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PERFORMANCE ENHANCEMENT OF DWDM-FSO SYSTEM UNDER DIVERSE WEATHER CONDITIONS WITH OPTIMIZED MODULATION FORMAT

Sooraj Parkash
Department of Electronics and Communication Engineering
CT institute of Technology & Research
Maqsuadan Campus Jalandhar, Punjab, India

Amita Banga
Department of Engineering Design and Technology
Torrens University
Flinders Street Campus
Melbourne, Victoria, Australia

Dinesh Kumar
Department of Electronics and Communication Engineering
CT institute of Technology & Research
Maqsuadan Campus Jalandhar, Punjab, India

Abstract − **This paper is successfully demonstrating simulating comparison and investigation of 48 channels of dense wavelength division multiplexing free space optical (DWDM−FSO) network with a 10 GB/s data rate on each channel separated by 100 GHz frequency spacing under a clear sky, haze and light rain climate conditions. Apart from this, comparison of a series of modulation formats such as non−return to zero (NRZ), return to zero (RZ), carrier suppressed return to zero (CSRZ), Soliton pulse, and offset quadrature phase shift keying (OQPSK) have been performed and optimized the performance of the designed system with best suited modulated system. The performance of the proposed work has been evaluated in terms of bit error rate (BER), quality factor (Q), signal−to−noise ratio (SNR), received signal power and eye diagrams. It has been observed that OQPSK modulated system has shown more robust performance as compared to other line encoding techniques. The minimum simulation work reports for OQPSK modulated system have been recorded with the acceptable performance BER $\leq 10^{-10}$, Q ≥ 6 dB at the 2000 meters FSO link range.**

Keywords − **DWDM−FSO, OQPSK, BER, SNR**

I. INTRODUCTION

In the present scenario, with an increase in population simultaneously the demand for high bandwidth with a high data rate is escalating drastically. Moreover, with the coming of the fifth−generation (5G) network, excessive increase in the number of subscribers using smartphones and social networking applications hence; a remarkable incline in huge data rate capacity demands which leads to telecom industries facing bottleneck problems [7]. To fulfill the needs of high data rate demands with a wide bandwidth range DWDM is a promising approach in which multiple signals can be multiplexed and transmitted via a single channel [6, 15]. In optical communication light is used as a carrier signal, therefore it's possible to transmit information signal wirelessly and utilize the optical transmission through the atmosphere. This system is called free−space optical (FSO). The FSO is also optical wireless communication (OWC). The FSO is a high data rate relaying technology which requires a line of sight between transmitter and receiver [11]. FSO links have numerous advantages such as high data transmission rates, availability of ample amount of license−free spectrum, no security upgrade requirement, high modulation bandwidth, immunity to electromagnetic interference, low power consumption, low cost of deployment, and easy and quick installation process [4, 16]. The FSO system has some advantages over fiber optic (FO) system like there is no need to dig the streets to lay fiber thus; it makes the FSO system cost−effective. In addition, FSO installation is very convenient where FO installation is impractical or impossible where the fiber−based systems are widely destroyed by natural disasters. Additionally, in the FSO system, the optical signal is directly transmitted ̶ inserted from optical fiber to free space and free space to optical fiber without any optoelectronic conversion. On the other hand, in the FSO system main matter of concern is signal attenuation caused by atmospheric turbulences like haze, rain, fog, dust, thunderstorms and scintillation these factors are responsible for deteriorating the performance of the FSO system which leads to degraded the power of transmitting signal [1]. In the FSO system to overcome these challenges dual channel, FSO transmitter−receiver and EDFA were adopted for high−power transmission. The EDFA optical amplifier is played a very critical role to overcome the effect of climate turbulences by increasing the amplitude and power of the transmitting signal thus; the signal can travel up to several kilometers without degrading its power. Apart from this advanced modulation techniques such as CSRZ, duo binary return to zero (DRZ), and modified duo binary return to zero (MDRZ) are used for transmitting data with high transmission power [9]. Apart from this (OQPSK) modulated signal offers a flexible hardware platform mainly used in wireless applications such as satellite communication where high data rate transmission is required [2, 5]. In the present contemporary era, the FSO system is next generation fibre access network with high scalability and flexibility. The FSO system is more efficient and cost−effective than rather FO communication system [14, 18]. At last, the FSO system installation on both ends of the FO network provides a solution for first−mile and last−mile problems in an optical communication system.

