Performance Analysis of Hybrid PDM-OFDM Technique for Free Space Optical Communication System under adverse weather conditions

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Abstract**—** Free Space Optical (FSO) communication is an optical communication technology in which optical data transmitted wirelessly from one place to another. Some of its main advantages are high security, faster installation, license free spectrum. The performance of the FSO system is affected by the atmospheric conditions like haze, fog and snow. To reduce the effects of atmospheric disturbance Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) with dual polarization, is proposed. A novel design for FSO communication system is considered. The proposed model is designed by hybridizing PDM and OFDM and its performance is analyzed under different atmospheric turbulences such as very clear weather, daily weather, fog and rain weather conditions. The proposed design exhibits an improved performance with SNR values of 55.64dB and 48.27dB at 3km in clear and cloudy skies respectively. The cardinality of the system is increased by utilizing dual polarization OFDM technique with 6dB penalty of SNR at 3km.PDM technique is used to boost the capacity and also enhances the spectral efficiency. OFDM modulation reduces the multipath fading occurred during the FSO transmission. The measured and simulated results confirm the benefits of the proposed design. The proposed system can also work as a reference for the FSO application even in bad atmospheric conditions.

Keywords— Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM), Free Space Optics (FSO) and Polarization Division Multiplexing (PDM).

I. INTRODUCTION

Free Space Optics (FSO) is an Optical communication technology that uses the propagation of light in a free space to transmit data between two points. Data rates comparable to optical fiber transmission can be carried by Free Space Optics (FSO) systems with very low error rates, while the extremely narrow laser beam widths ensure that there is almost no practical limit to the number of separate Free Space Optics (FSO) links that can be installed in a given location. The various characteristics of these optical wireless systems also provide better security against wiretapping with the help of point to point communication. The transmission losses are very less compared to baseband or RF technologies. Free Space Optics (FSO) is an Optical communication Technology that uses the propagation of light in a free space to transmit data between two points. The increasing demand for high bandwidth in communication networks is persistent. Free-space optics (FSO) technology makes it possible to obtain the wireless optical communication with high data rate. FSO technology reduces the difficulty while laying optical fibers and has the following advantages: flexible network, better speed than broadband, easy installation, very low initial investment, straight forward deployment system, requires no spectrum license or frequency coordination between users, secure system and no security system upgradation is needed. Its practical applications are terrestrial and outer space communications. Some of its practical application is Outdoor wireless access, Storage Area Network (SAN), Last-mile access, Enterprise connectivity, Fiber backup, Metro-network extensions, Backhaul, Service acceleration, Bridging WAN Access, Point-to-point and point-to-multipoint communication, Military access. The energy beams are collimated and are sent through clear air or space from the source to the destination, rather than guided through an optical fiber. Collimation can be done with lenses if the energy source does not produce a sufficiently parallel beam to travel the required distance. FSO systems can function over distances of several kilometers. It is theoretically possible as long as there is a clear line of sight between the source and the destination, communication. Strategically positioned mirrors can be used to reflect the energy, even if there is no direct line of sight. The beams can pass through glass windows with less or no attenuation. FSO systems can be a good solution for some broadband networking needs, there are some limitations such as physical obstruction, scintillations, geometric losses, absorption, atmospheric turbulence, atmospheric attenuation, scattering. Most significant demerit of this technology is the fact that rain, dust, snow, fog, or smog can block the transmission path and shut down the network.

This paper has been organized as a detailed description of the work, in the order of their chronological significance. 1 gives the detail description of overview, free space optics, orthogonal frequency division multiplexing and polarization division multiplexing. Section 2 contains the literature review done regarding the work. Section 3 explains about the method proposed for the system. Section 4 includes the results. Section 5 includes conclusion and future work.

II. RELATED WORKS

Some of the works related to proposed work is discussed below.

AvneetKaur et al., [1] proposed TWDM-OFDM-PON scheme in which OFDM modulation is used for downstream at a rate of 25Gbps and then re-modulation is done for upstream at a rate of 10Gbps using an Electro Absorption Modulator(EAM). Swaminathan and Raajan [2] proposed Orthogonal Frequency Division Multiplexing as multi carrier modulating technique which involves many subcarriers to carry user information from source to destination.

Zhaocheng Wang et al., [3] proposed orthogonal frequency division multiplexing in VLC systems, because of its high data rate and robustness to inter symbol interference. Performance comparisons are conducted for optical OFDM schemes such as DC-biased optical OFDM (DCO-OFDM), asymmetrically clipped optical OFDM (ACO-OFDM), pulse amplitude modulated discrete mutitone (PAM-DMT), unipolar OFDM (U-OFDM) and flip OFDM in terms of energy efficiency, spectral efficiency and computational complexity. Sambi et.al, [4] proposed the performance of RF signal through an optical FSO channel using OFDM technique and it is analyzed for different distances.

