Performance Analysis of OFDM-ODSB, OFDM-OSSB and OFDM-OVSB FSO Communication System by Employing Spatial Diversity

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Abstract: For the future optical broadband networks, Free Space Optical (FSO) communication system becomes a promising solution. This paper is focused to analyse the performance of Orthogonal Frequency Division Multiplexing (OFDM) FSO communication system using the Optical Double Sideband (ODSB), Optical Single Sideband (OSSB) and Optical Vestigial Sideband (OVSB) modulation techniques by employing the Spatial Diversity that uses multiple Transmitter/Receiver (TX/RX) system. A 10 Gbps data is transmitted by using 4-QAM technique through the free air space under the clear, haze and fog weather conditions. Results shows that by employing the spatial diversity using 8 TX/RX, OFDM-FSO system provides communication up to 292 km with acceptable Signal to Noise Ratio (SNR) under clear weather condition whereas under the fog weather condition, this system prolongs to 3.24 km and also concluded that for long haul free space optical communication, OVSB-OFDM FSO system performs better than OFDM-ODSB and OFDM-OSSB FSO system.

Keywords: Free Space Optics (FSO), Optical Double Sideband (ODSB), Orthogonal Frequency Division Multiplexing (OFDM), Optical Single Sideband (OSSB), Optical Vestigial Sideband (OVSB), Signal to Noise Ratio (SNR), Transmitter/Receiver (TX/RX).

Introduction

FSO is wireless optical communication system that uses the line of sight (LOS) path propagating in a free space to send the data/information between any two desired points. “Free space” refers to the air, vacuum, outer space, wireless or something very much similar. FSO is very similar to optical fiber communication technology in which the data is transmitted by modulated laser light [1]. In an optical fiber communication system, light pulses are transmitted within the glass fiber, but in FSO system these are transmitted in a narrow beam through the free air space. As light travels through the air is faster than through glass, so that FSO is classify as optical communication at the speed of light [2]. FSO technology is used where physical connection is not a feasible solution due to the high cost, high required bandwidth or other considerations for the today’s converged network requirements. FSO technology enables the optical transmission up to range of hundreds Gbps of data, video and voice communication [3]. The FSO technology is basically based on LOS that provides a full duplex communication and uses optical radiation as a carrier signal through an unguided channel. The unguided channel of FSO communication system is an atmospheric channel. Atmospheric channel is the mixture of haze, fog, smoke, rain through which the signal is passing. FSO communication technology is capable of higher data transmission up to the range of 100 Gbps data rate over a distance of 1-2 km [4]. The main problem of FSO communication system is the atmospheric attenuation which is caused by the absorption and scattering processes. Absorption reduces the power density of the FSO beam whereas the scattering reduces the intensity of beam for the longer distances. The effect of fog attenuation is much more than rain, haze and snow that influence the reliability and range of FSO link [5].

In case of wireless optical communication, OFDM reduces the effect of multipath fading that is caused by the atmospheric turbulences in FSO communication as data is divided over a number of orthogonal carriers that are spaced suitably at narrow frequencies with the overlapping bands. Fast Fourier transform (FFT) used in OFDM gives orthogonality to the subcarriers, and preventing the demodulators from seeing the other frequencies than their own [6].

Diversity provides high quality of services by transmitting the number of copies of the same signal. It gives reliability to the FSO communication. Due to the availability of multiple antennas at transmitter or receiver side, spatial diversity has the potential of giving diversity. The transmitter and receiver side of FSO system contains multiple laser beams which provide the diversity. Multiple laser beams from the transmitter side are transmitting to different paths. After propagation through the channel, beams get attenuated due to the atmospheric disturbances. The attenuation faced by each path will be different and all the multiple copies of the transmitted signals are then received at the receiver side [7].