II. RELATED WORKS

In the previous research, Sharma et al. 2021 in this research, authors investigated a hybrid FSO 32 channels DWDM−FSO system with a 10 GB/s data rate under different climate conditions at 125 meters link range. This research also showed a performance comparison of RZ an NRZ modulation format and an acceptable BER report has been achieved with NRZ without any dispersion compensation technique [3]. Hamza et al. 2021 authors have investigated 8 channels of WDM−FSO dual transmitter and receiver having 2.5 GB/s and 1.25 GB/s data at a 4.7 km link range under different atmospheric turbulences with NRZ modulation format. The authors have shown acceptable BER performance [10]. Singh, 2018 the author has successfully analyzed and investigated 32 channels wavelength division multiplexing free space optical (WDM−FSO) system having each channel 10 GB/s by using NRZ modulation format under adverse weather conditions. The minimum simulation report of BER has been reported as 10^{-9} under diverse climate conditions [12]. Paliwal et al. 2021 authors have investigated 4 channels WDM−FSO system with a 2.5 GB/s data rate at a 25 km link range by using NRZ modulation format. This research has also perceived that an erbium−doped fiber (EDF) amplifier can be used to overcome the effect of attenuation [20]. Alnajjar et al. 2022 authors have demonstrated a comparison of two models single and multichannel channel FSO transmitter and receiver under distinct values of attenuation by using NRZ line encoding with 10 GB/s. This research has revealed that the dual−channel FSO system is more robust as compared to the conventional FSO system [17]. Parkash et al. 2016 authors have successfully simulated and investigated 8 channels DWDM−FSO system with a 5 GB/s data rate on each channel with RZ modulation format under clear sky and haze weather conditions. The minimum simulation report of BER has been identified as 10^{-15} at 5000 meters. A sharp increase in BER has been seen by a surge in data rate and link distance [13].

This paper is comprised of five sections, the introduction in section 1 with the influence of atmospheric turbulence on the FSO system, section 2 is proving information about the literature survey, section 3 describing the simulation setup of proposed thereafter, section 4 consists of results and discussion. Eventually in section 5 conclusion of this research paper.

III. PROPOSED DWDM−FSO SYSTEM MODEL

The proposed 48 channels DWDM−FSO system is designed, simulated and investigated in OptiSystem v.19 simulating software. Figure.1 (a) represents the block diagram of the 48 channels FSO proposed system. The DWDM−FSO system is mainly comprised of three sections ̶ the transmitter section, the propagation channel and the receiver section. In the transmitter section, the main components are a pseudo−random binary sequence (PRBS) generator, OQPSK electrical pulse generator, continuous wave (CW) laser array, optical multiplexer and Mach−Zehnder modulator (MZM). The PRBS generator produces 10 GB/s information data rate in the form of binary sequence and converted into electrical form with an OQPSK electrical pulse generator. The OQPSK signal retains its bandwidth−limited nature even after nonlinear amplification [8, 19]. Figure 1(b) shows the OQPSK transmitter and its components. It has phase shift keying (PSK) sequence generator which consist three x couplers used for redistributing the electrical signal with 45^0 phase shifts. Time delay is biased in such a way that alternating optical phases between 0^0 to 180^0 for the adjacent time slots. The one output of OQPSK is a 1−bit delay from the other. When transmitting information, we can vary the phase of a signal according to the source symbols. The phase values take the values in the set of angles expressed as in [21].

$$\emptyset_i = \left(\frac{2\pi}{M}(i-1) + \emptyset\right), i = 1, 2, \dots M \qquad (1)$$

Where M is the number of a possible sequence of binary digits. A reduction of the signal fluctuations is possible by delaying the Q channel by a one−bit period. This model generates the pulse according to the equations given below in [21].

$$I_{K-Out}\ (t) = I_K, 0 \le t < T \tag{2}$$

$$Q_{K-Out}\ (t) = Q_K, T_S \le t < T + T_S \tag{3}$$

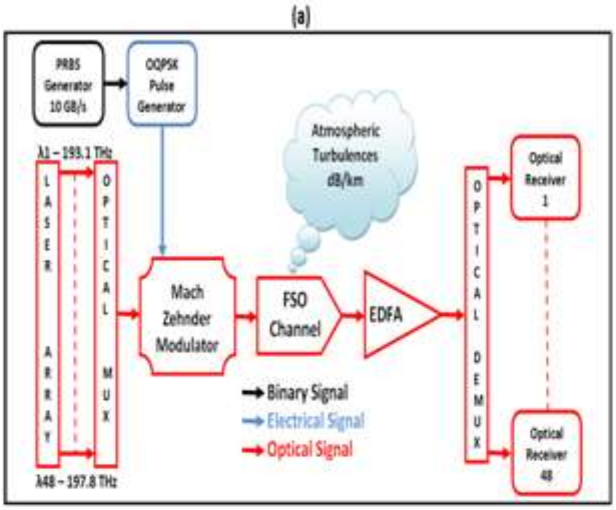
Where K is the amplitude of signal I, T is the bit period and T_S is the input bit period.

TABLE 1- key parameters used in the DWDM−FSO system

Parameters	**Measurements**
Number of channels	48
Data rate per channel	10 GB/s
CW laser array frequency	193.1 THz – 197.8 THz
Input signal power	10 dB
OQPSK Phase offset	45 degree
Frequency spacing	100 GHz
FSO link range	2000 meters
EDFA length	5 meters
FSO beam divergence	5 mrad
FSO Tx. aperture diameter	5 cm
FSO Rx. aperture diameter	20 cm
Cut off frequency	0.75*bit rate
Additional losses	0 dB

The CW laser array is producing 48 different wavelengths channel range of 193.1 THz to 197.8 THz with 100 GHz frequency spacing and is multiplexed by an optical multiplexer having 48 input ports and one output port. The output of the optical multiplexer and OQPSK electrical pulse generator is merged and then modulated by MZM optical modulator and transmitted via the FSO channel in free space. Table 1 reveals the key parameters used in the proposed designed system. In the FSO communication system the main factor is attenuation caused by atmospheric turbulence, therefore to overcome its effect EDFA with a 5m length is placed after the FSO channel and boosts the strength of weak signals. Table 2 represents the different atmospheric weather conditions concerning diverse attenuation values. To observe power at the receiver and calculate the link margin, one can determine factors that affect the quality of the link. The link margin is the ratio of received power P_R and receiver threshold or sensitivity (S) and is usually expressed in dB as in [13].