C. Chen, W. Zhong, X. Li, D. Wu (2014) proposed a FSO communication system enabled with NE-OFDM (Non-equalization OFDM) technology by considering modified Rician distribution channel model and MDPSK (M-ary differential phase shift keying) method which reduced the system design complexity but did not deal with importance of coherent detection [5]. Chaudhary et al., (2014) proposed Free space optics technology mainly offers high data transmission when compared to RF technology. The work mainly focuses on the performance analyses of an FSO system with OFDM and FSO.A data stream is transmitted using 4-QAM sequence through a FSO channel. The results show that under clear weather conditions we can achieve better results up to a distance of 185km but under fog weather condition we can get better results up to a distance of 2.5km [6].

V. Sharma, Sushank (2014) proposed CO-OFDM technique and its performance is compared with of ODSB (Optical Double Sideband Modulation) and OSSB (Optical Single Sideband Modulation) and it is concluded that coherent detection can decrease the link attenuation effect by 1 dB with obtaining the similar BER performance [7].

Veena Gopinath and Sudhi Sudharman (2014) concluded that OFDM is the best solution for inter symbol interference which is due to a dispersive channel and OFDM can also be used in new and emerging broadband communication systems both in wired and wireless. The main disadvantage of OFDM is its high peak to average power ratio (PAPR) and this PAPR can be eliminated by a technique called pilot assisted OOFDM (PA-OOFDM) [8].Vishal Sharma and Gurimandeep Kaur(2013) proposed Free Space Optics (FSO) for a variety of climate state of affairs that bound the FSO range. FSO is a building block for wide area space networks, high speed data services for small satellite terminals and serving as a backbone network for high speed trunking. FSO is extremely expensive in replacing the current wireless networks[11].

A. Vavoulas et al.,(2012) proposed that FSO link is adversely affected due to unpredictable bad meteorological conditions such as rain, fog, haze and drizzle [12].Henniger and Wilfert (2010) proposed that among the various technologies for the transmission of data, Free Space Optical (FSO) communication is a line of sight optical communication system that transmits the modulated optical data wirelessly and provides high bandwidth transmission link for next generation access networks. The gains and losses along the path between the transmitter and receiver through the medium are introduced [19].

III. PROPOSED METHODOLOGY

The proposed system is based on hybridization of PDM and OFDM. Actually atmospheric turbulence is one of the main challenge in FSO systems, which causes amplitude variations and phase fluctuations during the propagation of optical beam. Under these situations, optical PDM is a promising technology to improve the performance.

The basic concept of optical PDM is transmitting the modulated optical signals of the same optical wavelength independently over orthogonal polarizations states. The states of polarization are the most stable characteristic of propagating optical signal and are determined by the pattern traced out by the transmitted light's electric-field vector in a fixed plane. As distinct modulated optical signal is transmitted through the orthogonal States of Polarization (SOP) of the same light beam so it provides the enhanced transmission capability. But the main issue of PDM FSO system is that it is not able to handle multipath channel fading of the system.

To overcome this problem OFDM can be hybridized with PDM which have the ability to beat multipath channel fading of the signal. OFDM divides wide band signal into several orthogonal narrow band subcarriers and transmits it in parallel. Each subcarrier experiences frequency flat fading caused by multipath atmospheric channel, hence in OFDM, there is no inter symbol interference in time domain, and has capability to reduce the effect of fading with lower computational complexity. OFDM technique can also protect the signal from random fading effects which are induced due to atmospheric turbulences.

The block diagram of proposed hybrid PDM/OFDM FSO system is shown in Figure 1 where PDM technique will boost the user capacity and enhances the spectral efficiency and OFDM modulation reduces the multipath fading occurred during the FSO transmission. The proposed system comprises of polarization splitter that splits the optical signal of laser source into its two polarized orthogonal signals. This signal is transmitted after amplification through atmospheric channel. At the receiver, two orthogonal signals are separated and demodulated.

