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FREE-SPACE OPTICAL SYSTEM BASED ON VERTICAL TRANSCEIVERS LINK UNDER VARYING SMOKE DENSITY

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Abstract

Free-Space Optics (FSO) system depends on the line-of-sight (LOS) Limitations, such as atmospheric conditions. The smoke plumes of crude oil fires cause serious challenges on the optical signal propagation through communication systems. The novelty of this paper is in the new design of vertical multiple-input multiple-output (MIMO-FSO) system of various influencing factors such as; transceivers heights, beam divergence and link distance that has been simulated and analysed under varying smoke plumes density. The results indicate that the received power and Q-Factor in the proposed model have demonstrated better results than the well knowing models under similar atmospheric conditions. Hence, it reduces optical signal attenuation and improves the stability of line of sight. The significance of this optimized performance system is its ability to be a good choice for regional environments that suffer from frequent oil wells fires.

Keywords: Free space optics communication, Infrared laser, Oil fires, Smoke concentration.

1. Introduction

Free-Space Optics (FSO) is an optical wireless system transmits digital signals on laser light between two transceivers. This system requires unplugged line of sight to appropriately operate. FSO Communication System used to solve the bottleneck broad -band connectivity problem instead of conventional radio frequency (RF) and fiber-optic systems [1]. Atmospheric attenuation is an important factor which was considered in the estimation of FSO system performance. Attenuation of FSO signal intensity and integrity occurs due to scattering and absorption over a propagation path [2].

One of obscuration issues based on the black smoke from realistic oil well fires of varying volumes. The smoke particles have similar size compared with (fog, dust) particles that can also be responsible for FSO performance degradation [3-5]. The smoke plumes from the burns at first rose 200-400 m into the air after that they disperse, perhaps due to solar heating of the smoke and disperse laterally downwind [6, 7]. When the smoke plumes go up from the fire, the smoke concentration is gradually diluted by air which is dragged into the plume. The transmitted signal is scattered due to the plentiful smoke particles according to "Mie" theorem [8]. The optimal number of transceivers that should be placed on FSO node is obtained by optimizing the total effective coverage area of the transceivers [9].

In order to design a specific system of actual propagation of the signal-carrying laser beam it is necessary to consider the inner and outer effects. Various design parameters can affect the FSO link including transmitter beam size, number of transceivers, receiver aperture, laser wavelength and FSO link length [10-12]. Many researchers investigated the impact of multiple-input multiple-output (MIMO) to enhance performance of FSO systems. A hybrid FSO was presented by combining the MIMO-FSO with secondary time diversity techniques [13], but a secondary system can cause a certain delay. Another system was examined the effect of an atmospheric turbulence for long terrestrial link and the error performance of proposed MIMO-FSO combined with subcarrier modulation system have been analysed [14].

It used the largest modulation order for adaptive modulation system without increasing the transmitted optical power, this adds complications due to the component used to increase the coupling efficiency between the main and sub systems. In another work, researchers focused on studying the divergence angle of the transmitted beam on FSO link [15]. They were investigating the combined effect of beam diverging and atmospheric attenuation under various weather conditions. It is shown that the polarization shift keying modulation mitigates the effects of increasing the divergence angle, but still there is divergence loss due to the beam diverged wider than the receiver aperture.

Moreover, a 5 km FSO link based on visibilities data vary from clear atmosphere to heavy rain or in presence of heavy dust have been investigated [16]. The effect of varying beam divergence angle and misalignment were evaluated and analysed. The signal availability improved as the number of transmitters and receivers increased as well as the beam divergence varies with the distance. The distance between two adjacent sites is about 2.7 km and 3.2 km where they were arranged as a ring. These systems have the disadvantages of high costs, complexity, probability of cuts and blockages between adjacent sites, need for wide area and several transceivers' locations. In order to overcome the restrictions imposed by the aforementioned studies.

This paper proposed a new system for vertical MIMO-FSO link based on different transceivers heights at single location and adaptive beam divergence angles under varying smoke plumes density to be simulated and analysed.

