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Design and Analysis of 32 channel WDM-MIMO Free Space Optics link under Different Atmospheric Conditions

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ABSTRACT: Free space optics (FSO) is a favourable technique to access the optical communication services. This technology used for transmitting data from one point to another point by using a laser beam. There are many projects to analyse the performance of free space optics system in different atmospheric conditions. But they are not applicable more than 2 km range on higher attenuation.

In the paper, the main objective is to increase the link range of the transmission channel and the capacity of the system by increasing the 32 channels of wavelength division multiplex (WDM). The losses considered are geometric losses, transmitter losses, receiver losses and most important atmospheric conditions (having different attenuation value for a different condition). The proposed design consists of forks & a power combiner and multi-input and multi-output technique (MIMO) which take benefits from the spatial diversity. For high-quality communication, multiple channels are used to achieve the goal. Theoretically, the analysis reveals that multiple inputs and multiple outputs (MIMO) improve the capacity, throughput, and reliability of the optical communication system. To prove it practically, the performance of the optical system is analyzed by the received power, Q-factor and bit error rate (BER) under different link range and atmospheric conditions.

KEYWORDS: Free space optics, MIMO, Wavelength division multiplexing, Geometric loss, Atmospheric attenuation, OptiSystem 7.0, BER and Q-Factor

I. INTRODUCTION

Free Space Optics is a communication Technology in which data is transmitted by propagation of light in free space or air. FSO is a line of sight technology for successful transmission of optical signal. The FSO based communication System used in hours in lesser economy. The basic characteristics of FSO are that it operates at a higher power level for long distance communication; high-speed modulation required for high-speed FSO based communication system. The FSO has various applications like it's used in outdoor wireless access, storage area network, last mile access, enterprise connectivity, fiber backup, Metro-network extension, backhaul, service acceleration, bridge WAN access, military Access, point to point or multi-point, ship to ship etc [1].

Systems with multiple transmitter and receiver antennas are called as Multiple Input and Multiple Output (MIMO) System. This wireless technique has significantly improved the capacity and range of wireless communication channel. A MIMO system provides multipath propagation by using different transmission path to the receiver, which provides redundancy of data thus increases the reliability of transmission. By this technique transmitting the amount of data transmitted is also increased. MIMO system has also offered high-speed reliable data range at the same power and bandwidth [2]. So, MIMO is a beneficial technique for FSO system.

As MIMO several laser diodes are used for transmitting the data and at the receiver, several photodiodes are used to collect the transmitted information [2]. MIMO technology is the most generally used in wireless communication systems is shown in fig. 1 The various space diversity combining techniques are used to combine the signal from multiple paths that are Selection Combining, Maximal Ratio Combining and Equal Gain Combining [2]. In paper equal gain combining technique is used in which the received signals are summed up coherently with equal weights at all the received diverse signals. This technique has better performance as compared to selection combining technique in terms of BER.

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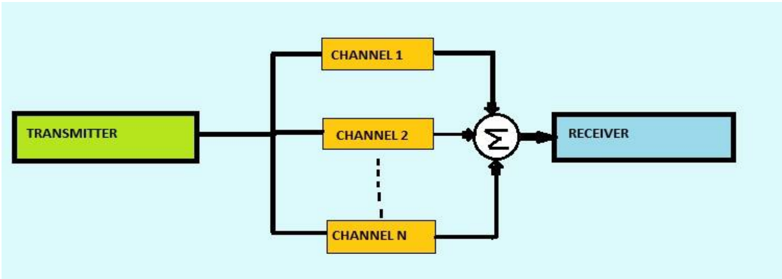

Fig. 1 MIMO systems

II. ATMOSPHERIC EFFECT ON FSO

FSO provides the best way to communicate for the geographical area where the optical fiber is not feasible but there are some performance limitations like atmospheric losses and geometrical losses.
The atmosphere is the transmission medium of optical communication System. The atmosphere has various conditions which attenuate the signal. These atmospheric conditions are fog, rain, Haze (smoke, dust and other dry particles.)