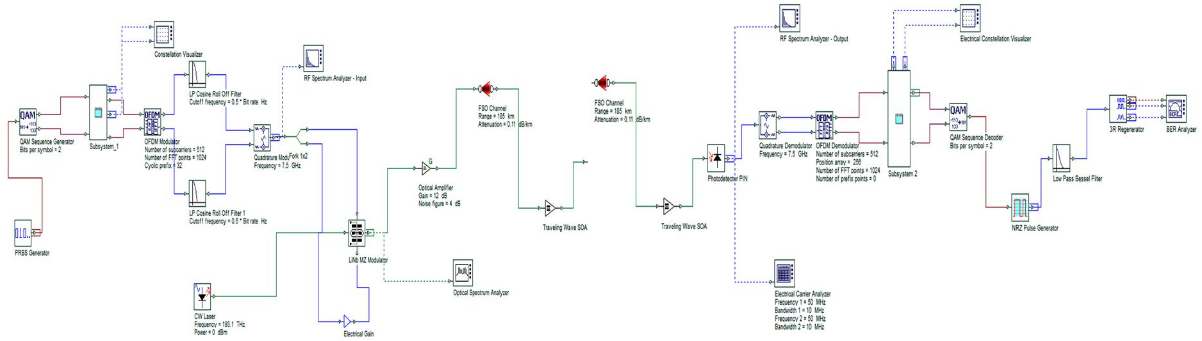
To increase the spectrum efficiency, there are different modulation techniques such as optical Single Side Band (OSSB) and optical Vestigial Sideband (OVSB). Optical SSB is a spectral efficient modulation technique in which one of the sideband of optical double sideband (ODSB) spectrum is fully suppressed while maintaining the other sideband [8]. On the other hand, in OVSB modulation technique, one of the sideband is partially suppressed. The improved spectral efficiency of these modulation formats compared to the conventional binary format such as ODSB makes them more attenuation immune. In double sideband system the information is carried in the two sidebands which are mirror image of each other and the transmission in which information is in only one sideband, then it is called single sideband transmission [9].

In previous research work, 10 Gbps data is transmitted using 4-QAM sequence through free air space under different atmospheric conditions. Results show that with an integration of SOA, OFDM-FSO covers the maximum achievable distance with acceptable SNR to 185 km under clear weather whereas under fog weather condition, the maximum distance achieved is 2.5 km [10].

System Description

Simulation Setup of OFDM-ODSB-FSO System

The OFDM-ODSB-FSO system is modeled using OptiSystem. PRBS produces bits at the rate of 10 Gbps and output of PRBS is send to QAM sequence encoder that maps the bits to a particular symbols. The QAM data signal is modulated by an OFDM modulator using 512 subcarriers, 1024 FFT and 32 cyclic prefix code before being modulated at 7.5 GHz using a QAM modulator. This QAM signal is transmitted over free space by means of a continuous wave (CW) laser having a wavelength of 193.1 THz and power of 0 dBm. The FSO network has pre and post amplification in which SOA is integrated for amplification. At the receiver side, the OFDM signals are recovered using a PIN photodetector and given to the QM demodulator and QAM sequence decoder recover the data successfully. A subsystem is used to examine the constellation diagram at OFDM-ODSB-FSO receiver side. The output is obtained from a QAM sequence decoder which maps the symbols into bits and is used to analyse the BER. Fig. 1 shows the simulation setup of (a) OFDM-ODSB-FSO transmitter system and (b) OFDM-ODSB-FSO receiver system.

