# Performance of Free Space Optical Communication Link under Foggy Weather

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***Abstract*—**In recent years, free space optical communication (FSO) has received considerable attention as a cost-effective, free-to-license and broadband approach to high data rate applications. However, the performance of the FSO connection suffers greatly from fading caused by the disturbance caused by different weather conditions. The weather considers a worthy influence on the laser beam to transmit over the atmosphere. The attenuation weather results in the quality of the receiver signal. This paper investigates the quality of the FSO communication system under foggy weather conditions. The analysis of the system based on the measured receiver signal, bit rate error and signal to noise ratio in an optical communications link.

***Index Terms*—**FSO, optical communications, OptiSystem 7.0, atmospheric attenuation, SNR, BER

## I. INTRODUCTION

Free Space Optics (FSO) is a type of communications technology which uses light for wireless transmission of data through the air as the same of fiber cable. Free Space Optics has the similar ability to fiber optics, but there is a very big difference in low cost and Very high spread. They are characterized by great speed, relatively low cost, very large frequency range, fast manumitting and installation, very safe and very large protection, as well as long range spectrum which is free of licenses. Free Space Optics (FSO) anticipate the laser technique, which employs light sources to transmit data through the air under an indistinguishable climate. The motivation of the FSO is to discard the cost, effort and time anticipated that would present the fiber optic connection, but then to keep up high information rates (up to 1 GB/s and past) for exchanging video cuts, sound, information, and pictures. Sending utilizing FSO is generally straightforward. Contrasted with Radio Frequency (RF) system, FSO system works have a high optical transmission capacity, which encourages fast information exchange [1]. Regardless of the benefits of FSO, these systems experience the ill effects of a few weaknesses. Where air unsettling influences and system blunder mistakes are the most harming wonders in these systems. Where climatic unsettling influence causes vacillations in the power of the getting sign and its optical stage, prompting a serious corruption of optical connection execution [2]. What's more, directing blunders can likewise prompt a debasement in the execution of FSO frameworks. Warm extensions, powerless quakes and dynamic breeze loads cause building motions, which cause mechanical vibration of the transmitted beams, resulting in communication problems between transmitter and receiver. FSO contains three components: a transmitter, an air channel, and receiver. Transmitter is considered as an optical source Laser Diode (LD) or Light Emitting Diode (LED) to transmit optical radiation through the atmosphere channel follows the Beer-Lambert‘s law [3**]** but wireless communication is a technology that has its own limits [4], a proper understanding of optical signal propagation in different atmospheric conditions has become essential, and thus arises the need to rationalize the effects of atmospheric channel on terrestrial FSO links. Which FSO link has become poor performance even link failure by a bad weather and losing in the atmospheric along the path link, it becomes a great challenge in FSO communications. This includes (fog, rain, dust, smoke, and turbulence, etc) [5], [6], also the intense scintillation effects causing the most severe impairment to the FSO links [7]. One of the solutions proposed to address the turbulence is by using hybrid system (FSO switches to RF) [8], or using Multiple-Input Multiple-Output (MIMO) FSO systems [9], or by decreased divergence angle and increasing receiver diameter [10].

## II. MODELS OF FOG SPECIFIC ATTENUATION

The atmosphere contents many particles such as (rain, fog, dust, etc.) effect on the signal and causes attenuation but the fog is dominant. It is considered a harsh weather and reduces the visibility. Mie scattering theory was the accurate way to calculate the attenuation by fog. This theory requires more information about particle size, refractive index, and particle size distribution. The Fog was inhomogeneous phenomena and change from time to another [11]. Another way used to calculate fog attenuation based on visibility data. These ways modeled by Kruse, Kim and Al-Naboulsi [12]–[14] use the approach to estimate the attenuation for the collecting data of visibility. For Kruse model the attenuation [12] is written as:

$$\gamma(\lambda)=\frac{3.912}{V}*\left(\frac{\lambda_c}{550}\right)^{-q} \tag{1}$$