2. Design and simulation of vertical MIMO-FSO channels

The presence of smoke particles in the atmospheric channel may cause strong attenuation in the transmitted Infrared laser (i.e. IR wavelengths) based on their size and concentration [17, 18]. For better understanding of the "Fire and Smoke Model", the atmospheric attenuation A_L of the transmitted optical signal rely on the absorption and scattering via atmospheric aerosols can be obtained as [17]:

$$A_L = 10\log(e^{-\sigma R}) \qquad (1)$$

where σ is the attenuation coefficient that describes the scattering and absorption effects, and R is the maximum range that can be reached (availability of light source in every direction) based on the transceiver's optoelectronic characteristics. For FSO communications, 'Mie" scattering dominates the other losses and σ (km) can be expressed in terms of the visibility V (km) for a transmitting wavelength λ [19]:

$$\sigma = \frac{3.91}{V}(\lambda/550)^{-q} \qquad (2)$$

where q represents the distribution size of the scattering particles that rely on the visibility. (i.e.: $q = 1.6$ (for $V \geq 50$ km, 1.3 (for 6 km $\leq V < 50$ km), and 0.585 (for $V < 6$ km). The crude oil fire can be assumed to be of arbitrary shape as shown in Fig. 1. The proposed simulation setup for the MIMO-FSO system illustrates in Fig. 2.

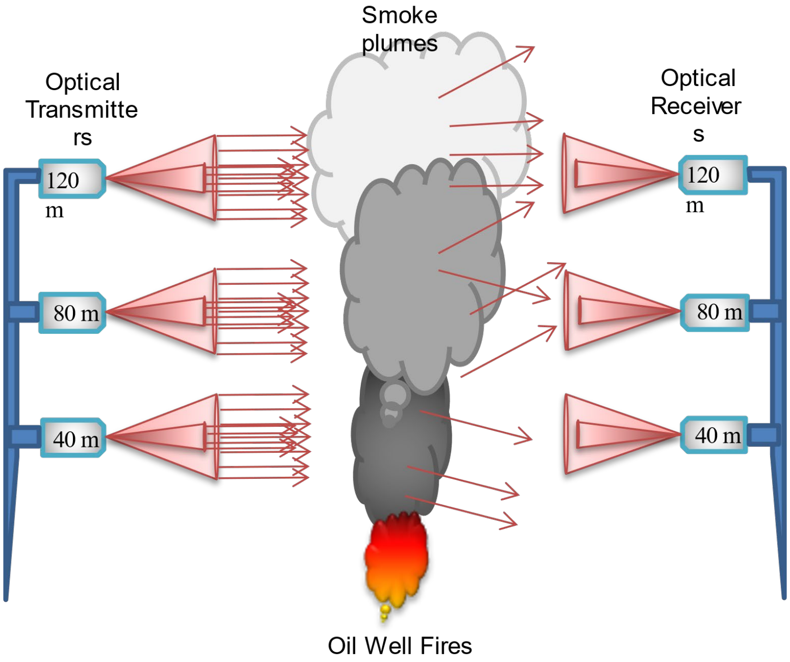

Fig. 1. Block diagram of vertical MIMO- FSO system.

The simulations are carried out in a circular area with diameter length of (0.5) kilometres. Commonly, the smoke rose through three cloud layers with high, medium and low optical density. They cause dissimilar reduction in atmospheric visibility depends on the smoke particles concentration [3, 6].

For optimizing received average power and Dispersion Compensation, the laser beams propagate through three vertical FSO channels. These channels will be at different heights to overcome the line-of-sight (LOS) Limitations of the horizontal channels. Each FSO system comprises of laser transceivers which is including transmitter and receiver units.

The proposed transmitter includes pseudo random bit sequence to generate a binary sequence of pseudo random bits, NRZ pulse generator to generate a series of non-return to zero pulses that are coded by a digital input signal, continuous wave (CW) laser diode, external Mach-Zehnder modulator for controlling the amplitude of an optical wave and Fork 1Xn to split the input signals into a number of output signals.

The proposed receiver unit comprises: power combiner to combine the optical power in two or more waveguides into a single waveguide, an avalanche photodiode (APD) to convert laser into electrical signal that filtered out by the low pass Bessel filter, 3R regenerator help to regenerated this filtered signal, BER analyzer analyse the Bit error rate (BER), quality (Q) factor (For good signal reception, the minimum Q factor is 6 and the BER value is 10^-9) [17] that used to evaluate the quality of received signal and diagnose problems such as attenuation, noise and dispersion in the system, and finally an optical power-meter to measure the optical power [20, 21]. Simulation parameters values are listed in Table 1.