Geometrical loss: - In FSO communication system, the geometrical losses directly affect the optical power and laser beam which spread the light from one point to another point of the link [3].
Geometrical effect can be calculated by received power

$$P_{Received} = P_{Transmitted} \frac{d_R^2}{(d_T + \theta R)^2} 10^{\frac{-\tau_{ATM} R}{10}}$$

Where d_R = received aperture diameter (m)
d_T = transmitter aperture diameter (m)
θ = beam divergence (mrad)
R = link range (km)
τ_{ATM} = atmospheric attenuation (dB/km)

Beer's law describes the atmospheric attenuation(τ_{ATM}) [4]

$$\tau_{ATM=} e^{-(\beta_{abs}+\beta_{scat})}\mathrm{R}$$

Where, β_{abs} and β_{scat} are absorption and scattering coefficients
R is a Link Range

Rain attenuation: -The highest attenuation factor in the environment is rain attenuation for light so it also effects FSO. The rain can reduce the visibility of FSO system. Due to Rain intensity factor, the FSO System and laser power are affected. The attenuation due to rain is:-

$$\tau_{rain} = 1.076R^{0.67}$$

Where,
R represents the rainfall rate.

The increase in rainfall rate and rain drop size causes a linear increase in attenuation. The scattering due to rain is non-selective as attenuation coefficient has no dependence on laser wavelength [5].

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Fog attenuation: -Fog is the most unfavourable attenuation factor among all atmospheric attenuations. Fog has scattered the incident light because it's a visible mass of water droplets which has reduced visibility. The attenuation is calculated from Kruse model by:

$$\gamma_{fog} = \left(\frac{17}{V}\right)\left(\frac{\lambda}{550}\right)^{-q}$$

Where V is the visibility in km and q is the particle size distribution.

Low visibilities increases atmospheric attenuation and reduce the availability of optical signals from free space [5].

Haze attenuation: -Haze is an atmospheric condition where dust, smoke, and other dry particles reduce the clarity of the sky. The particles are staying longer in the atmosphere as compared to rain. This attenuation has more serious degradation of FSO performance. Kim and Kruse's model is used to calculate specific attenuation as

$$\beta_{haze} = \left(\frac{3.91}{V}\right)\left(\frac{\lambda}{550}\right)^{-q}$$

Where V is visibility in km and q is particle size distribution. The q values are obtained from Kim and Kruse model [5]

III. SYSTEM DESIGN AND ANALYSIS

The fundamental elements of FSO communication system are Transmitter, transmission channel, and receiver. To analyse the performance of the optical communication system the simulator software namely Optisystem version 7 is used. The block diagram of the optical communication system is shown in fig. 2

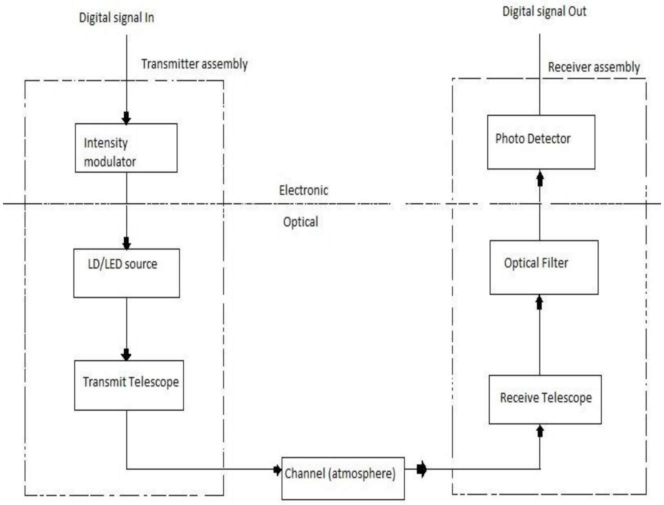

Fig. 2 The block diagram of the optical communication system

In the simulation design, the transmitter section consists of 32 channels. Each channel has CW laser, Mach-Zehnder modulator, Pseudo-random bit sequence generator (PRBS), NRZ pulse generator and an optical amplifier. The CW laser is used as a carrier signal with 7.7 dBm input power. PRBS generate the binary input. With the help of Mach-Zehnder, the binary input is converted into a light signal or optical signal.

To enhance the optical signal strength amplifier is used. The specification of the simulation design is shown in Table 1

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These signals are multiplexed by WDM MUX carrying 32 wavelengths. The input laser has the wavelength range from 1525.2 nm to 1550 nm with 100 GHz (0.8 nm) channel spacing. The bandwidth of the WDM is 10 GHz. WDM system is used in FSO optical System to maximize the bandwidth usage but in low cost.