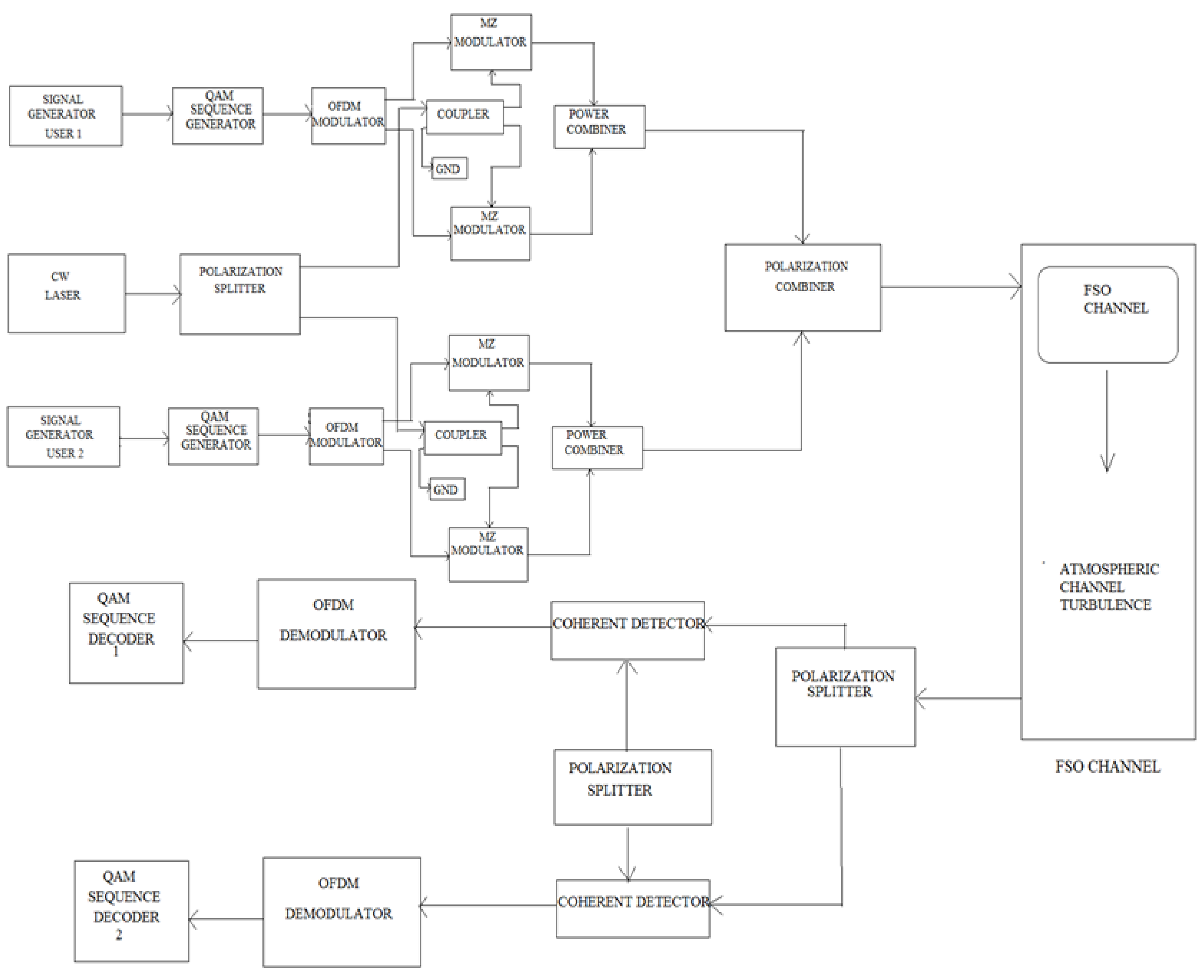


Figure 1. Block diagram of PDM-OFDM FSO system

The hybrid PDM/OFDM FSO optical system sketched in Figure 1 has been simulated in Optisystem 16.0. Main blocks in this system are Polarization Splitter, OFDM transmitter, RF to Optical Converter, Polarisation Combiner, FSO link, Optical to RF convertor, OFDM Receiver. It demonstrates a coherent 512-subcarrier 4-QAM OFDM system. On the transmission side, an inverse fast Fourier transform (IFFT) used to achieve modulation and multiplexing digital in nature. The subcarrier frequencies are mathematically orthogonal over one OFDM symbol period.

CW Laser is used to generate the carrier signal. Two Mach-Zehnder Modulators and a power combiner are used to up-convert the RF data to the optical domain. After converting a signal from Electrical to optical, the optical signals of the two users are combined using a polarization combiner and then it is transmitted through the free space optical link and becomes degraded due to fading and weather conditions.

At the receiver end, the optical signal is splitted by a polarization splitter which is used to split the optical signal into two orthogonal polarization states. A coherent receiver with a local oscillator, used to down-convert the data to the RF domain and finally, demodulate and sent the resultant signal to the detector.

Coherent receiver consists of a local oscillator, photodiode, optical coupler and a polarization controller. The incoming optical signal and local oscillator are combined in an optical coupler. To match the polarization state between the input optical signal and local oscillator, a polarization controller is used. This polarization controller can be placed either at the local oscillator or at the incoming optical signal.