(a)



(b)

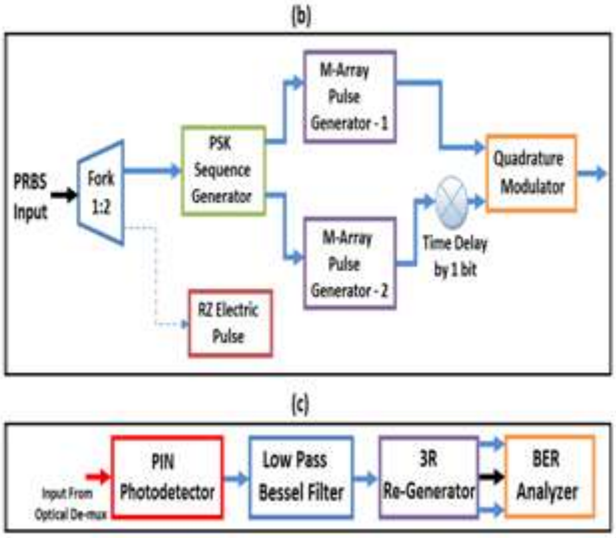


Fig. 1. Proposed 48x10 GB/s DWDM−FSO simulation setup
(a) multichannel DWDM−FSO system model
(b) OQPSK transmitter (c) Optical receiver

TABLE 2- shows different climate conditions with corresponding attenuation values in dB/km

Weather conditions	**Attenuation (dB/km)**
Clear sky	0.14
Haze	4
Light rain	10

$$\text{Link Margin} = 10\log_{10}\frac{P_R}{S} \tag{4}$$

For the signal to be recovered at the receiver side, its power must be higher than the receiver's sensitivity. Sensitivity is usually given by the manufacturer and it ranges from −20 to 40 dBm. Power at the receiver can be expressed as in [13].

$$P_R = P_T \times e^{-\alpha L} \times \frac{A_{Rx}}{(\theta L)^2} \tag{5}$$

Where P_R and P_T are the received and transmitted power respectively, whereas A_{Rx} is the receiver aperture space, while θ is the divergence angle, α is the region attenuation and L is the distance between the transmitter and receiver. Figure.1 (c) represents the optical receiver with its components. At the receiver terminal, an optical de−multiplexer is installed to decode the optical signal with one input port and 48 multiple output ports. The optical signal is detected by a PIN photo detector and converted into an electrical signal. Furthermore, a low−pass Bessel filter is used for removing high−frequency noise in the electrical signal coming from the photo detector. Moreover, the 3R re−generator is used to recover the degraded binary signal into an original binary sequence. Eventually, the error rate and received signal power of the information signal are measured with BER and electrical carrier analyzer respectively.

IV. RESULTS AND DISCUSSION

In this paper performance comparison of NRZ, RZ, CSRZ, Soliton pulse & OQPSK modulation formats have been performed under a clear sky, haze and light rain. Moreover, their performances have been compared on the bases of BER, Q−Factor and eye diagrams. The results have been reported on sampled bases by selecting extreme upper channel 1 (193.7 THz), centre channel 32 (196.2 THz) and extreme lowest channel 48 (197.8). Figure 2 (a) and (b) represents the transmission spectrum and encoded 480 GB/s information data rate of 48 channels with 10 dB input power at 2000 meters link range for OQPSK modulated system respectively.

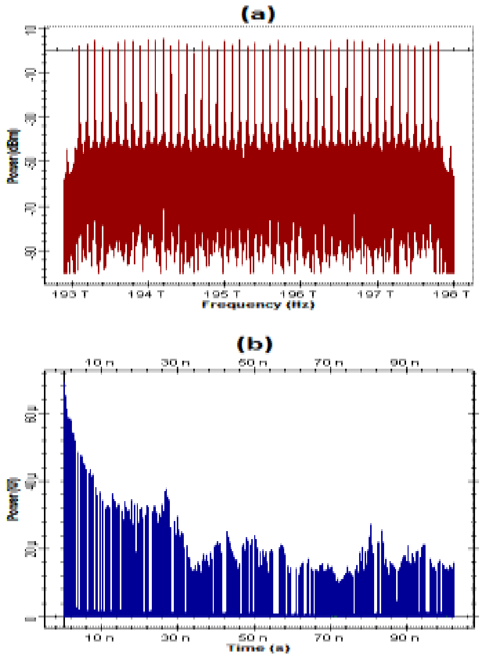


Fig. 2. Shows the emission spectrum of 48 channels (a) Transmission spectrum (b) 480 GB/s encoded data