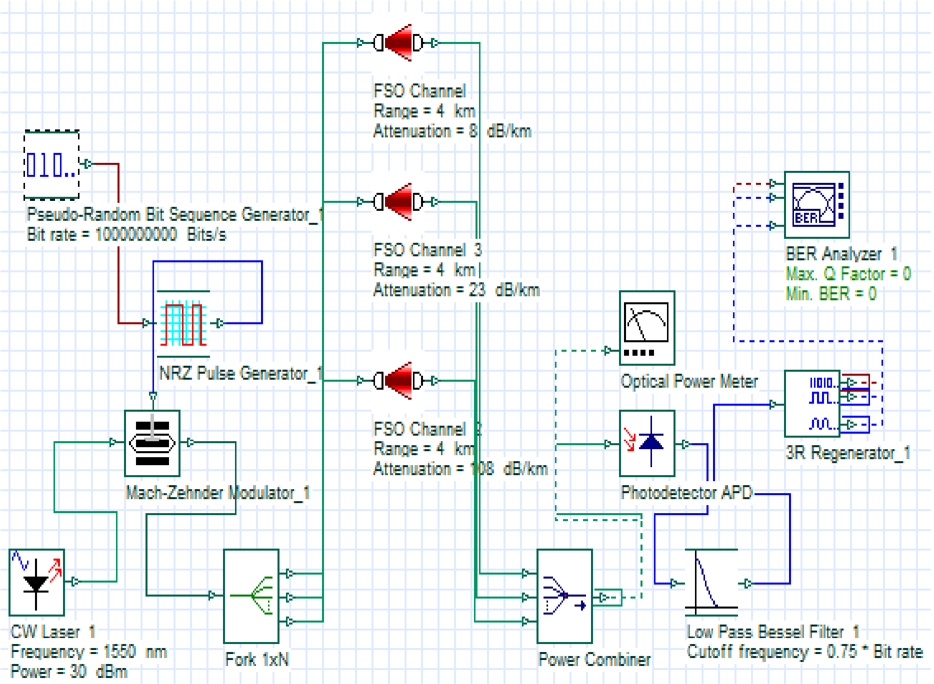

Fig. 2. Block diagram of the proposed MIMO-FSO simulation setup.

Table 1. Simulation parameters of the proposed FSO link [22].

Parameters	Values
Wavelength	1550 nm
Beam Divergence	0.5-3 mrad
Transmitted Power	30.0 dBm
Transmitter Diameter	5.0 cm
Transmitter efficiency	0.5
Receiver sensitivity	-20.0 dBm
Receiver Diameter	20.0 cm
Receiver efficiency	0.5

3. Results and Discussion

Tables 2-5 illustrate average results for the performance analysis values, including the receiving power, Q-factor and BER. The beam sizes are adjusted from 0.5-3 mrad to estimate the optimum beam sizes over various transmission link distances of 1-4 kilometres.

Table 2. Performance analysis of the Link distance 1 km.

Diverging angle (mrad)	Receiving Power (dBm)	Receiving Power (W)	Q-Factor	BER
0.5	4.0	3 e-3	217	0
1	-0.8	831 e -6	155	0
1.5	-4.18	831 e -6	117	0
2	-6.6	218 e -6	93.3	0
2.5	-8.2	151 e-6	79.7	0
3	-9.5	113 e-6	70	0

Table 3. Performance analysis of the Link distance 2 km.

Diverging angle (mrad)	Receiving Power (dBm)	Receiving Power (W)	Q-Factor	BER
0.5	-8.4	143 e-6	77.8	0
1	-12.8	52 e-6	49	0
1.5	-15	31 e-6	38.3	1.43 e -32
2	-16.4	22 e-6	32.8	1.43 e -23
2.5	-17	18 e-6	29.4	1.9 e-190
3	-18	15 e-6	27	4.1 e-162

Table 4. Performance analysis of the Link distance 3 km.

Diverging angle (mrad)	Receiving Power (dBm)	Receiving Power (W)	Q-Factor	BER
0.5	-16.2	23.6 e-6	33.5	1.74 e-24
1	-19	12.7 e-6	24.6	2.42 e-13
1.5	-20	9.7 e-6	21.5	2.21 e-10
2	-20.7	8.4 e-6	20	3.01 e-08
2.5	-21.1	7.7 e-6	19	3.3 e-081
3	-21.5	7 e-6	18.3	4.85 e-07

Table 5. Performance analysis of the Link distance 4 km.

Diverging angle (mrad)	Receiving Power (dBm)	Receiving Power (W)	Q-Factor	BER
0.5	-20.4	9.1 e-6	20.8	1.27 e-09
1	-21.6	6.9 e-6	18	3.07 e-07
1.5	-22	6.2 e-6	17	5 e - 066
2	-22.2	5.9 e-6	16.6	1.49 e-06
2.5	-22.4	5.7 e-6	16.3	1.67 e-06
3	-22.5	5.6 e-6	16.1	3.71 e-06

The receiving power availability as a function of beam divergence angle θ for various transmission links illustrated in Fig. 3.

