Utilization of MIMO Concept for Optical Communication System under Fog Condition

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ABSTRACT

Free-space optical (FSO) communication is considered to be license free, high data rate, wide bandwidth and cost-effective. Multi-input Multi-output (MIMO) systems can be employed to reduce the attenuation by heavy fog and improve FSO channel capacity. In this paper, single-input single-output and multiâĂŞinput multi-output systems are examined to investigate the performance of these systems under heavy fog. A comparison is made in terms of received optical power, signal to noise ratio, and bit error rate (BER) using OptiSystem version 7.0. The signal reaches up to 1.7 km, 1.55 km, 1.5 km, and 1.4 km for 4Tx/4Rx, 3Tx/3Rx, 2Tx/2Rx, 1Tx/1Rx respectively. The results showed that the quality of received power is enhanced by using up to four beams.

Keywords: Free-Space Optical, FSO, Atmospheric Attenuation, OptiSystem 7.0, MIMO, BER, Q-Factor.

1. INTRODUCTION

Free Space Optics (FSO) is optical wireless communication technology that uses light to transmit data between two points. Optical communications are considered a more effective technology which uses visible and infrared wavelengths to propagate high-speed data optically wirelessly through the atmospheric channel. FSO communication systems are considered to be an efficient solution due to some advantages including immunity to interference, excellent security, and a huge license-free spectrum. The FSO systems allow high-speed data transmission and high bandwidth availability. The largest application of the FSO systems is in local area network (LAN) to LAN connectivity and metropolitan area network (MAN) extension [1]. Despite the advantages of the FSO system, this system is not without disadvantages. Atmospheric turbulence and pointing errors are the most common phenomena in FSO systems which cause damage in the optical signal. Atmospheric turbulence results in fluctuations in both the phase and intensity of the received signal, reducing the link performance [2].

FSO system includes three components: the transmitter unit, free space channel, and the receiver unit. The transmitter unit is considered an optical light with a laser diode (LD) or light emitting diode (LED) to propagate through the atmosphere and obey Beer-Lambert's law [3] but wireless communication is a technology that has its own limits [4]. The suitable understanding of optical beam propagation in FSO has become essential and brings about the need to understand the effects of an atmospheric channel on FSO links. FSO links can have poor performance and even link failure due to weather effects and atmospheric losses along the optical path link. It becomes a great challenge in FSO communications. These challenges include rain, dust particles, fog, snow, dense smoke, fading due to turbulence, etc [5, 6], also the scintillation effects increase the impairment of the FSO links [7]. One of the solutions proposed to address the turbulence is by using hybrid system (FSO switches to RF) [8], multiple-input multiple-output (MIMO) FSO systems [9], and Radio over FSO (RoFSO) [10]. MIMO technology not only increases the transmitted data rate but also improves the system reliability [11]. The effects of fog and haze are deemed the major obstacles to the optical beam and can reduce the path length of light. Fig. (1) shows the elements of the FSO link [12].

2. THEORETICAL BACKGROUND

An FSO system contains atmospheric weather (absorption, scattering, and turbulence) in a channel for establishing an optical wireless link between two points. The path link of LOS has a range up to tens of kilometers [13]. When the visible and IR wavelengths propagate through FSO they suffer from absorption and scattering phenomena due to the suspended particles and the liquid present in the atmosphere. These particles were fog, dust, mist, and haze [14, 15]. Beer-LambertâĂŹs describe the relationship between the receiver and the transmitter optical signal for the distance L by the following model [3]:

$$\tau(\lambda, L) = \frac{P_R}{P_T} \exp\left(-\alpha(\lambda, L)\right) \tag{1}$$

where, $\alpha(\lambda)$ is the total attenuation coefficient m^{-1}, P_R is the received optical signal at a distance L, P_T is the transmitted optical signal at the optical source,