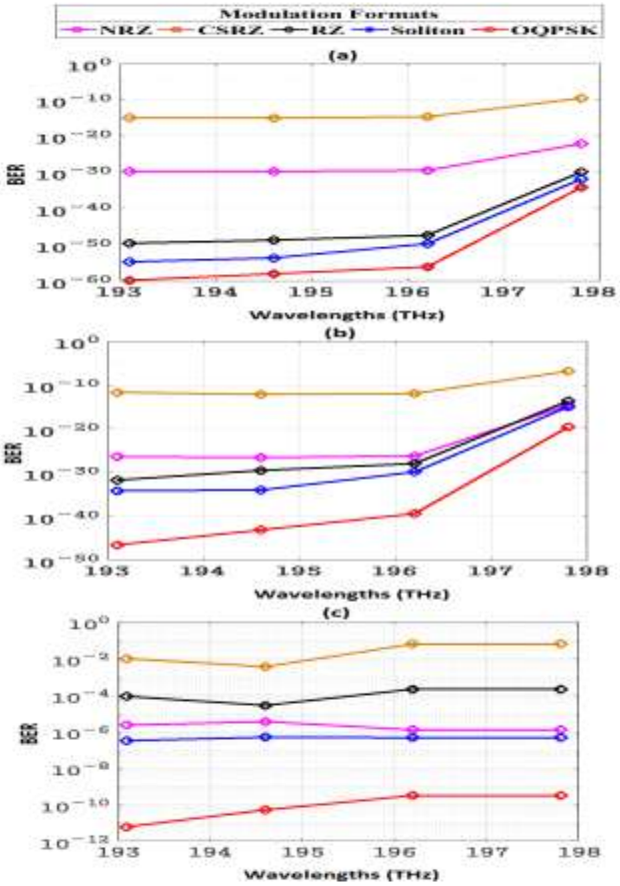


Fig. 3. Reveals the BER comparison of different modulation formats (a) clear sky (b) haze (c) light rain

Figure.3 (a), (b) & (c) depict the BER comparison on different wavelengths for distinct modulation formats at 2000 meters link range under clear sky, haze and light rain weather conditions respectively. Figure 3(a) the BER values at 2000 meters link range under a clear sky for channel 1 are founded 10^{-60}, 10^{-55}, 10^{-50}, 10^{-30} and 10^{-15} similarly for channel 32 BER values are recorded as 10^{-57}, 10^{-53}, 10^{-49}, 10^{-29} and 10^{-14}, alike for the lowest frequency channel 48 are 10^{-35}, 10^{-32}, 10^{-30}, 10^{-23} and 10^{-14} for OQPSK, Soliton, RZ, NRZ and CRZ respectively. Furthermore, in Figure 3(b) the BER values at 2000 meters under haze weather conditions at channel 1 are observed at 10^{-47}, 10^{-35} 10^{-32}, 10^{-27}, and 10^{-12} likewise for channel 32 are remarked 10^{-40}, 10^{-30}, 10^{-28}, $10^{-27}$and 10^{-12} alike for channel 48 are noticed 10^{-20}, 10^{-15}, 10^{-14}, 10^{-14} and 10^{-7} for OQPSK, Soliton, RZ, NRZ and CSRZ modulation formats respectively.

Moreover, in Figure 3(c) the BER values at the 2 km link range under light rain conditions are perceived for channel 1 are 10^{-10}, 10^{-7}, 10^{-6}, 10^{-4} and 10^{-2} equivalently for channel 32 are noted 10^{-10}, 10^{-7}, 10^{-6}, 10^{-4} and 10^{-2} then as well for channel 48 are 10^{-10}, 10^{-7}, 10^{-6}, 10^{-3}, 10^{-2} for OQPSK, Soliton, NRZ, RZ and CSRZ modulated system respectively. It has been observed that with an increase in the number of channels and attenuation dB/km the BER is also increasing. As consequence the OQPSK modulation system has more decreased BER values as compared to other line encoding under clear sky, haze and light rain climate turbulences hence; OQPSK is best suited modulated system for the designed system.

Figure 4 (a), (b) & (c) describe the comparison of Q values on different channels by using a diverse modulation system at 2000 meters link range for clear sky, haze and light rain respectively. Figure 4(a) the Q values for the clear sky at 2000 meters range for channel 1 are observed (20, 18, 16, 11.3 and 7.8) dB similarly for channel 32 values are noted (18, 14.6, 15.7, 11.3 and 7.8) dB alike for channel 48 values are identified (14.4, 12.8, 11, 9.32 and 6.1) dB for OQPSK, Soliton, RZ, NRZ and CSRZ respectively. Furthermore, in Figure 4(b) the Q values under haze climate at channel 1 are remarked (17, 15, 14, 10 and 6.8) dB then after for channel 32 values are noticed (13.4, 13.2, 12.7, 10 and 7) dB alike for channel 48 values are observed (11, 8, 7.3, 7.8 and 5.6) dB for OQPSK, Soliton, RZ, NRZ and CSRZ respectively.

