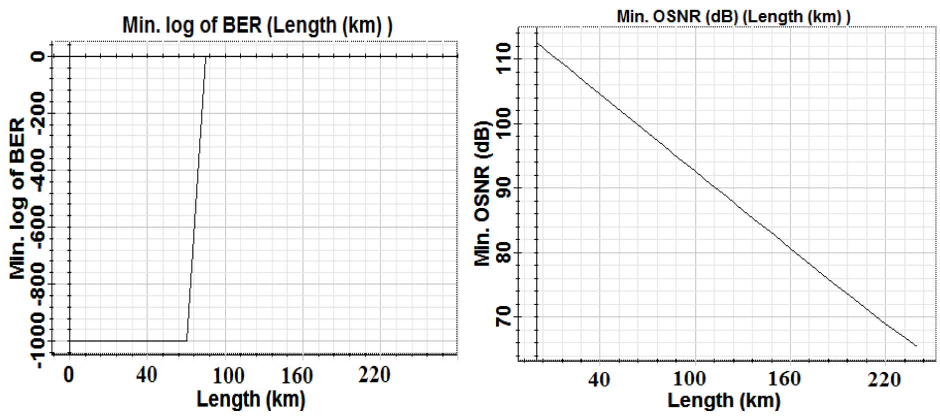


**Figure 10: Evaluation of OSNR / BER v/s Length obtained for OFDM 16-QAM 1024 Sub-carriers at 30 Gbps**

**OFDM 16-QAM 1024 Sub Carriers 40Gbps**

From the various constellation diagrams depicted in Figure 11 we notice that for the fiber length up to 20 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference. Figure 12 shows that the OSNR are function of the length of fiber and decreases linearly with its length, also the bit error rate deteriorates as fiber span increases beyond 30 Km. it approaches to a negligible value at approximately 20 Km.

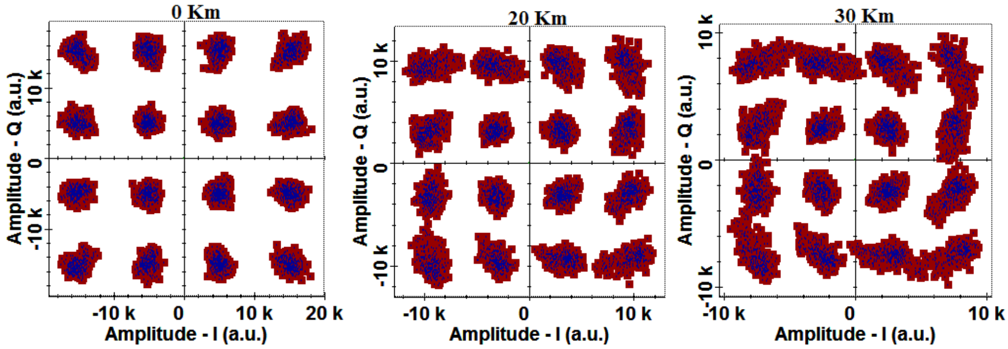


**Figure 11: Constellation for the received data for OFDM 16-QAM 1024 Sub-carriers at 40 Gbps**

Therefore from the performance analysis of the various parameters (i.e., constellation diagrams, BER and OSNR) it can be notice that the comprehensive performance of the introduced optical communication system with using OFDM for 40 Gbps data rate with 1024 sub carriers is reasonably good up to transmitted distance of 20 Km only and subsequently the performance is highly degraded