Table 1 Different attenuation constants for different weather conditions

WEATHER CONDITIONS	ATTENUATION CONSTANTS
Clear weather	0.5dB/km
Daily weather	5 dB/km
Fog weather	10 dB/km
Rain weather	15 dB/km

In the proposed simulation arrangement, the light source is a CW laser diode with an emission wavelength of around 1550nm and power of 10dBm; a polarization splitter is used to splits the optical signal of laser source into its two polarized orthogonal signals i.e (in horizontal and vertical states). After combining these two polarization states by polarization combiner, the resultant optical signal is allowed to pass through an FSO channel with attenuation values according to the weather condition in which it has to be operated.

Different weather conditions are achieved by setting different attenuation constants. For clear visibility, the attenuation value lies somewhere around 0.2–0.5dB, while for Fog the values measured to be 10dB. The Rain being the main disaster has values ranging from 15dB to 35dB. Table 1 shows the corresponding attenuation constants values for different weather conditions.

IV. RESULTS AND DISCUSSION

The proposed work is carried out by optisystem software. The results are shown below.

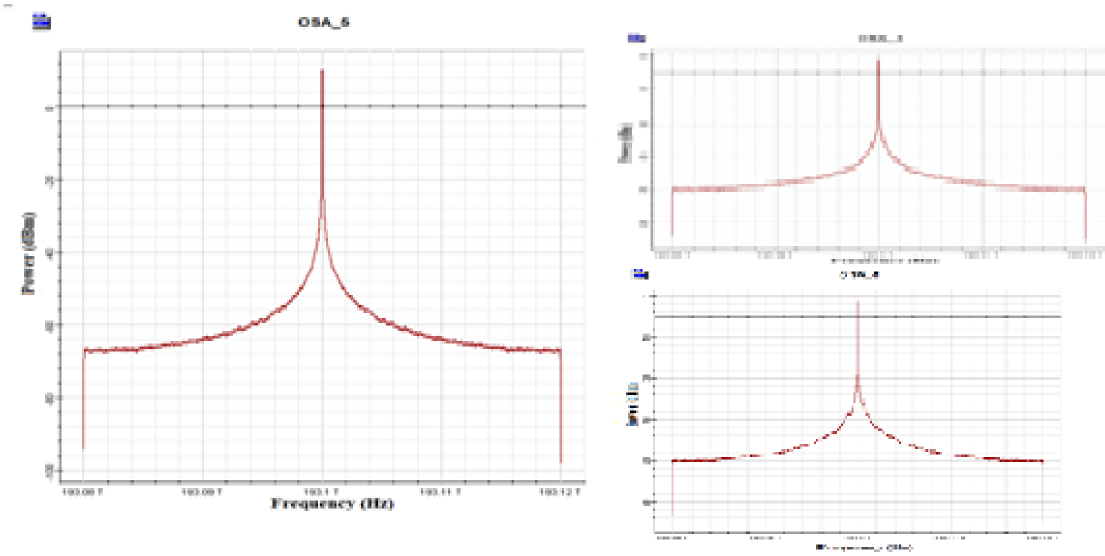


Figure 2 Laser light and orthogonally separated signals

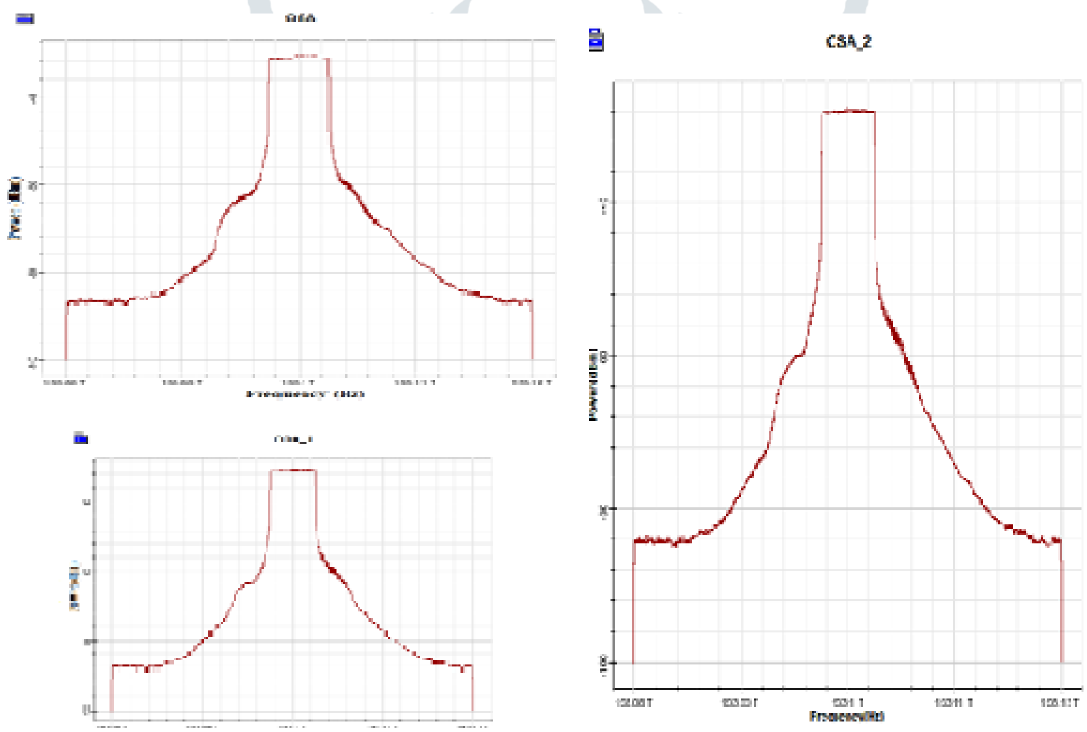


Figure 3 Polarization division multiplexed OFDM signal generation of user 1 and user 2.

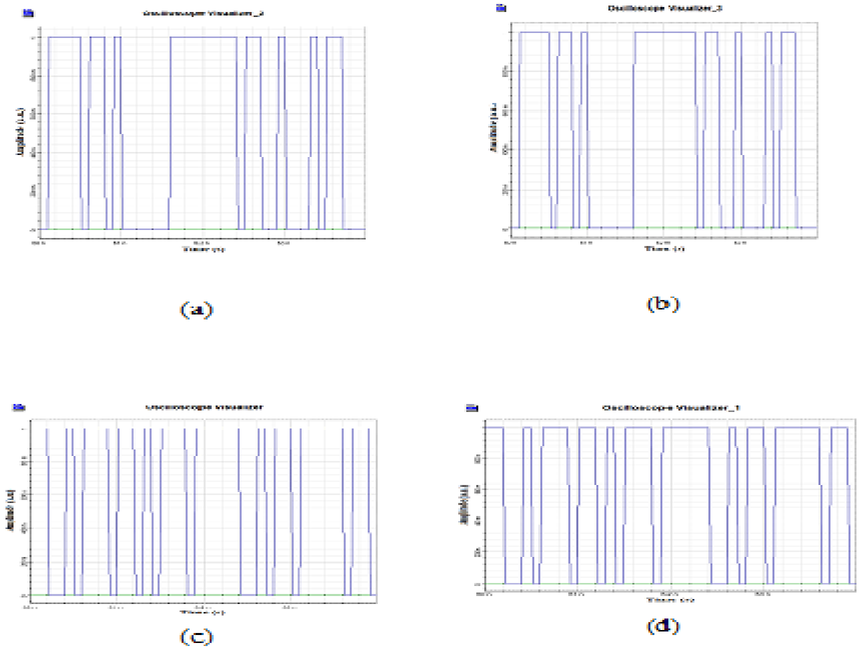


Figure 4 Propagation of Signals in PDM-OFDM FSO system (Visualizer outputs)
(a) At transmitter end of user 1 (b) At receiver end of user 1
(c) At transmitter end of user 2 (d) At receiver end of user2

The following figures show the constellation plot at various atmospheric conditions for OFDM FSO system. The various atmospheric conditions considered in this work are Very Clear Weather Condition, Daily Weather Condition, Fog Weather Condition and Rain Weather Condition