Moreover from Figure 4(c) for light rain atmospheric turbulence the Q values for channel 1 are found (6.4, 4.9, 2.1, 3.9 and 2) dB equivalently for channel 32 values are observed (6.1, 4.8, 2, 3.6 and 2) dB similarly for channel 48 values are perceived (6, 4.8, 2, 3 and 2) dB for OQPSK, Soliton, RZ, NRZ and CSRZ modulated system. It has been observed BER and Q factors are both inversely proportional to each other with a decrease in BER Q factor increasing. Furthermore, the Q value is the defined quality of the received information signal, therefore, it is clear that with an increase in the number of channels and attenuation dB/km Q factor decreases. Moreover, it also has been remarked that OQPSK modulated system has a higher value of Q in clear sky, haze and light rain climate conditions among other modulated systems. It has been concluded that the OQPSK performed better as compared to other modulated systems.

Figure 5 (a), (b) & (c) comparison of eye diagrams for different modulation formats at 2000 meters under a clear sky, haze and light rain respectively. The eye diagrams are used for measuring intersymbol interference (ISI) which leads to describing the distortion in the received signal. Furthermore, the wide opening of an eye has less ISI, on the other hand, a less wide opening eye has more ISI thus; more distortion in the received signal. Apart from this, Soliton is also performed close to the OQPSK system but not as well in light rain. It has been observed that only OQPSK modulated system has a wide opening eye in all three climate conditions clear sky, haze and light rain climate conditions, therefore OQPSK modulated system has shown robustness and optimized performance as compared to others.

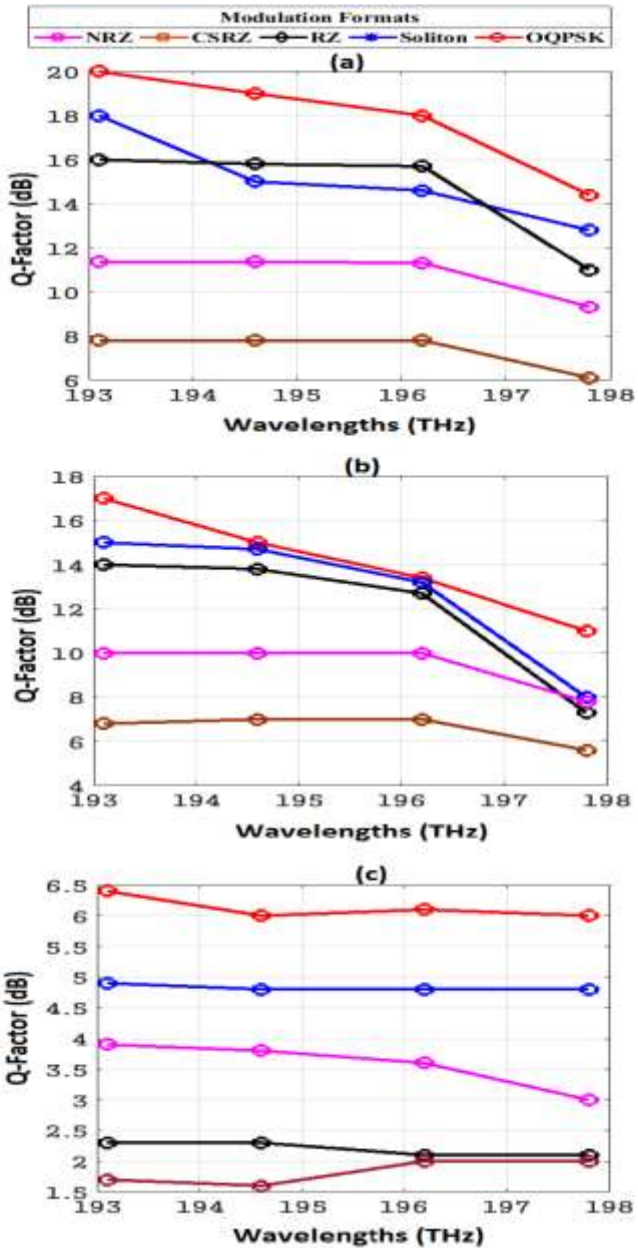


Fig. 4. Q−Factor comparison of diverse modulation formats (a) clear sky (b) haze (c) light rain