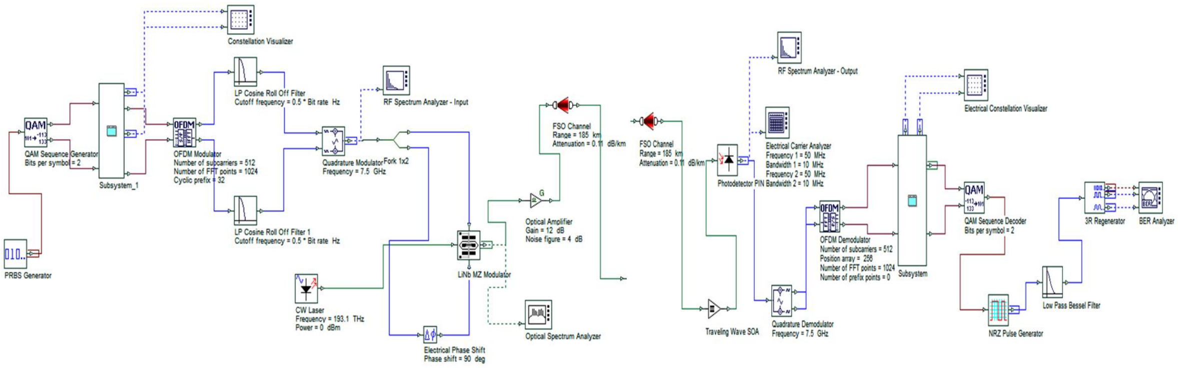


(a) (b)

Fig. 1 (a) OFDM-ODSB-FSO transmitter system and (b) OFDM-ODSB-FSO receiver system

Simulation Setup of OFDM-OSSB-FSO System

Fig. 2 shows the simulation setup of (a) OFDM-OSSB-FSO transmitter system and (b) OFDM-OSSB-FSO receiver system. NRZ pulse generator’s output is given to two arms of lithium niobate MZM modulator. Phase shift of 90 degree is introduced to generate OSSB. CW laser is used as optical carrier source. At transmitting end, a 10 Gbps data is generated by using 4 QAM sequence generator and then OFDM modulated by means of OFDM modulator to generate OFDM data signals which is further QAM modulated at 7.5 GHz modulator frequency. This high rate OFDM data signal is then transmitted over FSO channel by means of OSSB schemes instead of using ODSB scheme as it is prone to fading problem. At the receiver side, the transmitted signals are recovered using PIN photodetector. The receiving end of the FSO system consists of a photodetector and a low pass filter to recover high rate OFDM data successfully.

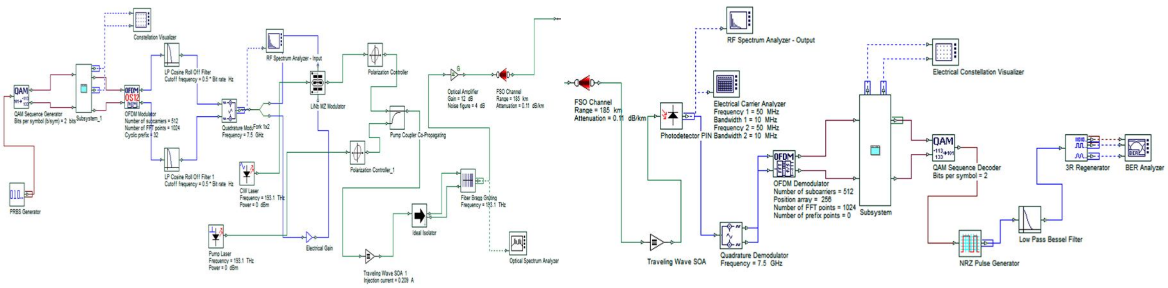


(a) (b)

Fig. 2 (a) OFDM-OSSB-FSO transmitter system and (b) OFDM-OSSB-FSO receiver system

Simulation Setup of OFDM-OVSB-FSO System

As shown in Fig. 3, the generation of OVSB with Machzender modulator, PRSB, CW laser. The coupler couples the two signals coming from pump laser and modulator. So that ODSB data signal is coupled with pump signal. Both the data signals are polarization controlled because of SOA polarization dependence. A fiber Bragg grating (FBG) is utilized after the SOA and act as a notch rejection filter to eliminate the pump, the rejection notch is centered at the pump wavelength. At transmitting end, a 10 Gbps OVSB data is generated by using SOA. At the base station, the OFDM signals are recovered using a PIN photodetector and given to the QM demodulator followed by OFDM demodulator and QAM sequence decoder in order to retrieved the 10 Gbps OVSB data successfully. The output then obtained from a QAM sequence decoder maps the symbols into bits and BER used to analyse the errors.