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Here γ(λ) is specific attenuation, *V(km)* stands for visibility, λ in nm stands for wavelength and the quantity coefficient q is depends on:

$$q = \begin{cases} 1.6, & if \quad V \rangle 50km \\ 1.3, & if \quad 6km \langle V \langle 50\,km \\ 0.585V^{1/3}, & if \quad V \langle\ 6km \end{cases} \qquad (2)$$

Equation (2) obey for any meteorological condition, this means that for higher wavelengths, the attenuation becomes lower. Kim revealed that a case of low visibility, the wavelength dependent on the attenuation under the dense fog. The parameter q for the Kim model [13] is given by:

$$q = \begin{cases} 1.6, & if \quad V \rangle 50km \\ 1.3, & if \quad 6km \langle V \langle 50\,km \\ 0.16V + 0.34, & if \quad 1km \ \langle V \langle\ 6km \\ V - 0.5, & if \quad 0.5km \langle V \langle 1km \\ 0, & if \quad V \langle\ 0.5km \end{cases} \qquad (3)$$

## III. Optical Communication Link Model

We explore three significant parameters to show the performance of optical communication links:

### A. Received Signal Power

Suppose the situation of laser beam propagation between two points in FSO. Consider a laser transmission with a power $P_{trans}$ at the wavelength λ. The received signal power can be detected by the photodetector and formulated as [15]

$$P_r = P_t \frac{D^2}{(\theta.L)^2} * \exp\left(\frac{-\gamma.L}{10}\right) \tau_t \tau_r \qquad (4)$$

where $D_r$ is the receiver diameter, θ is the divergence angle, γ is the attenuation factor (dB/m), $\tau_t$, $\tau_r$ are the transmitter and receiver optical efficiency respectively.

### B. Signal to Noise Ratio (SNR)

The free space optical propagation link model can be suggested to evaluate the performance optical wavelengths with Line of Sight (LOS) link. The (SNR) requirements are produced from the formula [16]:

$$SNR = P_t - 30 + G_T + G_R - 20\log\left(\frac{4\pi}{\lambda_c}\right) - 10\log(k_B.BW.T) - \gamma - NF - FM \qquad (5)$$

where:

$P_T$: the transmitter power; $G_T$: the transmitter antenna gain;$G_R$: the receiver antenna gain; $\lambda_c$ : wavelength; $k_B$ : the Boltzmann's constant ($1.38*10^{-34}$ J/K). The receiver Bandwidth (B.W=1 MHz), T: the ambient temperature in K,NF: is the receiver noise figure,

Fm: is the Fade margin, and γ: is the total attenuation in dB/km. The maximum link distance (L) is given by [17]:

$$L = 10^{\gamma/20} \qquad (6)$$

The transmitter $G_T$ and receiver $G_R$ antenna gains are given by the following:

$$G_T = \frac{32}{\theta_{div}^2} \qquad (7)$$

$$G_R = \left(\frac{\pi.D_r}{\lambda_c}\right)^2 \qquad (8)$$

where $D_r$ is the receiver aperture diameter and $\theta_{div}^2$ is the divergence beam which can be written as follows:

$$\theta_{div}^2 = \frac{4\lambda_c}{\pi.D_t} \qquad (9)$$

where $D_t$ is the transmitter aperture diameter and $\lambda_c$ is the wavelength

### C. Bit Error Rate (BER)

For the optical link, the basic formula obeys to an exponential behavior of the length of the path (L) as eqs. (4-6) [18], [19]. Also, the Bit Error Rate (BER) can basically determine the average probability of selecting the wrong bits. BER is inversely related to the Signal to Noise Ratio (SNR) and can be written as: [20], [21].

$$BER = \left(\frac{2}{\pi.SNR}\right).\exp\left(\frac{-SNR}{8}\right) \qquad (10)$$