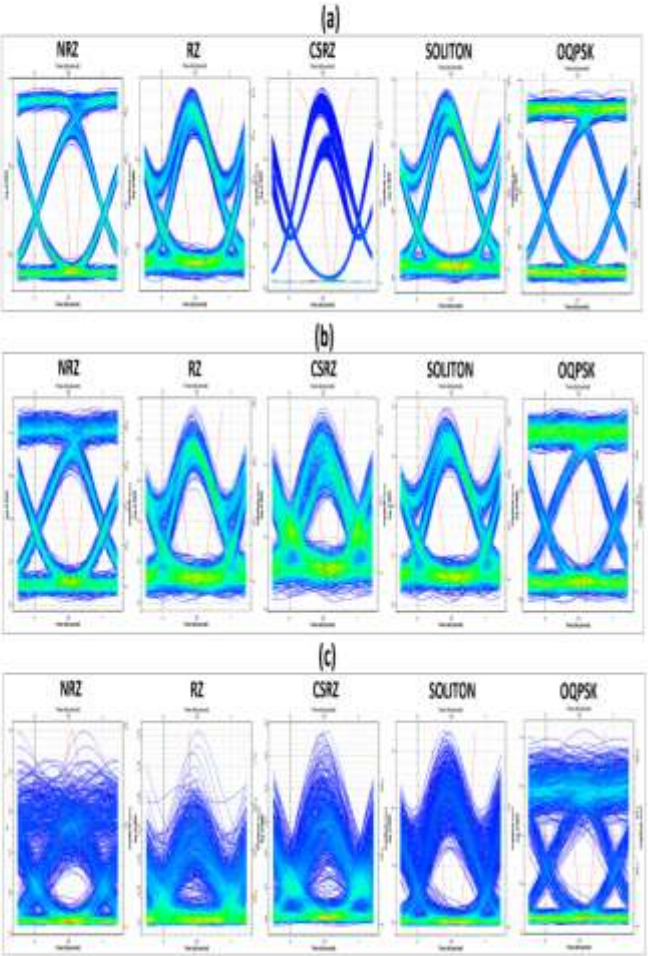


Fig. 5. Comparison of eyes opening at 197.8 THz (a) clear sky (b) haze (c) light rain

Figure 6 (a), (b) & (c) reveals a comparison of SNR on different values of link ranges under a clear sky, haze and light rain respectively. The SNR value of the received signal is a very imperative parameter for analyzing the overall performance of the system as the decreases in received signal power cause a decline in SNR value thus; the resulting increase in BER of the received information signal [12]. From the results presented in Figure 6 (a) the value of SNR in clear sky reduces from [56, 46] dB, [50, 41] dB and [44, 35] dB for channel 1, channel 32 and channel 48 respectively.

Similarly from the results presented in Figure 6 (b) for haze climate conditions the SNR values are decreased from [57, 45] dB, [51, 39] dB and [42, 30] dB for channel 1, channel 32 and channel 48 respectively. Likewise from the results presented in Figure 6 (c) for light rain conditions, SNR rates declined from [54, 39] dB, [47, 33] dB and [40, 25] dB for channel 1, channel 32 and channel 48 respectively. The link distance is varied from 500 meters to 2000 meters in a clear sky, haze and light rain. It has been observed that the SNR value is decreasing with an increase in the FSO link range thus; the proposed system is shown the acceptable performance of SNR ≥ 25 dB for all weather conditions.

Figure 7 (a), (b) and (c) present a comparison of received signal power on different values of FSO link ranges under a clear sky, haze and light rain respectively. From the results shown in Figure 7 (a) the values of received power in the clear sky are decreased from [−42, −52] dBm, [−49, −57] dBm and [−56, −66] for channel 1, channel 32 and channel 48 respectively.

Alike from the results presented in Figure 7 (b) the rates of received power in haze weather are deteriorating from [−42, −54] dBm, [−47, −59] dBm and [−59, −71] for channel 1, channel 32 and channel 48 respectively. Equivalently from the outcomes presented in Figure 7 (c) the received power amount in light rain declined from [−45, −61] dBm, [−59, −74] dBm and [−69, −85] dBm for channel 1, channel 32 and channel 48 respectively. The visibility range is varied from 500 meters to 2000 meters in all weather conditions. Hence, the proposed system has shown acceptable performance with received power ≥ −60 dBm in all weather conditions.

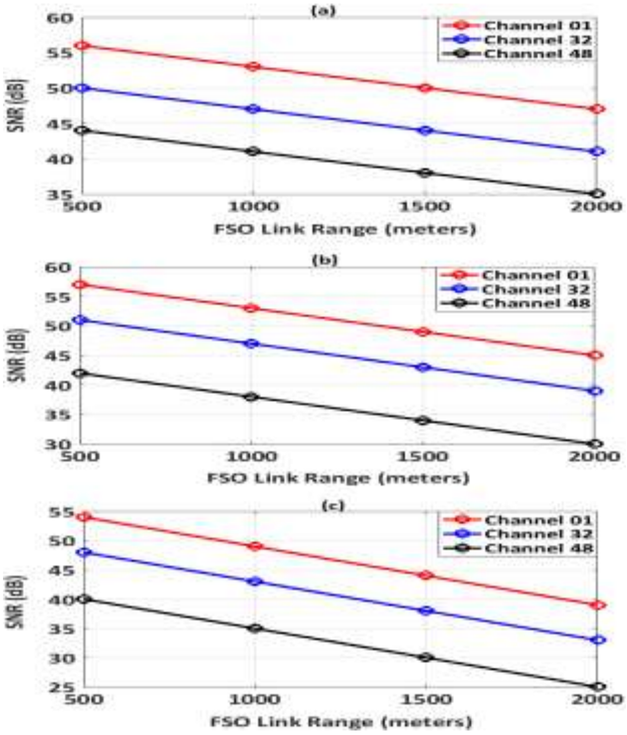


Fig. 6. Comparison of SNR vs. FSO link distance (a) clear sky (b) haze (c) light rain