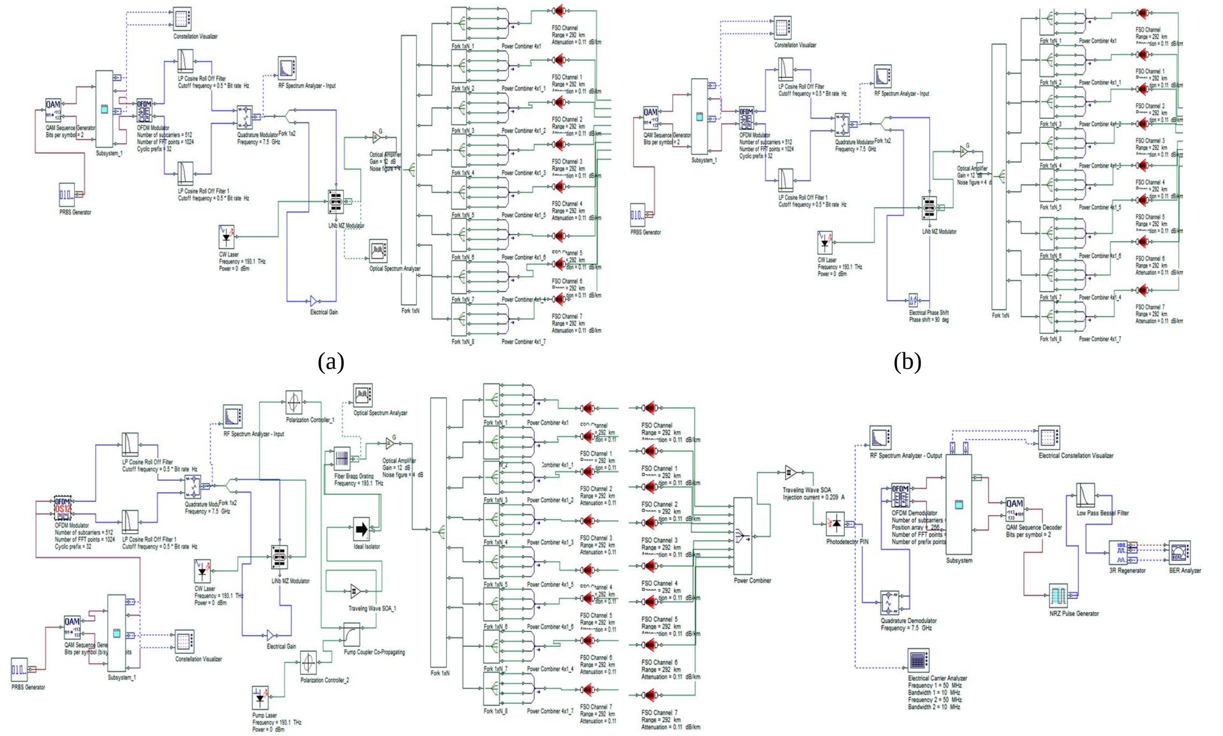


(a) (b)

Fig. 3 (a) OFDM-OVSB-FSO transmitter system and (b) OFDM-OVSB-FSO receiver system

ODSB, OSSB AND OVSB OFDM-FSO Systems employing Spatial Diversity

Spatial diversity provides high quality services by sending several copies of the same signal by using multiple transmitter/receiver (TX/RX) system. Multiple TX/RX system is the proposed architecture that can be used to enhance the FSO link range. Fig. 4 shows the simulation setup of (a) OFDM-ODSB-FSO transmitter system (b) OFDM-OSSB-FSO transmitter system (c) OFDM-OVSB-FSO transmitter system and (d) OFDM-ODSB-FSO receiver system employing spatial diversity. Attenuation for different weather conditions is considered as 0.11dB/km, 4dB/km and 22dB/km for clear, haze and fog weather conditions respectively. From Fig. 4, it is observed that the output of TX is connected to the fork. Fork is a special type of component which can produce multiple laser beams from one laser beam source. Each of the multiple laser beams or signals produced from the fork's output has similar value with the laser beam that is linked to it from previous component. Another set of Forks are also used before transmitting the signal through FSO channel to produce multiple laser beams again in order to improve the strength of the optical signal. Power combiner is used to combine the multiple laser beams coming out from the fork. Next combined output optical signal is transmitted through FSO channel. The multiple transmitter and receiver system for OFDM-ODSB/OSSB/OVSB-FSO is examined from 1 TX/RX to 8 TX/RX by employing Spatial Diversity technique. Finally, signals coming out from 8 FSO channels are combined by another set of power combiner and then combined signal is injected to the optical receiver.