## IV. Design and Simulations

The first step in designing a wireless communication, such as FSO communication system in different media channels is to know what happens to an optical wave or a signal as it travels through that medium. The tremendous bandwidth favorable by FSO communications is available only under clear weather case. Where there is no dispersion and power loss is practically zero. However, this is not a realistic situation and to exploit is the large potentials of FSO communications, appropriate measures should be used in transmitter and receiver devices. Using (OptiSystem version 7.0) simulation software, a design of free space optical Link at 1km. This system is equipped with a wavelength of 1550 nm and the ability of about 30 dBm. The transmitter contents the PRBS (Pseudo Random Bit Sequence) generator, NRZ pulse generator, laser source and the Mach Zehnder Modulator (MZM). Using the simulation system, the data generated by the PRBS generator is encrypted at 2.5 Gbps, and the transmitted light is encrypted using MZM, where the laser source is considered as the main source of information, the laser is Pass through the one air channels in free space, to be provided the air channel capacity of approximately 30dBm. Where the opening of the active area for receiver are determined for (1≤ D(cm)≤ 10). The beam divergence is (1≤ θ(mrad) ≤ 3), and the calculation contents all the loss effect on the link and we can show the simplex main design model can be shown in Fig. 1.

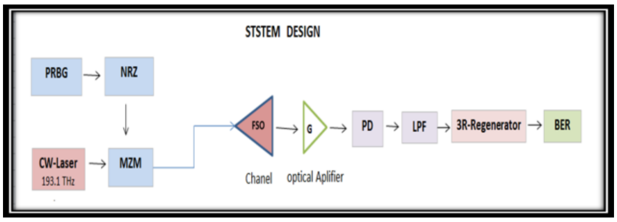


Fig. 1. Simulation layout of 1TX/1 RX FSO system.

In the link design, the loss effect on the main link of a free space optical communication system resulting from different weather condition (Haze, Light fog, Heavy Fog) is studied. The optical signals propagate along of FSO channel are received by (APD) photodetector. These simulations use three visualizers namely optical power meter to measure the power received, the quality of signal power, finally a Bit Error Rate (BER) analyzer.

## V. Results and Discussions

Consider a case of optical laser diffusion between two points in ground applications. Therefore, the attenuation coefficient, optical receiver power, SNR and BER of the 1550nm laser beam were studied in this simulation. FSO systems are analyzed with power (30 dBm), a range of 1 km under different weather conditions. The infrared laser was used with the parameters contained in the table (1) together with other parameters assumed in this simulation. The achievement of the FSO communication system can be evaluated and examined by the quality of the receiver signal power and signal to noise ratio. This work focus on the best performance of FSO communication link and the quality of the signal under the different foggy weather. The investigating carried out based on the computer simulation to model the weather effect on the optical link and operation parameters are shown in the Table I.

TABLE I: SYSTEM OPERATING PARAMETERS WHICH USED IN THIS SIMULATION [22]-[23]

| Operating parameter | | value |
|---|---|---|
| Wavelength | | 1550 (nm) |
| Transmitter power | | 30mw |
| Transmitter divergence angle | | 1≤ θ (mrad) ≤ 3 |
| Efficiency of transmitter | | 0.8 |
| Efficiency of receiver | | 1 |
| Sensitivity of receiver | | -20dBm |
| Diameter of receiver | | 1≤ D (c m)≤ 10 |
| Range | | 1≤ L (m) ≤ 1000 |
| The APD gain | | 100 |
| System temperature, T | | 290K |
| Noise figure, FT | | 4dB |
| Weather condition | Haze | 7.76 |
| | Light Fog | 15.98 |
| | Heavy Fog | 34.95 |

Fig. 2 represents the receiver power signal with the diameter of the receiver under the influence of weather case. The power of the signal for (1550 nm) has been increased with increasing receiver diameter. It is also noted that 1550nm wavelength is very high signal power received when there is haze compared to other conditions.