Table 1 Specification of the simulation design

PARAMETER	VALUE
Data rate	2.5 Gb/s
Wavelength	1550 nm
Laser Power	7.7 dBm
No. of inputs	32
Bandwidth	10 GHz
Channel spacing	0.8 nm (100 GHz)
Transmitter aperture diameter	10 cm
Receiver aperture diameter	30 cm
Range	500 m to 4500 m
EDFA	5 m
No. FSO channels	4

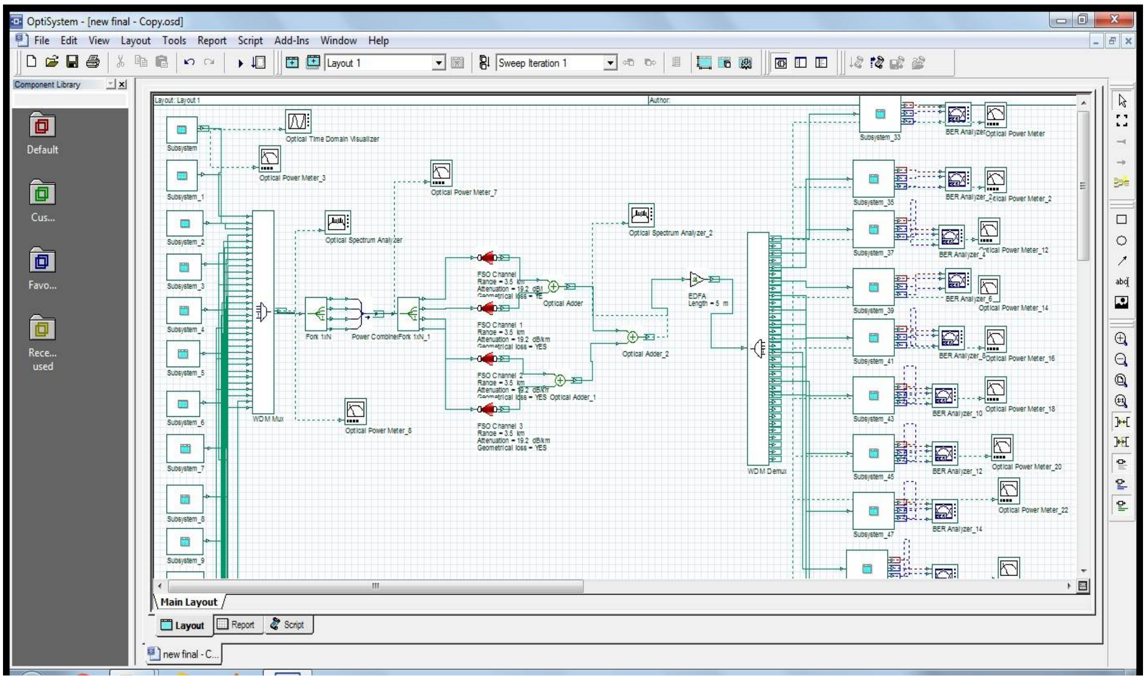

Fig. 3 Simulation design in the optical communication system

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The output of the MUX is connected to the fork. The fork is used for duplicating the input beam. The power combiner is used to combine the outputs or multiple laser beam of a fork. The output coming from power combiner is send to the FSO transmission channel. The FSO system is called the two telescope subsystem with intermediate FSO channel. The optical adder sums the two optical signals. The adder adds up the amplitude of the two input signals. EDFA amplifier is used to improve the signal quality and increase the range of communication.
In the receiver section, a WDM DEMUX is used with same specifications of the multiplexer. DEMUX divide the signal according to wavelength. Then a photodetector, a low pass filter, 3R regenerator and a visualizer is used at every port of DEMUX. The visualizer gives the value of maximum Q factor, minimum BER, eye height, threshold value. The simulation design of optical communication system is shown in fig. 3

IV. RESULT AND CONCLUSION

All the experiments done on FSO channel shows that heavy rain (19.2km/dB) is the most severe factor in tropical regions, that reduce the availability of the link. There is no problem of fog and snow in tropical regions. In this section, numerical results for the FSO Communication System are presented with different attenuation values and distance. In FSO Communication System transmit and receiving aperture of lens system is10 cm and 30 cm respectively.
The attenuation value of 19.2dB/km for heavy rain is considered. The table 2 shows the Q-factor, BER and received the power of the system.