(a) (b)

(c) (d)

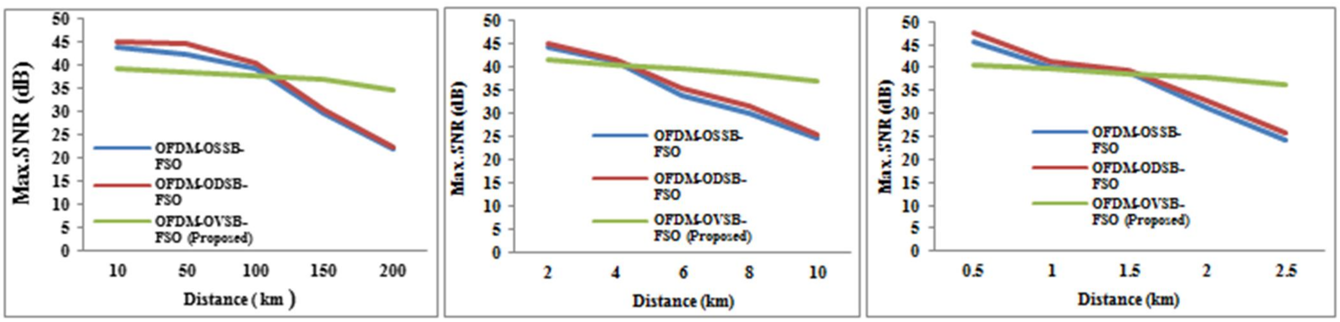
Fig. 4 Simulation setup of (a) OFDM-ODSB-FSO transmitter system (b) OFDM-OSSB-FSO transmitter system (c) OFDM-OVSB-FSO transmitter system and (d) OFDM-ODSB-FSO receiver system employing spatial diversity using 8TX/RX

Results and Discussion

We have evaluated the proposed hybrid FSO system performance using a simulated test-bed, employing OFDM-ODSB, OFDM-OSSB, OFDM-OVSB modulated signals transmitted through FSO link using spatial diversity under different weather conditions such as clear, haze and fog with the data rate of 10 Gbps. The threshold for acceptable operation was set at an acceptable bound of 25 dB on the SNR under clear, haze and fog weather conditions.

Evaluation of SNR with Distance under clear, haze and fog weather condition:

Fig. 5 shows the comparison of SNR vs. Distance under (a) clear, (b) haze and (c) fog weather condition. It is observed that under clear, haze and fog weather condition, there is a 10 dB, 12 dB and 11 dB improvement in SNR value at 185 km, 10 km and 2.5 km respectively by using OVSB modulation scheme which shows that the OFDM-OVSB FSO system is better as it is more attenuation immune for long haul communication than OFDM-ODSB and OFDM-OSSB FSO System.