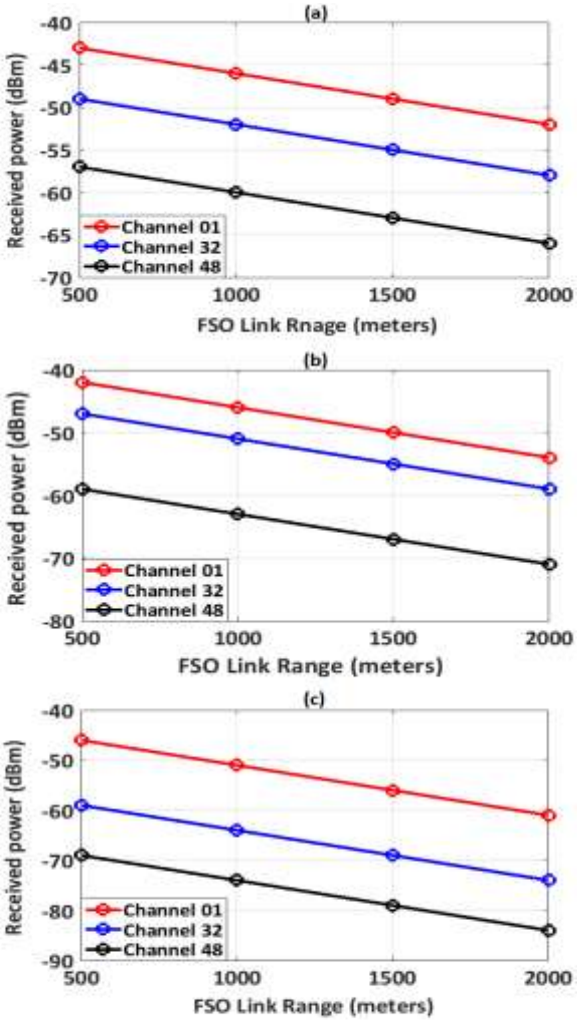


Fig. 7. Comparison of received power vs. FSO link distance (a) clear sky (b) haze (c) light rain

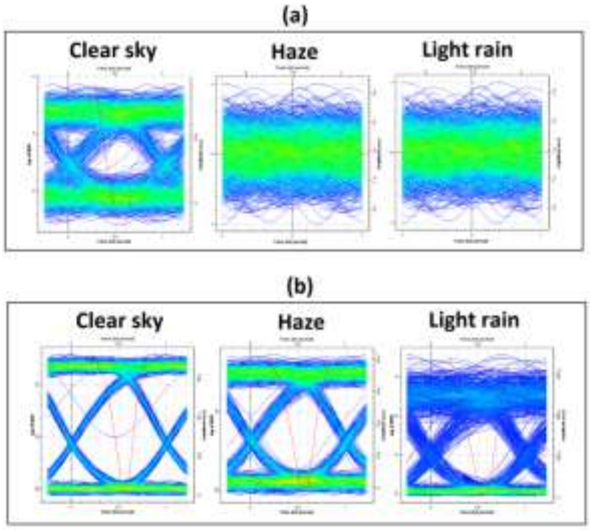


Fig. 8. Eye−opening comparisons (a) without EDFA (b) with EDFA

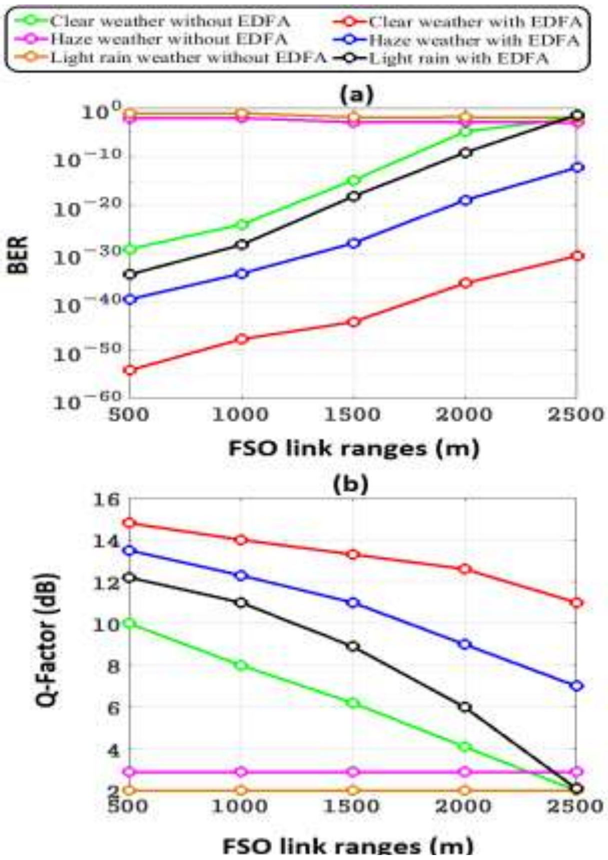


Fig. 9. Shows the effect of EDFA under diverse weather (a) BER vs. FSO link ranges (b) Q−Factor vs. FSO link ranges

Figure 8 (a) and (b) present eye diagrams comparison under a clear sky, haze and light rain at 2000 meters including BER values without EDFA and with EDFA respectively. The more wide eyes opening are cleared that EDFA significantly vanished the ISI effect as well as distortion in the received informative signal.