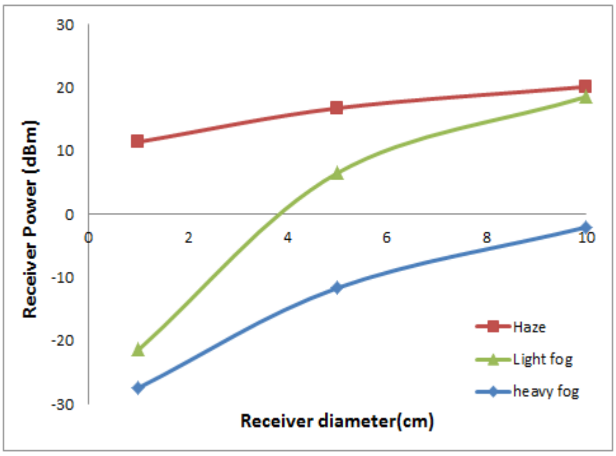


Fig. 2. Receiver signal power versus receiver diameter aperture.

Fig. 3 represents the intensity of the receiver signal with the change of divergence angle of the laser same conditions, where optical signal power suffers from problematic with increased transmitter divergence angle. It is also noted that the wavelength of 1550 nm is a very high reception power in haze weather compared to other conditions.

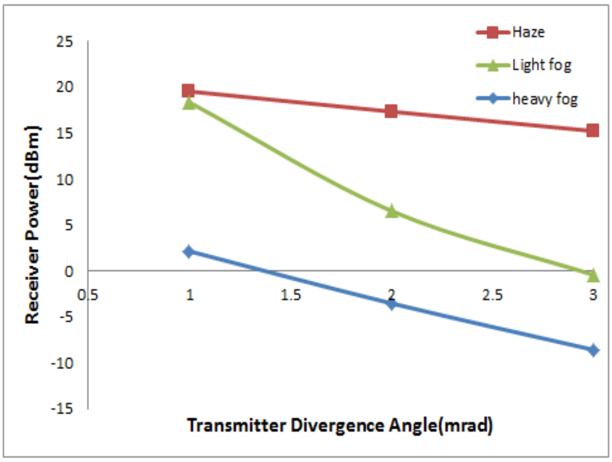


Fig. 3. Receiver signal power versus transmitter divergence angle.

To study the quality of the signal to noise ratio under the foggy weather, the analyzed and the simulation results as shown in Fig. 4. It is observed that when the diameter of the receiver increases, the signal to noise is increasing directly under various weather case, especially in the case of the haze, which is as high to the same diameter of the receiver. In the case of heavy fog, the proportion of the signal to noise ratio was low.

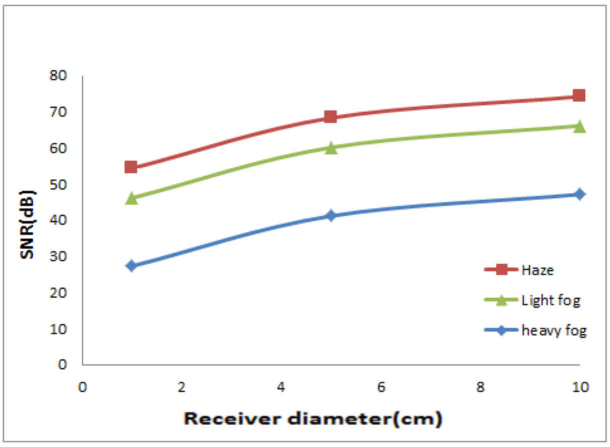


Fig. 4. Signal to Noise Ratio (SNR) verses receiver diameter aperture.

The signal-to-Noise Ratio (SNR) was plotted against the transmitter divergence angle as shown in Fig. 5. When the divergence angle increased the signal to noise ratio is decreased, especially in the case of heavy fog. Where SNR about 38 dB for heavy fog. While for haze about 65 dB.