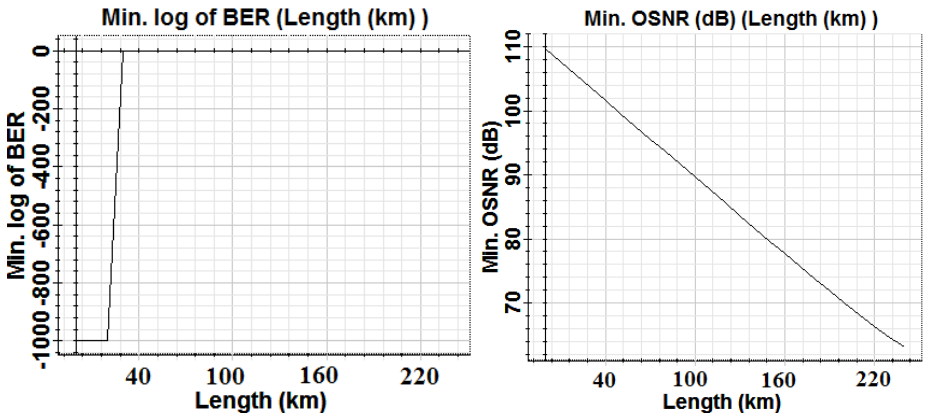


**Figure 12: Evaluation of OSNR / BER v/s Length obtained for OFDM 16-QAM 1024 Sub-Carriers at 40 Gbps**

### 4.2 Performance Analysis of Optical Communication System without Using OFDM by employing QAM Modulation

The analysis of the above system as shown in Figure 13 has been carried out in this work and the performance of system has been assessed without using OFDM for comparison purpose only. The transmission bit rate is 1.0 – 10 Gbps. The PRBS sequence generator is used at the transmitter followed by a QPSK encoder. After passing through the optical fiber channel model & the receiver, the transmission performance of the optical communication system is then examined by evaluating the performance of the received signal.For the performance evaluation of the received signal various transmission parameters i.e., the Signal Constellation Diagrams / BER / OSNR is then assessed at the receiver end for different fiber span and data transmission rates. The constellation diagram clearly shows that as the fiber length increases the constellation points distorted because the dispersion increases and which in turn affects the data transmission rate and channel capacity. Hence we must reduce either the maximum data rate or the fiber span to accomplish error free uniform Distance - Data rate Product.

#### 16-QAM 1.0 GBPS

From the various constellation diagramsdepicted in Figure 14 we notice that forfiber span up to 40 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference.

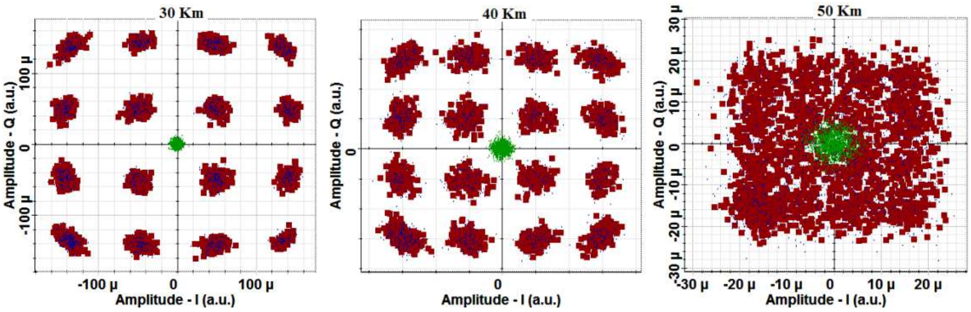


**Figure 13: Constellation Diagram for the Received Data for 16-QAM at 1.0 GBPS Data Rate without OFDM**

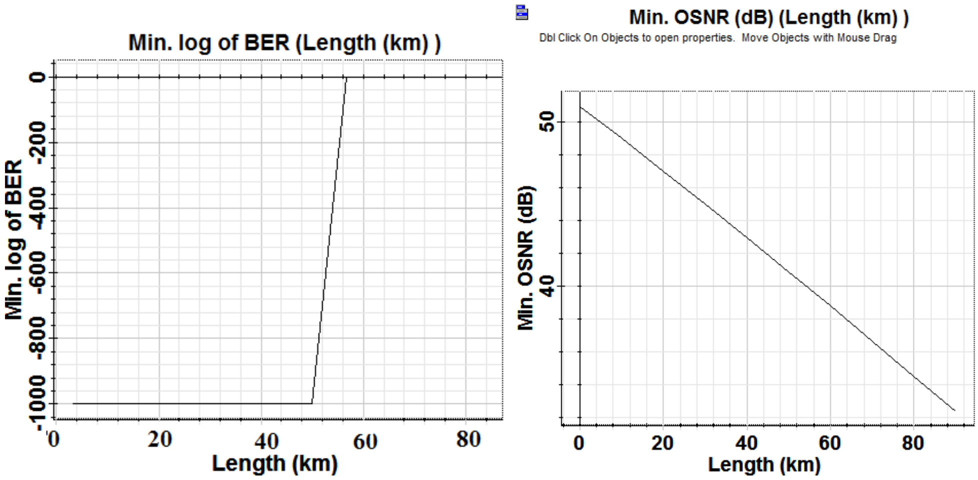


**Figure 14: Evaluation of OSNR and BER v/s Length obtained without OFDM 16-QAM at 1.0 Gbps data rate**

**16-QAM 5.0 Gbps**

From the various constellation diagramsdepicted in Figure 15 we notice that forfiber span up to 30 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference. As shown in Figure 16, the OSNR is function of the length of fiber and decreases linearly with its length. Also, the bit error rate deteriorates as fiber span increases beyond 30 Km. it approaches to a negligible value at around 35 Km. Therefore, from the performance analysis of the various parameters (i.e., constellation diagrams, BER and OSNR) it can be notice that the comprehensive performance of the optical communication system for 5 Gbps data rate is reasonably good up to transmitted distance of 30 Km only and subsequently the performance is unacceptable.