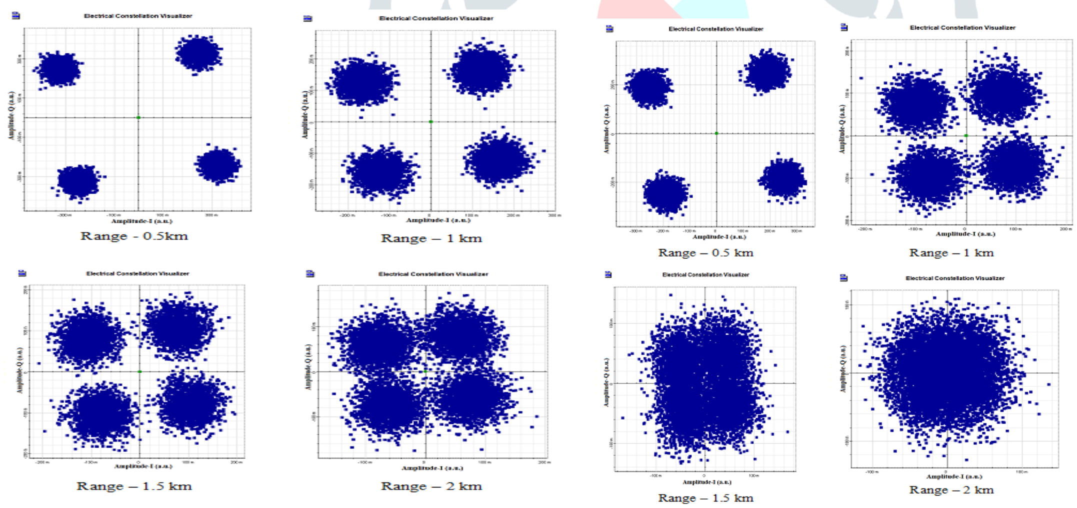


Figure 5 Constellation plot at Very Clear weather condition and daily weather condition (OFDM)

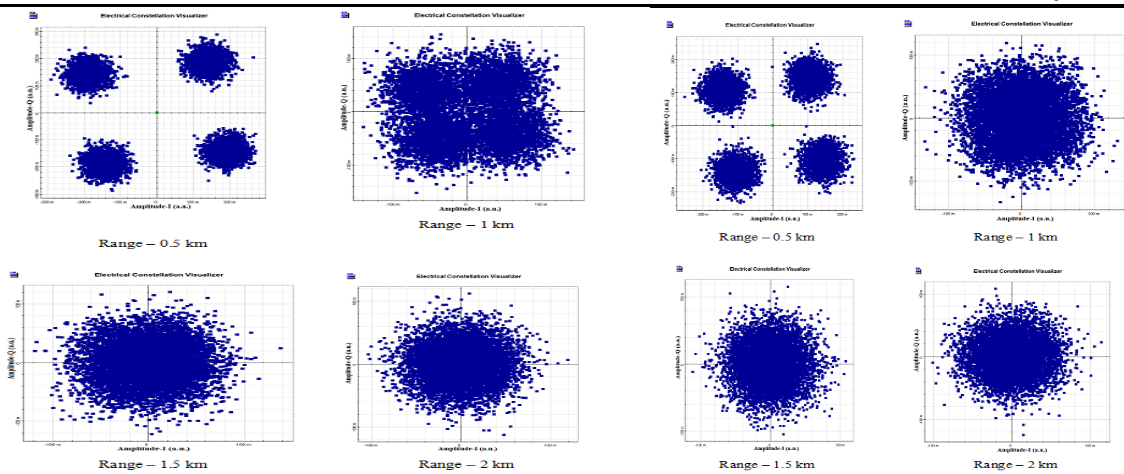


Figure 6 Constellation plot at Fog and Rain weather condition (OFDM)

From the above figures, it is observed that as distances increases, the signal degradation also increases. Fading effect is within acceptable limits till 1km and as the distance increases it becomes dominant. Using OFDM coherent detection in free space optics, we can recover the signals at 0.5 km and 1km. These signals are quite good compared to the higher distances where fading is high.

The following figures show the constellation plot at various atmospheric conditions for PDM-OFDM FSO system.

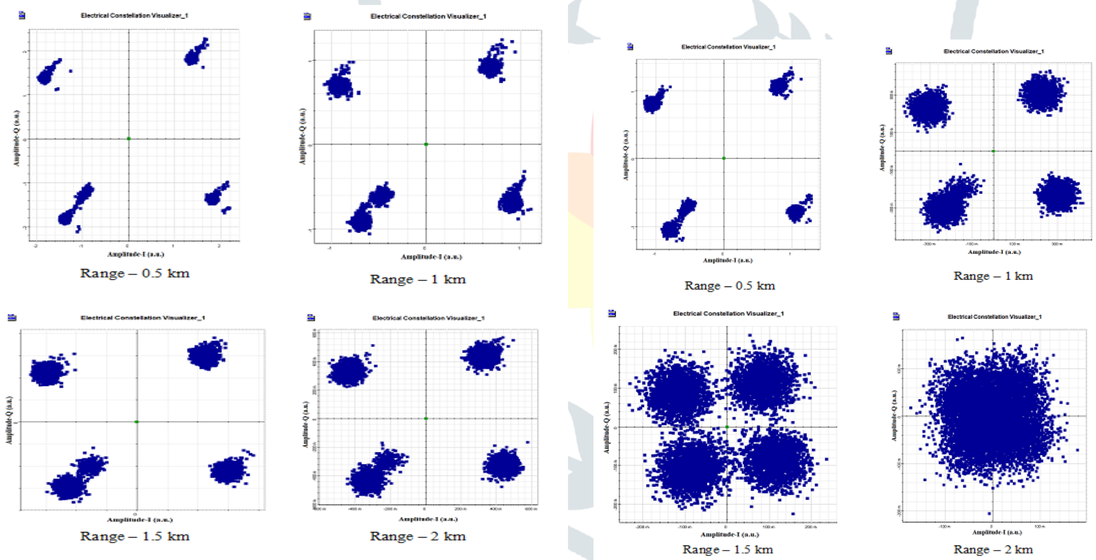


Figure 7 Constellation plot at Very clear and Fog weather condition (PDM-OFDM)