Table 2 Performance at different link range

Link Range (km)	Q factor	BER	Power (dBm)
0.5	249.813	0	39.479
1	249.498	0	24.256
1.5	243.308	0	12.483
2	211.077	0	6.636
2.5	130.854	0	3.697
3	50.5899	0	0.123
3.5	14.4087	1.55433e-047	-5.347
4	3.56791	0.00050323	-12.968
4.5	0	1	-17.429

The performance of the system has linearly changed by varying the link range of FSO (500 m to 4500m) as shown in fig. 4 and 5

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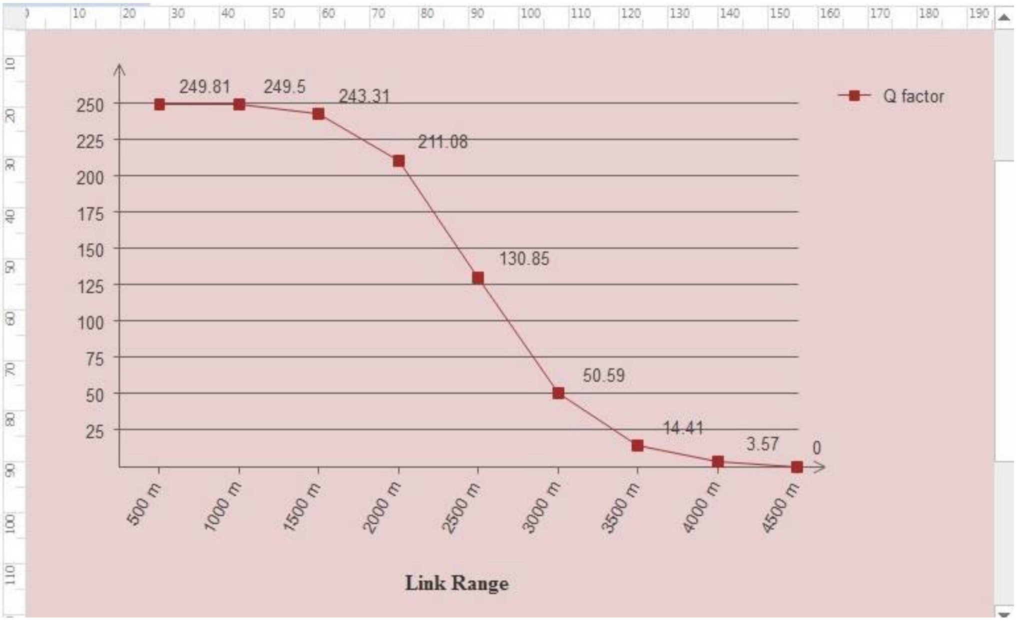

Fig. 4 The Q factor Vs Link Range

Table 3 shows the performance of the FSO optical communication system according to atmospheric attenuation at the link range 3.5 km.

Table 3 Q factor, BER, Power of system at link range 3.5 km

Atmospheric condition	**Attenuation value (dB/km)**	**Q factor**	**BER**	**Power (dBm)**
Very clear	0.065	249.763	0	32.525
Clear	0.233	249.756	0	31.938
Light haze	0.55	249.740	0	30.832
Heavy haze	2.37	249.517	0	24.517
Light rain	6.27	242.850	0	12.206
Medium rain	9.64	210.497	0	6.600
Low fog	15.55	61.1459	0	0.812
Heavy rain	19.2	14.4087	1.55433e-047	-5.347
Heavy fog	43	0	1	- 18.300