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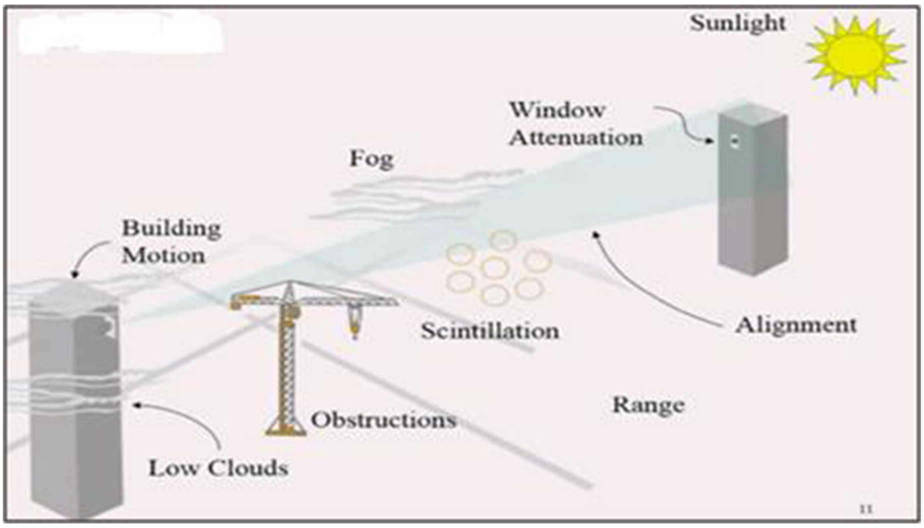

Fig. 1: *Challenges faced by an FSO system under turbulence condition.*

and $\tau(\lambda, L)$ is the transmittance of the atmosphere at wavelength λ.

The total attenuation coefficient is the sum of the absorption and scattering and is given by [16]

$$\alpha(\lambda) = \alpha_m(\lambda) + \alpha_a(\lambda) + \beta_m(\lambda) + \beta_a(\lambda) \quad (2)$$

where $\alpha_m(\lambda)$ and $\alpha_a(\lambda)$ represent the molecular and aerosol absorption coefficients respectively, while $\beta_m(\lambda)$ and $\beta_a(\lambda)$ represent the molecular and aerosol scattering coefficients respectively. The aerosol scattering coefficient is considered to be much greater than other parameters in Eq. (2). So, Eq. (2) can be written as [16].

$$\alpha(\lambda) \simeq \beta_a(\lambda) \quad (3)$$

Eq. (3) supposes that the total attenuation coefficient is approximately equal to the aerosol scattering coefficient. This assumption is based on the aerosol scattering coefficient having a high value compared with the other parameters in free space.

There are different models used to compute the attenuation caused by fog, smoke, and dust based on an empirical model and theoretical approach relying on visibility range. Therefore, the attenuation coefficient resulting by scattering phenomena can be estimated by [16]:

$$\alpha(\lambda) \simeq \beta_a(\lambda) \simeq \frac{17.35}{V} \cdot \left(\frac{\lambda}{550}\right)^{-q} \quad (4)$$

where V represents the visibility range (km), λ represents the wavelength in nm. $\alpha(\lambda)$ represents the total attenuation coefficient and q is the particle size distribution. The particle size distribution is related to visibility range and can be expressed by Kruse model [17]:

$$q = \begin{cases} 1.6 & \text{if } V > 50 \text{ km} \\ 1.3 & \text{if } 6 \text{ km} < V < 50 \text{ km} \\ 0.585V^{1/3} & \text{if } V < 6 \text{ km} \end{cases} \quad (5)$$

Eq. (5) shows that for any weather condition, there will be less attenuation for higher wavelengths. Kim reformulated Eq. (5) for low visibility. So, the particle size by Kim model can be written as [16]:

$$q = \begin{cases} 1.6 & \text{if } V > 50 \text{ km} \\ 1.3 & \text{if } 6 \text{ km} < V < 50 \text{ km} \\ 0.16V + 0.34 & \text{if } 1 \text{ km} < V < 6 \text{ km} \\ V - 0.5 & \text{if } 0.5 \text{ km} < V < 1 \text{ km} \\ 0 & \text{if } V < 0.5 \text{ km} \end{cases} \quad (6)$$

The link equation for the FSO system can be written as [18]:

$$P_R = P_T \times \frac{d_R^2}{(d_T + \theta \times L)^2} \times 10^{-\alpha L/10} \quad (7)$$

where: P_R is the received power, P_T is the power transmitted, α is attenuation coefficient, L is the distance of propagation, θ is the beam divergence and d_R is receiver diameter (cm), d_T is transmitter diameter (cm).