From the above figures, it is observed that the signal degradation increases with distance. Fading effect is within acceptable limits till 1.5km and as the distance increases it becomes dominant. Using PDM-OFDM coherent detection in free space optics, we can recover the signals at 0.5 km, 1 km and 1.5 km.The SNR vs. Range graph for OFDM and the SNR Vs Range graph for hybrid PDM-OFDM FSO systems is shown in figure 8.

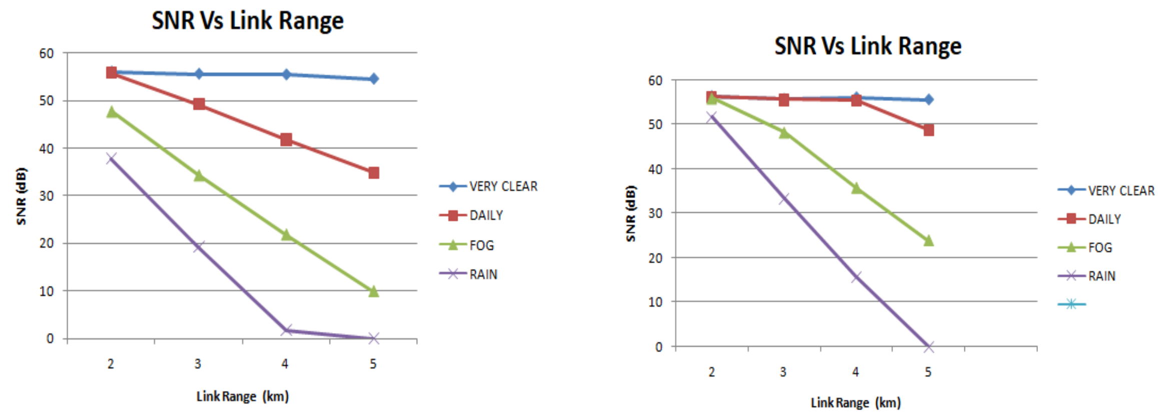


Figure 8 SNR Vs Link Range for OFDM and PDM-OFDM FSO system

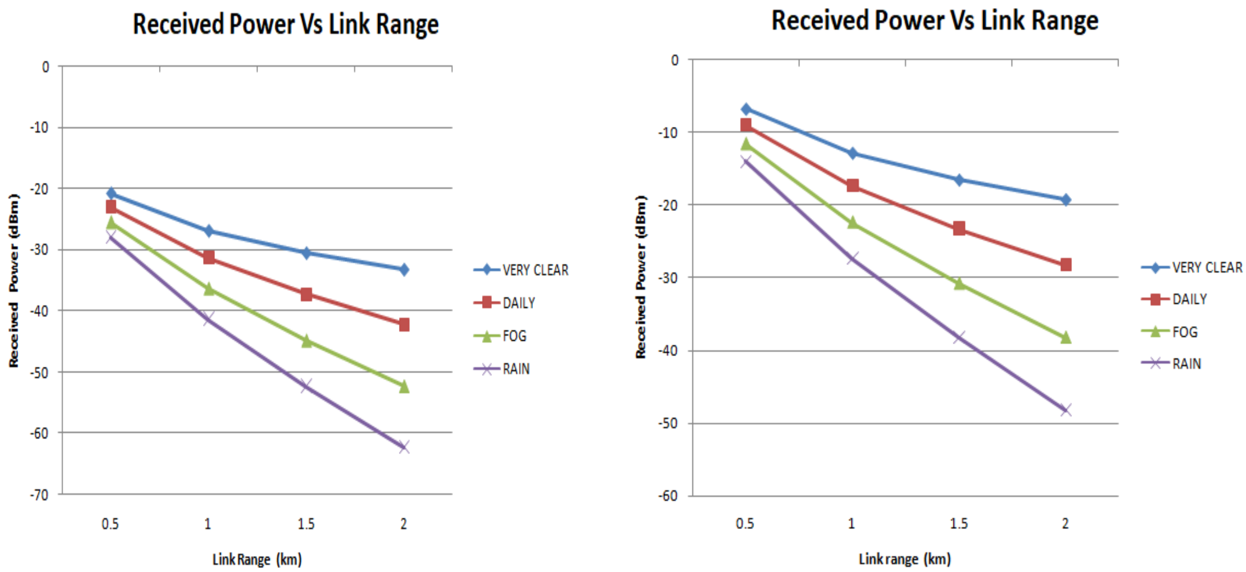
Table 2 SNR values for various link ranges at different weather conditions for OFDM FSO system