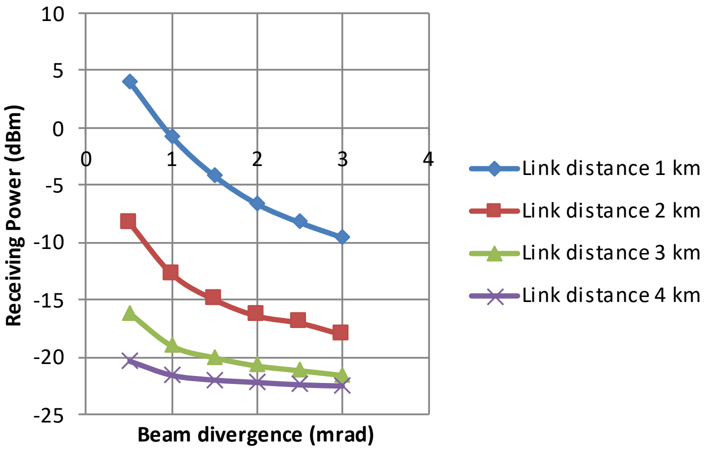

Fig. 3. Receiving power vs. beam divergence for different link distance.

The Q-factor has been studied as a function of free space medium parameters such as Beam divergence and link distance to estimate the influence of the smoke plume. The variation of Q- factor vs. beam divergence angle θ for various transmission links illustrated in Fig. 4. An intensity temporal fluctuation can be observed at some Link distance as a result of optical power losses due to temperature variation [23]. It is observed that the increase in link distance, results in decreasing of the values of the Q- factor for all transmission divergence angles under similar atmospheric conditions. Also, it is observed that all the values of Q-factor is (> 6), which is represent good signal reception [10]. Moreover, from the obtained results it’s found that there is a sharp decrease in the received power and Q-Factor at the low values of Beam divergence while, by increasing the values of beam divergence, the link performance will be more stabilized (improved) and helps in receiving the signal better.

Finally, it is noticed that the proposed system has demonstrated better results than the well knowing models under similar atmospheric conditions [22]. Comparing to the single-input single-output (SISO) system [22] under same conditions at 1 km distance and 1 mrad divergence angle, the Q-factor= 4 and the receiving power = -67dBm, while in the proposed system Q -factor= 155 and the receiving power= -0.8 dBm. Also, for 1 km distance and 2 mrad divergence the Q-factor= 0 and the receiving power= -77 dBm, while in the proposed system Q -factor =93.3 the receiving power=-6.6 dBm. From other hand, comparing to horizontal (MIMO) system [18] at a distance of (1.5 km) and 2 mrad divergence the Q-factor= 12 -16 and the receiving power= - 48 dBm under same smoke conditions. Thus, the proposed system is much better than (SISO) and horizontal (MIMO) systems which is mean less error, low loss and better stability in line of sight. For the future work this system can be tested under heavy rain and dusty regional environments.

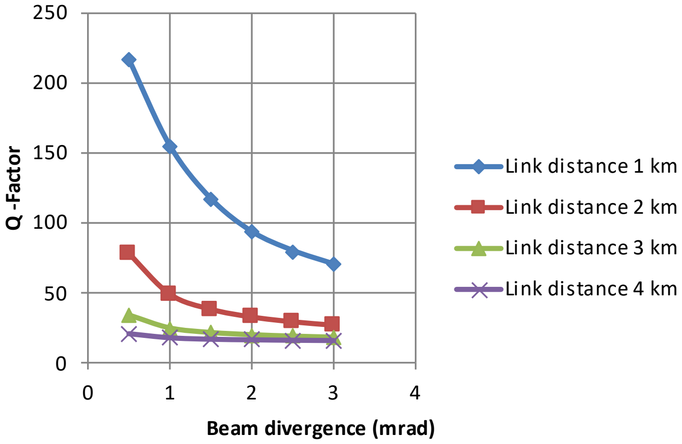

Fig. 4. Q-Factor vs. beam divergence for different link distance.

4. Conclusion

The novelty of this paper is in the new design of vertical MIMO-FSO system that analysed under varying smoke plumes density for various influencing factors such as; transceivers heights, beam divergence and link distance. It is observed that the received power and Q-Factor in the proposed model has demonstrated better results than the well knowing models (such as SISO and horizontal (MIMO) systems) under similar atmospheric conditions. Hence, it reduces optical signal attenuation and improves the stability of line of sight. The significance of this optimized performance system is its ability to be a good choice for regional environments that suffer from frequent oil wells fires.

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