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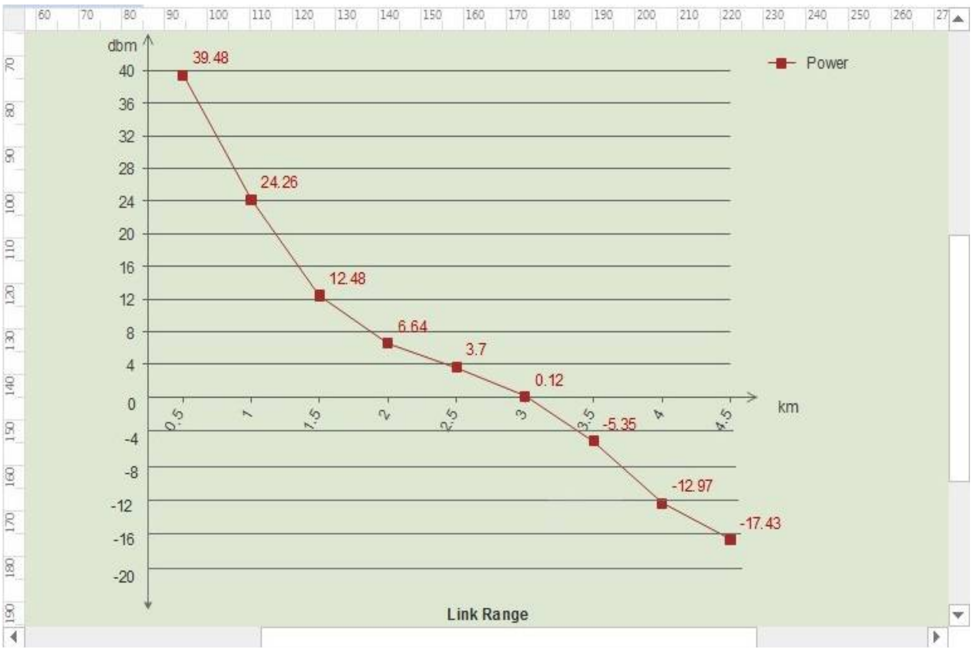

Fig. 5 Power Vs Link range

The eye diagram of the FSO communication system under heavy rain attenuation is shown in fig. 6 For heavy rain optimized link range is 3.5 km with 19.2 dB/km attenuation of heavy rain.

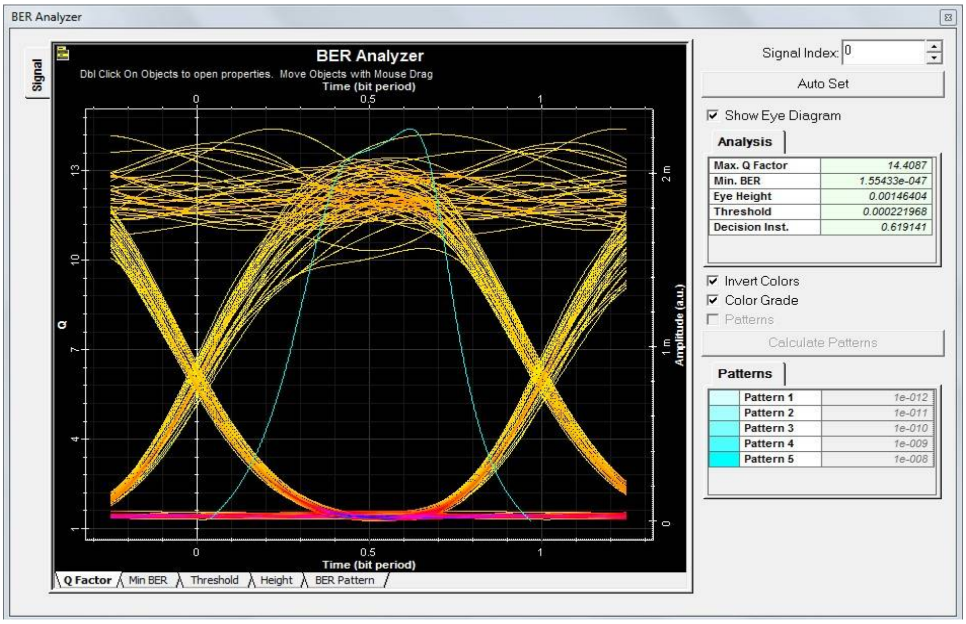

Fig. 6 Eye Diagram

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Free Space Optics is the promising communication technology. Due to atmospheric losses and geometrical losses the signal gets distorted at receiver. To overcome this problem the new MIMO technology is implemented which has reduced the atmospheric effect on signal and increase the capacity of the system. The information can transmit in the range 3.5 km. By using MIMO technology, the reliability of the system is also improved.
It is realized that MIMO FSO system can operate successfully for a link distance of 3500 m at BER of 1.55433e-047 with a received optical power of -5.347dBm and link distance of 4000 m at BER of 0.000150323 with a received optical power of -12.968dBm for heavy rain.

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