3. DESIGN AND SIMULATIONS OF MIMO TECHNIQUE

The first step to designing an FSO communication system in different media channels is to know what happens to an optical signal that travels through the medium. Based on OptiSystem ver. 7 simulation software, four channels of FSO systems have been designed. First, we design the main free space optical Link (SISO) at 1.39 km. This system is equipped with a wavelength of 1550 nm. The transmitter unit

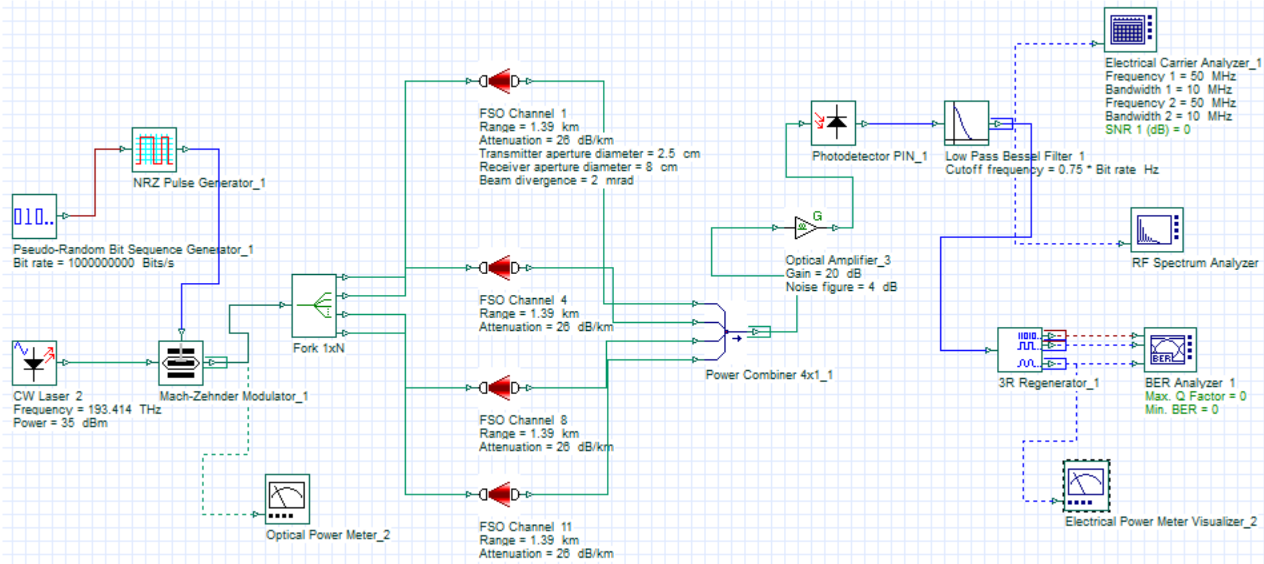

Fig.2: *Simulation layout of MIMO (4TX/4RX) FSO system.*

includes the Pseudo Random Bit Sequence (PRBS) generator, NRZ pulse generator, a CW laser source and Mach-Zehnder Modulator (MZM). The data generated by the PRBS generator at 1 Gbps was encoded and modulated using MZM over carrier laser signal. PRBS is the first subsystem, which represents data from the information that needs to be transmitted. The PRBS is a bit string composed of two parts of the order '1' (on) and '0' (off) talking to the double beats of a global clone look. The yield is given from a PRBS to a second subsystem NRZ driver. Encoding information that used NRZ encoding technique, whose "1" represents a significant bit and "0" for another considerable bit. The yield of the driver is also given to the subsystem of another MZM that has information levers [20]. The laser signal propagates through FSO with transmitter power 35 dBm and the divergence angle was 2 mrad. The aperture diameters of the transmitter and receiver were 2.5 cm and 8 cm, respectively. Fig. (2) shows the simulation design of the system, where four channels are used as MIMO link (4Tx/4Rx). The Fork is employed to distribute the input of an optical beam to the four channels. The other side of FSO channels connected to power combiner to combine the signals. The optical receiver containing a PIN photodiode is tailed by a Bessel low-pass filter (LPF) [21]. An LPF is used with a cut-off frequency of (0.75*bits rate). There are different metrics used to study the quality of the signal. The first metric was an optical power meter to measure the received power. The second was optical spectrum analyzer which provides the facility to analyze the optical spectrum, finally BER analyzer, Q-factor and display eye diagram. To enhance the received power and decrease generated losses due to weather, the MIMO design is used to improve the efficiency and quality of the system and is compared

Table 1: *System parameters which used in this simulation.*

Parameter	Value
Transmitter optical power	35 dBm
Transmitter divergence angle	2 mrad
Transmitter efficiency	0.5
Receiver sensitivity	–20 dBm
Transmitter diameter d_T	2.5 cm
Receiver diameter d_R	8 cm
Receiver efficiency	0.5
Attenuation coefficient	26 dBm
Data rate	1 Gbps

with the performance of SISO design.

4. RESULTS AND DISCUSSION

We suppose that an optical beam propagates between two points in the FSO channel. The received optical power, SNR, BER and Q-factor of the 1550 nm laser beam was studied. The simulation supposes that the optical signals transmitted in FSO with link consist of (1Tx/1Rx), (2Tx/2Rx), (3Tx/3Rx), (4Tx/4Rx). The link distance of (1.39 to 1.6) km is analyzed under heavy foggy weather condition. The typical value of attenuation for the heavy fog was equal to 26 dB/km [22]. The optimal design (4-beam) has been done by using (4Tx/4Rx) link to increase the efficiency of the communication system; we made a comparison between it and the other channels. In this work, a different link distance has been applied to observe the improvement of the performance of the systems. The data rate was 1 Gbps imposed in the simulation to observe the capability of the system to transmit the data rate with 1-beam, 2-beam, 3-beam, and 4-beam. Table 1 gives the pa-