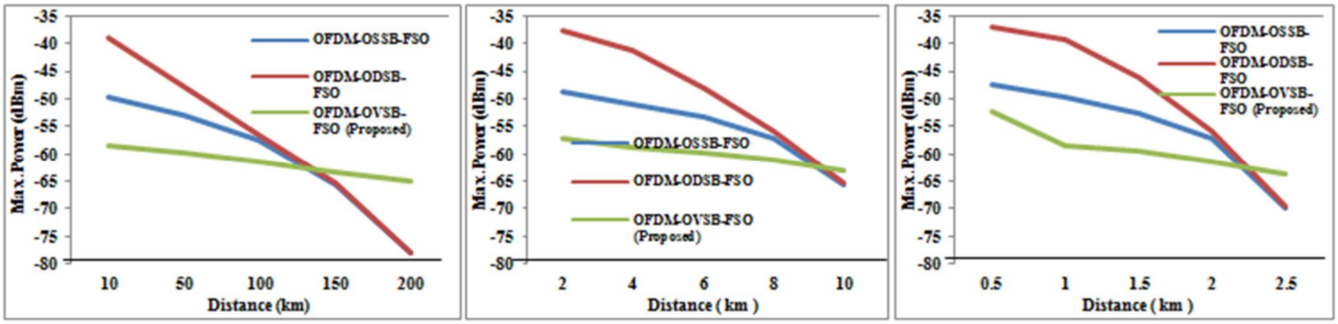


(a) (b) (c)

Fig. 5 Comparison of SNR vs. Distance under (a) clear, (b) haze and (c) fog weather condition respectively using OFDM-ODSB, OFDM-OSSB, OFDM-OVSB techniques

Evaluation of Power Received with Distance under clear, haze and fog weather condition

Fig. 6 shows the comparison of Power vs. Distance under (a) clear, (b) haze and (c) fog weather condition. Under clear, haze and fog weather condition, initially by using ODSB modulation scheme more power is received but at high distances by using OVSB modulation scheme, there is improvement of 9 dBm, 3 dBm and 6 dBm in values of power received. Fig. 6 shows that the OFDM-OVSB FSO system is better than OFDM-ODSB and OFDM-OSSB FSO System at maximum achieved distance.



(a) (b) (c)

Fig. 6 Comparison of Power vs. Distance under (a) clear, (b) haze and (c) fog weather condition using OFDM-ODSB, OFDM-OSSB, OFDM-OVSB techniques

Evaluation of Distance by employing Spatial Diversity

Spatial diversity provides high quality services by sending several copies of the same signal by using multiple transmitter/receiver (TX/RX) system and enhances the FSO link range. Table 1 shows the maximum distance achieved using spatial diversity under clear, haze and fog weather condition. Under clear, haze and fog weather condition, maximum distance increases from 185 km to 292 km, 10 km to 14.6 km and 2.5 km to 3.24 km respectively with acceptable SNR of 25 dB.

Table 1 Maximum distance covered using spatial diversity under clear, haze and fog weather condition

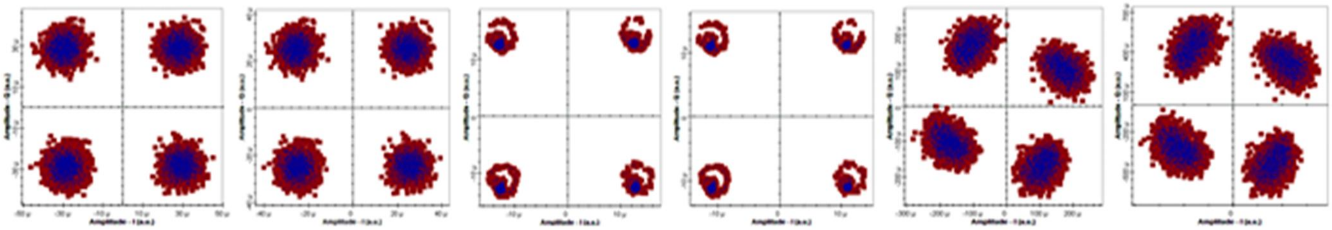
No. of TX/RX	Maximum distance covered under clear weather condition (km)	Maximum distance covered under haze weather condition (km)	Maximum distance covered under fog weather condition (km)
1	185	10	2.5
2	250	13.2	2.95
3	260	13.6	3.05
4	270	13.8	3.10
5	277	14	3.14
6	283	14.2	3.18
7	288	14.4	3.22
8	292	14.6	3.24

Evaluation of Constellation diagram

Electrical Constellation Visualizer is used for analyzing the constellation of received signal. The constellation diagrams of OFDM-FSO system using ODSB, OSSB and OVSB modulation scheme under clear atmospheric conditions are shown in Fig. 7. It is observed that constellation points are arranged in equal horizontal and vertical spacing having much distance between them so these are less susceptible to noise and data error.