Figure 9 (a) demonstrates a comparison of BER rates concerning different values of link ranges with and without using EDFA under a clear sky, haze and light rain weather conditions on channel 48 by using OQPSK modulation. The BER values at the 500 meters link range without EDFA are observed at 10^{-30}, 10^{-2} and 10^{-2} similarly for EDFA 10^{-55}, 10^{-40} and 10^{-30} under a clear sky, haze and light rain respectively. Likewise, the BER values at the 2000 meter visibility range without EDFA are observed at 10^{-5}, 10^{-3} and 10^{-2} like with EDFA 10^{-40}, 10^{-19} and 10^{-10} under a clear sky, haze and light rain respectively.

Figure 9(b) shows a comparison of Q values on diverse values of the FSO link range with and without EDFA under a clear sky, haze and light rain at channel 48 with the OQPSK modulated system. The Q values at the 500−meter link range without EDFA are remarked (10, 3 and 2) dB, similarly with

EDFA (14.8, 13.5 and 12.2) dB under a clear sky, haze and light rain respectively.

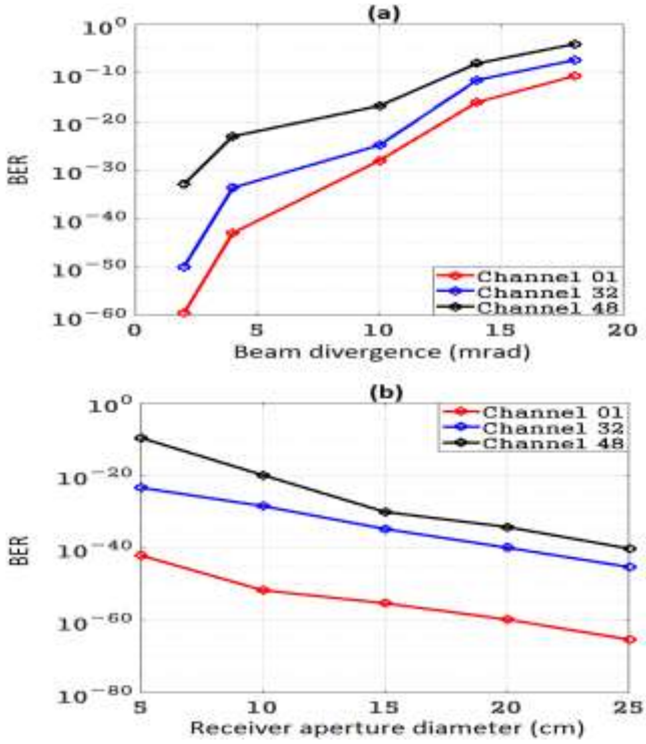


Fig. 10. (a) BER vs. beam divergence for a clear sky (b) BER vs. receiver aperture diameter for a clear sky

Moreover, the Q values at the 2000 meter FSO visibility range without EDFA are perceived (3, 2 and 2) dB, like with EDFA (12.6, 9 and 6) dB in a clear sky, haze and light rain respectively. It has been concluded that with an increase in the FSO link range BER is also increasing and the quality of the received signal is degrading. Apart from this, it also has been observed that EDFA significantly enhance the BER as well as improves the quality of the received information signal.

From the results presented in Figure 10 (a) the BER values are observed at 5 mrad as 10^{-60}, 10^{-50} and 10^{-34} for channels 1, 32 and 48 similarly the BER values at 20 mrad are remarked as 10^{-15}, 10^{-12} and 10^{-10} for similar channels respectively. It has been clear that with an increase in values of beam divergence of the laser source the BER of the informative signal is also increasing. Moreover, from the results presented in

Figure 10 (b) the BER rates at 5 cm receiver aperture diameter are observed as 10^{-48}, 10^{-28} and 10^{-10} similarly the BER values at 25 cm are perceived as 10^{-65}, 10^{-45} and 10^{-40} for channels 1, 32 and 48 respectively. Therefore, it has been observed that with an increase in the diameter of the receiver aperture the BER of the received information signal is decreasing

V. CONCLUSION

In this research DWDM based on 48 channels, the FSO system is simulated and investigated at 2000 meters FSO link range under a clear sky, haze and light rain weather conditions. Furthermore, this proposed work consists comparison of different modulation techniques and their performances have been evaluated on the bases of BER, Q−Factor and eye diagrams. It has been concluded that OQPSK is an optimized modulated system for the proposed designed system and has shown robust performance in all weather conditions among other modulated systems. Moreover, it has been observed that EDFA significantly reduced the effect of atmospheric turbulences and successfully enhanced the BER of received information signal at 2000 meters FSO link distance. In addition, it is also has been perceived that with an increase in FSO link range and number of channels BER is also surging simultaneously. Additionally, this research has shown acceptable performance with SNR ≥ 25 dB and received power ≥ −60 dBm in all weather conditions. Thus the proposed system is providing an effective solution for increasing the demand for channel capacity and spectrum.

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