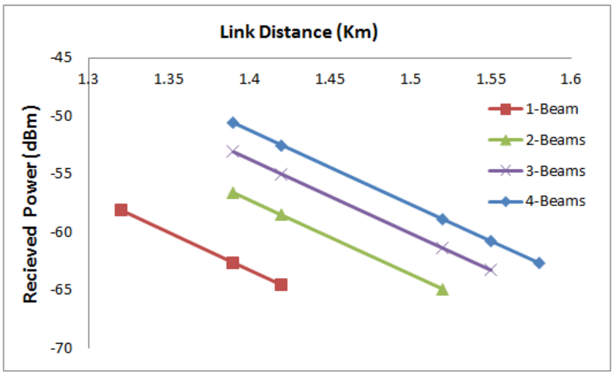

Fig.3: *Received Power versus Link Distance for FSO system.*

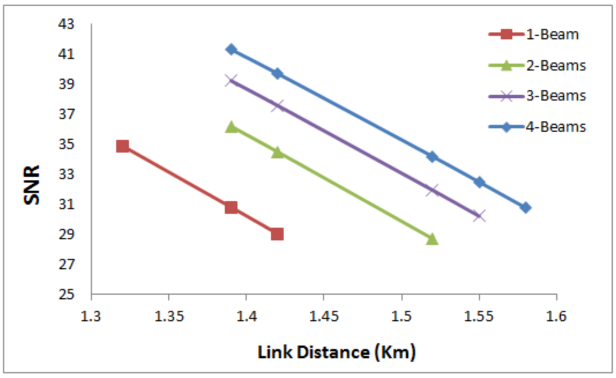

Fig.4: *SNR versus Link Distance for FSO system.*

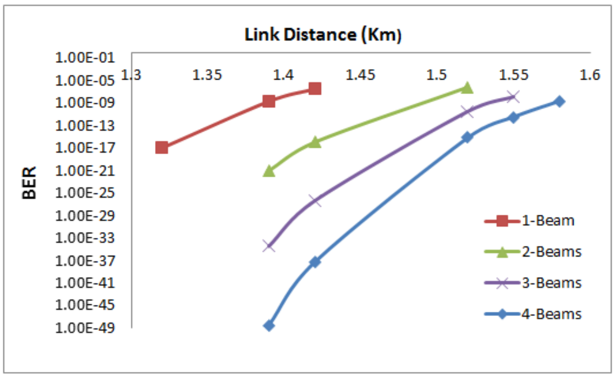

Fig.5: *BER versus Link Distance for FSO system.*

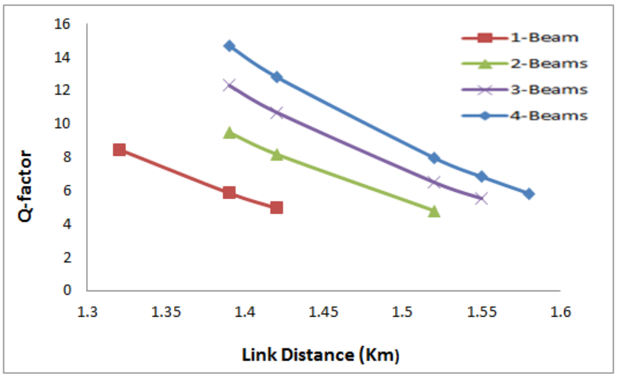

Fig.6: *Q-factor versus Link Distance for FSO system.*

rameters supposed in the simulation.

Fig. 3 shows the received signal power as a function of link distance under heavy fog. It is noticed that the received power will gradually improve especially when the system applied 4- beams. It is also observed that the distance link can reach to 1.58 km for 4-beams while it is about 1.43 km for 1-beams.

Fig. 4 shows the relationship between the signal to noise ratio and the link distance for the transmission beams under heavy fog. Due to the increase in the distance, the signal to noise ratio is decreased. In addition, when 4-beams are applied in the system the signal can reach a long distance compared to the other beams. It is observed that the increase in the transmission beams the quality of the signal will gradually improve when the system applies 4-beams. It is also noted that the link distance is increasing under the same conditions.

Fig. 5 demonstrates the BER of the FSO system under heavy fog for 1-beam, 2-beam, 3-beam, and 4-beam. The simulation results of the system show poor performance of 1-beam compared with the other cases. In this situation, the data cannot be transmitted to long link distance. Furthermore, 4-beams shows a good improvement to the performance of the link distance. It is able to work with heavy fog and high link distance. The system can work with the link distance about 1.39 km, 1.45 km, 1.55 km, and 1.6 km for 1-beam, 2-beam, 3-beam, and 4-beam respectively.

Fig. 6 shows the Q-factor as a function of the link distance carried out on 1-beam, 2-beam, 3-beam, and 4-beam. The increase in the link distance leads to a decrease in the performance of Q-factor. For the case of 4-beams, a good result is achieved compared with the other beams. This indicates that the system can work with a good quality of the signal under heavy fog.

Fig. 7 shows the eye diagrams for the four cases of the system under study. When the system is used with 1.39 km, 1-beam has a good Q-factor but is limited by short link distance. While for 4-beam, the eye opening has a good aperture size. These results indicate that an error in bit rate occurs for the system with 1-beam.