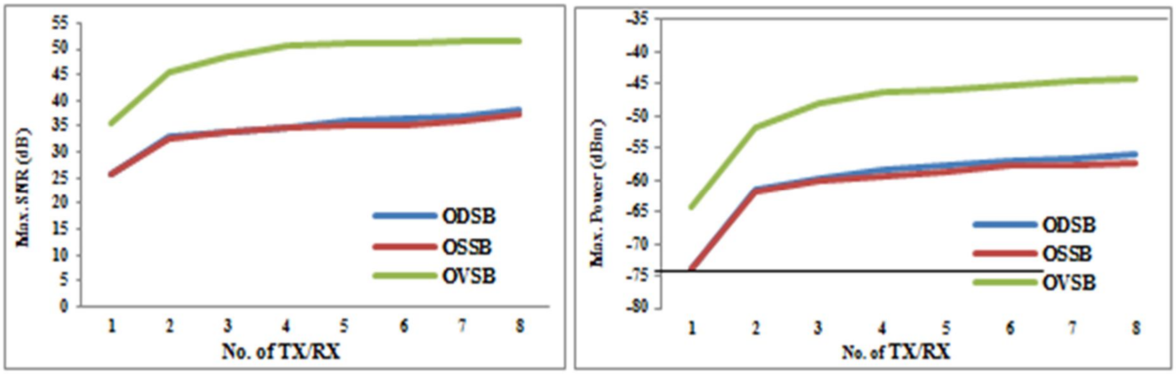
Evaluation of SNR and Power with No. of TX/RX under clear weather condition having attenuation 0.11dB/km at 185 km

It is observed that at 185 km, for OFDM-ODSB, OFDM-OSSB and OFDM-OVSB FSO system, SNR increases from 25.84 to 38.03, 24.47 to 37.49 and 35.71 to 54.74 respectively and power received increases from -73.78 to -56.04, -73.92 to -57.27 and -64.28 to -44.16 respectively by increasing the number of TX/RX system. Fig. 8 shows the (a) SNR and (b) power received with increase in no. of TX/RX system at 185 km under clear weather.



(a) (b) (c) (d) (e) (f)

Fig. 7 Constellation diagram under clear weather using (a) 1TX/RX ODSB at 185 km (b) 8TX/RX ODSB at 292 km (c) 1TX/RX OSSB at 185 km (d) 8TX/RX OSSB at 292 km (e) 1TX/RX OVSB at 185 km (f) 8TX/RX OVSB at 292 km

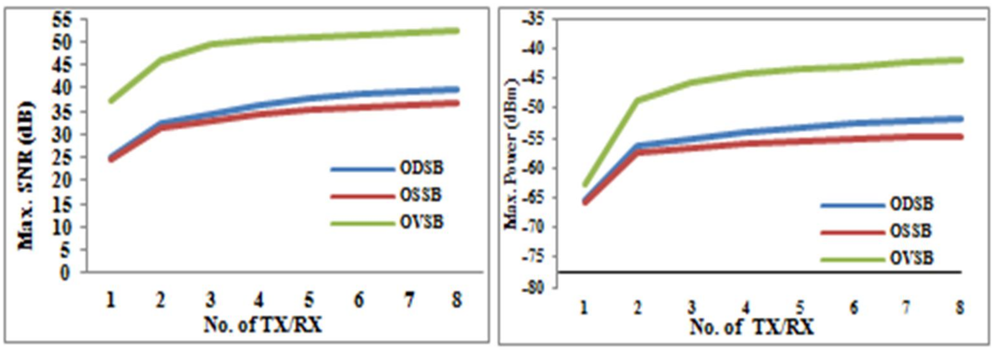


(a) (b)