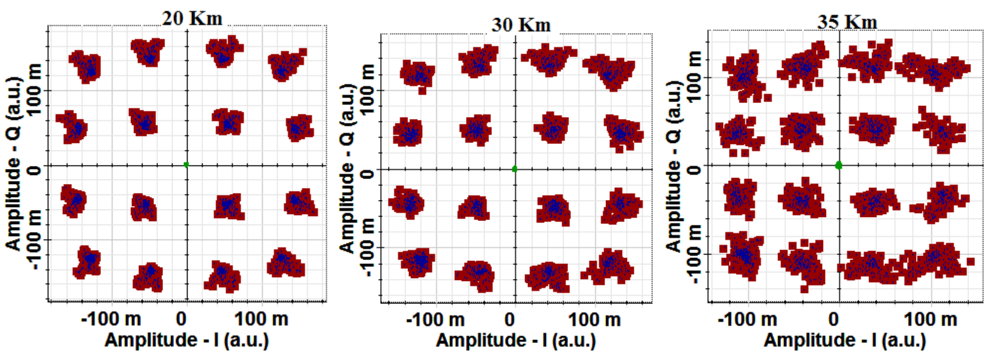


**Figure 15: Constellation diagram for the received data for 16-QAM at 5.0 Gbps data rate without OFDM**

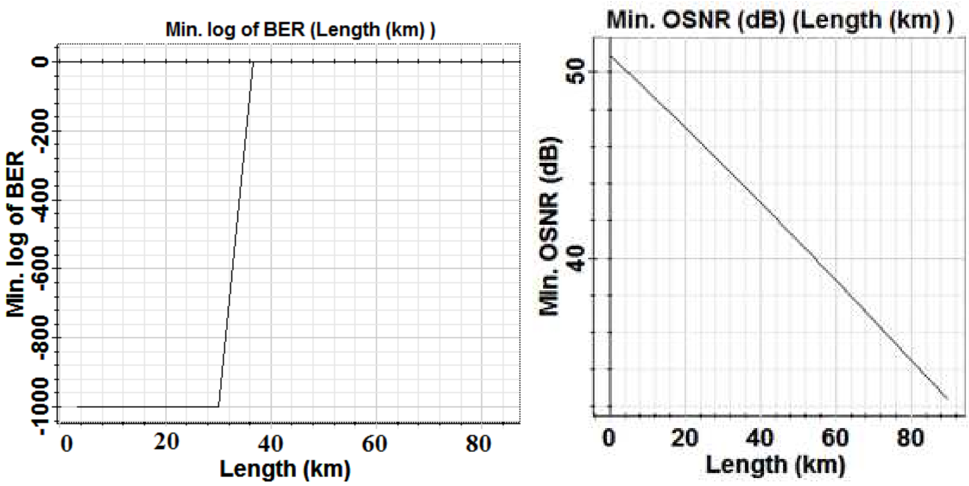


**Figure 16: Evaluation of OSNR and BER) v/s Length Obtained Without OFDM 16-QAM at 5.0 GBPS Data Rate**

**16-QAM 10 Gbps**

From the various constellation diagramsdepicted in Figure 17 we notice that forfiber span up to 15 Km the signal quality is duly satisfactorily, subsequently it degrades due to dispersion causing inter-symbol interference. As shown in Figure 18, the OSNR is function of the length of fiber and decreases linearly with its length. Also, the bit error rate deteriorates as fiber span increases beyond 15 Km. it approaches to a negligible value at around 20 Km. Therefore, from the performance analysis of the various parameters (i.e., constellation diagrams, BER and OSNR) it can be notice that the comprehensive performance of the optical communication system for 10 Gbps data rate is reasonably good up to transmitted distance of 15 Km only and subsequently the performance is unacceptable.