5. CONCLUSION

In this paper, we proposed and analyzed a MIMO optical wireless communication system. The performance of MIMO FSO system has been analyzed and

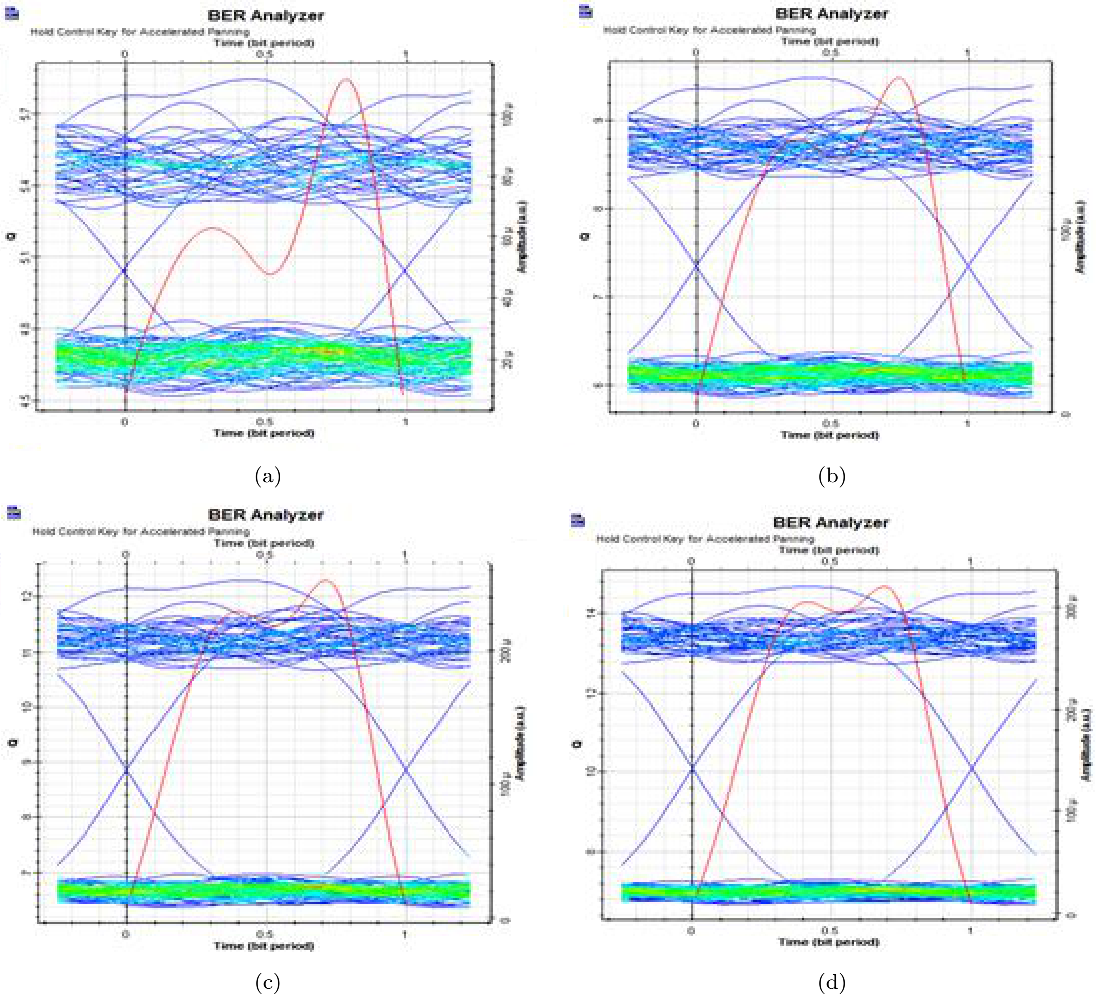

Fig.7: *Eye diagram of the received signal for FSO system (L = 1.39 km); blue line represents the eye diagram, red line represents the received signal. (a) 1-beam, (b) 2-beam, (c) 3-beam, and (d) 4-beam.*

examined under heavy fog weather conditions. The simulation results show that the multiple transmitted beams in the FSO system provide a significant improvement in the maximum optical link, received optical power, and Q. factor under heavy fog weather. The four-beam FSO system outperforms the other beams. It is also observed that beams lead to BER enhancement and the quality of the signal was improved. To develop the system to work with harsh weather conditions, different parameters can be applied such as: use more than 4-beams to transmit the data rate in free space, high power optical beam, and low divergence of beams.

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