Fig. 8 Evaluation of (a) SNR (b) Power with increase in the no. of TX/RX system at 185 km under clear weather

Evaluation of SNR and Power with No. of TX/RX under haze weather condition having attenuation 4 dB/km at 10 km

It is observed that at 10 km, for OFDM-ODSB, OFDM-OSSB and OFDM-OVSB FSO system, SNR increases from 24.94 to 39.75, 24.67 to 36.77 and 37.10 to 52.61 respectively and power received increases from -65.42 to -51.69, -65.64 to -54.68 and -62.89 to -41.82 respectively by increasing the number of TX/RX system. Fig. 9 shows the (a) SNR and (b) power received increase in no. of TX/RX system at 10 km under haze weather.

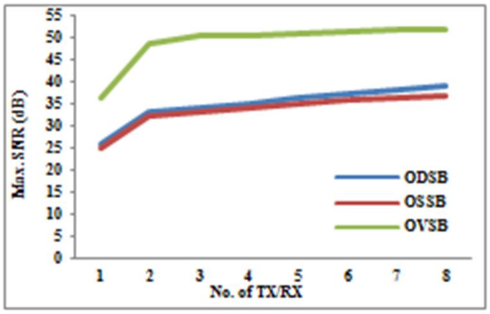


(a) (b)

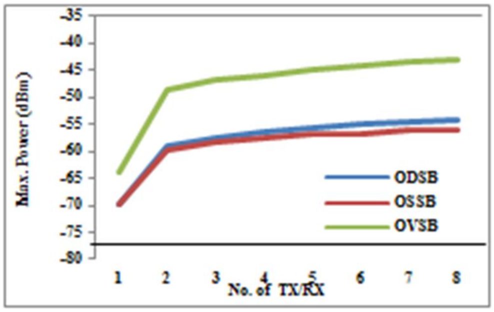
Fig. 9 Evaluation of (a) SNR (b) Power with increase in the no. of TX/RX system at 10 km under haze weather

Evaluation of SNR and Power with No. of TX/RX under fog weather condition having attenuation 22 dB/km at 2.5 km

It is observed that at 2.5 km, for OFDM-ODSB, OFDM-OSSB and OFDM-OVSB FSO system, SNR increases from 25.87 to 38.85, 24.65 to 36.89 and 36.27 to 51.79 respectively by increasing and power received increases from -69.65 to -54.09, -69.98 to -55.98 and -63.71 to -43.05 respectively by increasing the number of TX/RX system. Fig. 10 shows the (a) SNR and (b) power received increase in no. of TX/RX system at 2.5 km under fog weather.



(a)



(b)

Fig. 10 Evaluation of (a) SNR and (b) Power with increase in the no. of TX/RX system at 2.5 km under fog weather

Conclusion

In this work, OFDM FSO System is designed by using ODSB, OSSB and OVSB modulation scheme along with Spatial Diversity technique by employing 8 TX/RX. From our results, it is concluded that OFDM-FSO system employing the spatial diversity technique increases the FSO link range. There is also increase in the values of SNR and power received of OFDM-FSO system by using OVSB modulation scheme as this technique is more attenuation immune for long haul communication. OFDM-OVSB-FSO system employing spatial diversity provides better results under different weather conditions. Under clear, haze and fog weather condition, there is a 10 dB, 12 dB and 11 dB improvement in SNR value at 185 km, 10km and 2.5 km respectively for long distances and at high distances, there is improvement of 9 dBm, 3 dBm and 6 dBm in values of received power by using OVSB modulation scheme. Maximum distance achieved by employing spatial diversity using 8 TX/RX under clear, haze and fog weather condition increases from 185 km to 292 km, 10 km to 14.6 km and 2.5 km to 3.24 km respectively. It is concluded that for OFDM-ODSB, OFDM-OSSB and OFDM-OVSB FSO system, SNR and power received increases by increasing the number of TX/RX system employing spatial diversity.

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