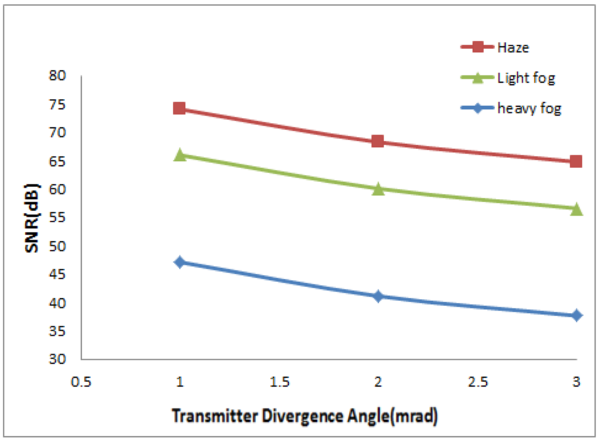


Fig. 5. Signal to Noise Ratio (SNR) versus transmitter divergence angle

Fig. (6) represents the Bit Error Rate (BER) versus receiver diameter. The (BER) is a decline when the diameter of the receiver increases under different weather conditions, especially in the case of heavy fog. While for haze weather the BER has linear behavior.

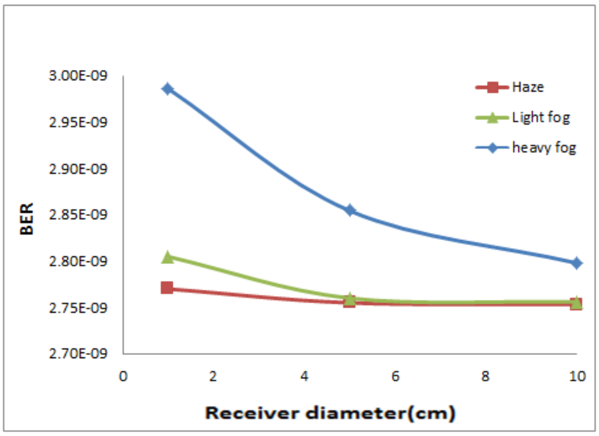


Fig. 6. Bit Error Rate (BER) verses receiver diameter aperture

The Bit Error Rate (BER) was plotted as a function of transmitter divergence angle for different weather conditions as shown in Fig. (7). The bit error rate increases with increasing transmitter divergence angle, it is noted that the highest error in the received bits was recorded in the case of heavy fog, while the lowest error of the received bit error rate was recorded in haze weather at the same transmitter divergence angle.

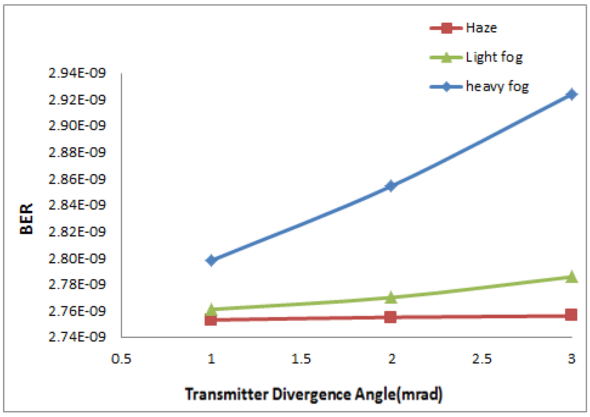


Fig. 7. Bit Error Rate (BER) versus transmitter divergence angle.

## VI. Conclusion

FSO systems offer a viable solution towards building visual communication in a cost-effective, performance-fast and reliable manner in certain situations. However, different weather conditions such as fog effects will affect the work of FSO communications systems. In this paper, we discussed the impact of fog weather as consider the important parameter affecting the performance of FSO system.

The received signal power and signal to noise ratio were performed in fog weather conditions. The results showed that BER increased by increasing the divergence angle and the strength of the received signal increased significantly with the increase of the receiver diameter for the parameters under study. It was noted that haze and the light fog had a preference performance and that the signal was of good quality compared to heavy fog**.**

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