LINK RANGE	2 (km)	3 (km)	4 (km)	5 (km)
VERY CLEAR WEATHER CONDITION	56.03 dB	55.59 dB	55.44 dB	54.53 dB
DAILY WEATHER CONDITION	55.76 dB	49.26 dB	41.79 dB	34.87 dB
FOG WEATHER CONDITION	47.76 dB	34.29 dB	21.80 dB	9.87 dB
RAIN WEATHER CONDITION	37.78 dB	19.27 dB	1.78 dB	0 dB

Table 2 gives the SNR values for various link ranges at different weather conditions for OFDM FSO system. Table 3 gives the SNR values for various link ranges at different weather conditions for PDM-OFDM FSO system. The SNR values of the proposed system are 55.64dB and 48.27dB at 3km in clear and cloudy skies respectively for PDM-OFDM FSO system whereas it is 49.26dB and 34.29dB at 3km in clear and cloudy skies respectively for OFDM FSO system. This is because the concentration and size of the fog particles are higher as compared to the clear weather but still it shows a good performance for hybrid PDM-OFDM FSO system. The cardinality of the system is increased by utilizing PDM OFDM technique with 6dB penalty of SNR at 3km.

Table 3 SNR values for various link ranges at different weather conditions for PDM - OFDM FSO system

LINK RANGE	2 (km)	3 (km)	4 (km)	5 (km)
VERY CLEAR WEATHER CONDITION	56.38 dB	56.27 dB	56.12 dB	55.61 dB
DAILY WEATHER CONDITION	56.29 dB	55.64 dB	55.59 dB	48.86 dB
FOG WEATHER CONDITION	56.02 dB	48.27 dB	35.79 dB	23.86 dB
RAIN WEATHER CONDITION	51.75 dB	33.27 dB	15.80 dB	0 dB



OFDM PDM-OFDM

Figure 9 Comparison between OFDM and PDM-OFDM technique for FSO systems in terms of Received Optical Power Vs Range

Table 4 gives the Received power values for various link ranges at different weather conditions for OFDM FSO system. Table 5 gives the Received power values for various link ranges at different weather conditions for PDM-OFDM FSO system.

Table 4 Received power values for various link ranges at different weather conditions for OFDM FSO system

LINK RANGE	0.5 (km)	1 (km)	1.5 (km)	2 (km)
VERY CLEAR WEATHER CONDITION	-20.75 dBm	-26.88 dBm	-30.51 dBm	-33.21 dBm
DAILY WEATHER CONDITION	-22.99 dBm	-31.30 dBm	-37.28 dBm	-42.22 dBm
FOG WEATHER CONDITION	-25.50 dBm	-36.30 dBm	-44.76 dBm	-52.22 dBm
RAIN WEATHER CONDITION	-27.99 dBm	-41.31 dBm	-52.27 dBm	-62.22 dBm

Table 5 Received power values for various link ranges at different weather conditions for PDM - OFDM FSO system

LINK RANGE	0.5 (km)	1 (km)	1.5 (km)	2 (km)
VERY CLEAR WEATHER CONDITION	-6.74 dBm	-12.81 dBm	-16.50 dBm	-19.22 dBm
DAILY WEATHER CONDITION	-8.99 dBm	-17.31 dBm	-23.26 dBm	-28.22 dBm
FOG WEATHER CONDITION	-11.49 dBm	-22.30 dBm	-30.76 dBm	-38.20 dBm
RAIN WEATHER CONDITION	-13.98 dBm	-27.30 dBm	-38.26 dBm	-48.22 dBm

V. CONCLUSION

The proposed work illustrates the simulation design of hybrid PDM/OFDM FSO communication system. The results demonstrate that the polarization division multiplexing and OFDM combined can enhance the system quality and shows that the availability of FSO link is decreased that means the concentration and size of the fog particles are higher as compared to the clear weather which corresponds to SNR values of 55.64dB and 48.27dB at 3km in clear and cloudy skies respectively. The cardinality of the system is increased by utilizing dual polarization OFDM technique with 6dB penalty of SNR at 3km. The proposed system can also work as a reference for the FSO application even in bad weather conditions.

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