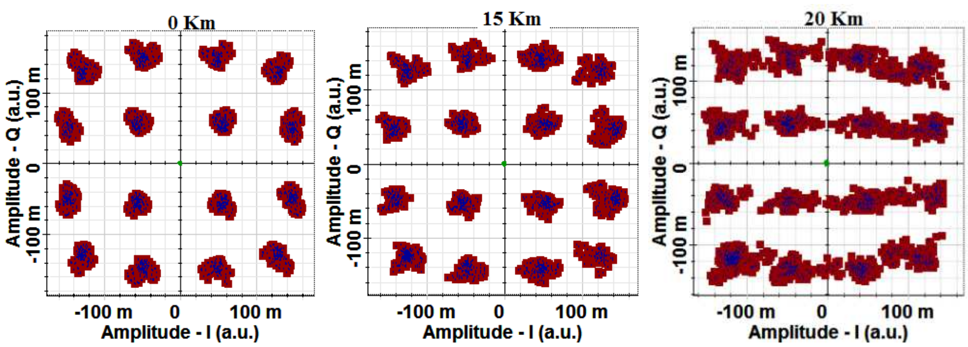


**Figure 17: Constellation for the Received Data for 16-QAM at 10 Gbps Data Rate w/o OFDM**

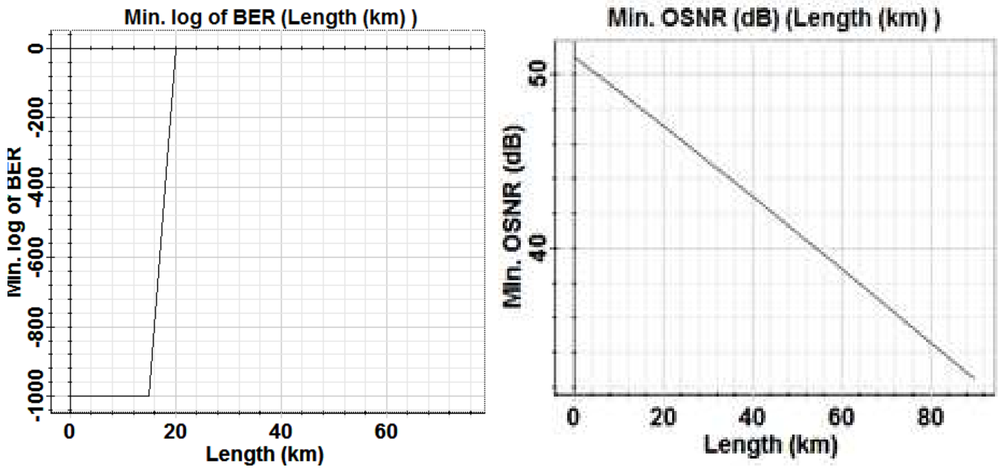


**Figure 18: OSNR and BER v/s Length Obtained without OFDM 16-QAM at 10 Gbps**

## CONCLUSIONS AND FUTURE WORK

A relative investigation of the optical communication systemby employing16-QAM modulation with and withoutusing OFDM has been conducted for militate the inter-symbol interference due to dispersion. The data rates ranging from 1.0 - 40 Gbps at the centre wavelength of 1550 nm for the fiber length varying from 0 - 200 Km.From the various simulated results comprises of constellation diagrams, BER and OSNR computed from the received signal, it is very much understandable that as fiber span and data transmission rate progresses the received signalbecomes distorted results in higher bit error rate because of the inter-symbol interference due todispersion. The different symbols in the constellation diagrams comes closer and closercauses distortion in the received signal. Therefore the performance of the system degrades. Consequently we must reduce either the overall transmission data rate or the fiber span to sustainconstant“Distance-Data Rate” product. The system with using OFDM givessuperior performance relative to the system without using OFDM. The various simulated results demonstrate that without using OFDM the maximum “Distance-Data Rate” product for the system is much less than that with using OFDM. From the various observation of the above comparative performance analysis, we can deduce that the acceptable bit error rate performance can be substantiated even up to 160 Km of the fiber span for the data transmission rate of 10 Gbps for optical communication system with using OFDM. This concludes that the optical communication system with using OFDM ismost effective technique to eliminate dispersion causing inter-symbol interference, whereby it can powerfully compensate the dispersion in optical communication system without utilizing any isolated dispersion compensating module in the network.

In pursuance of the researchsubstantiate in this work, OFDM seems to be a good compensation technique for resisting the dispersion for the overall dispersion mitigation in optical communication system with better spectral utilization efficiency / better performance. on the other hand, in the case of OFDM the maindrawbacks are the high peak to average power ration and the sensitivity to phase noise and frequency offset. Theseaspects could not be investigatedhere e.g., peak to average power ratios, peak power clipping, start time error, effect of frequency stability errors. Furthermore, the performance of the optical communication system using OFDM can be elevated by integrating various error detecting and correcting techniques in the system.the existing work has become absolutelyextensive, so to fully utilize advantages and diminish side effects of OFDM a cautious design using different parameters of the can be studied later on as part of future work..

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