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The Vulnerability of Free Space Optical Communication Systems Against Severe Weather Conditions

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Abstract. This paper presents the effect of atmosphere attenuation during serve weather conditions such as clear, fog and rain weathers. The usage of FSO is still rare in all the world due to environmental factors but it can be use in EGYPT because it has a good weather most of days and high visibility. FSO links are depends on the weather conditions and attenuation factor like temperature, height, visibility and the operating wavelength. In this paper, the attenuation of different wavelengths of the FSO links has been analyzed.The main aim is to examine the vulnerability of FSO against severe weather conditions. Models have been designed to simulate most of the weather conditions in Egypt by using MATLAB software and Application designer interface. Also, optimization has been done for the parameters to improve the FSO link capability to detect the weak signal at the maximum range.

Keywords: Free space optical communication, atmospheric attenuation and scattering, turbulence, noise.

1. INTRODUCTION

Free space optical communication (FSO) is a wireless communication technology which employ the light to transmit data through the free space without any wire[1]. FSO have the same capability of fiber optics [2], FSO use laser source and detector to transmit and receive data through the atmosphere, same as Fiber Optics Link which use laser source and detector to transmit data but through fiber cable. The purpose of using FSO is to eliminate the cost, time and speed of installing the fiber optic cable. FSO system are used in various area, it can be used for network extension in area which need to connect new network rings, and in military systems. FSO technology have many features that attract military interest, because it can be easy and rapid development, high transmission rate and high security. FSO can solve the last-mile connection problem because its higher transmission speed of data, which can reach to 2.5 GbPs. FSO system is affected by the atmospheric conditions such as clear, fog, dense fog, light rain, medium rain, heavy rain and etc. [3]. This is due to the absorption and scattering of the light signal propagating through the atmospheric channel and turbulent distortion of amplitude of an optical system. Most of FSO systems operate at 850 nm, 980 nm and 1550nm wavelengths.

2.System Configuration:

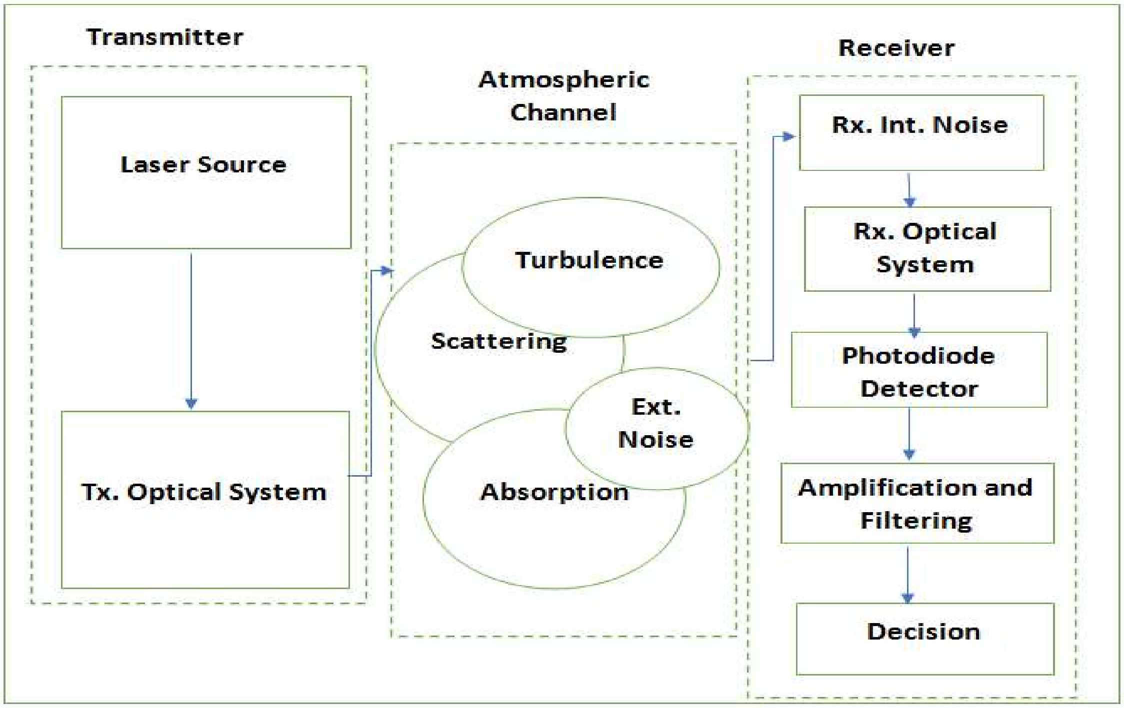

Figure1: FSO System Configuration

Figure 1. shows the model of Free space optical communication. First blockis the laser pulse formation ,second block represents the whole types of attenuation that can be found in the atmosphere such as turbulence, absorption and scattering. In the receiver side the optical system block has been done to focus the radiation on the sensitive area of the photo detector, the next block represents the noise, this noise includes external and internal noise, internal noise includes shot and thermal noise, external noise includes solar background noises, it is one of the most significant sources of noise. The photodiode block which carrying out the function of transforming the optical signal to electric one. The amplification block to control the required gain factor for the electrical signal and to filter the required signal only. The last block is the decision block.

3. Attenuation models for FSO channel

The atmospheric losses play an important role in FSO channel. So FSO channel must aware of the losses such as turbulence distortion, temperature sensitivity, absorption and scattering losses. These losses are wavelength dependence, so choosing the best wavelength is important to minimize these losses. Also decrease the background noise will improve the channel efficiency.

3.1 Turbulence Distortion

Turbulence distortion occurs due to atmospheric refraction, it makes distortion in the amplitude of the optical signal.This distortion can be given by [5]:

$$KA(\lambda) = \exp(-\sigma\mathrm{I}) \qquad (1)$$

Where $\sigma\mathrm{I}$:
is the the dispersion of logarithm emission intensity for heavy fluctuations [6]:

$$\sigma_l^2 = 1 - (1 + 6\,\sigma_o^2)^{-\frac{1}{6}} \qquad (2)$$

$$\sigma_o^2 = 1.23\ Cn^2\, K^{\frac{7}{6}} R^{\frac{11}{6}} \qquad (3)$$

where σ_o: *is the* the dispersion of logarithmic emission intensityfor slack fluctuations

$K = \dfrac{2\pi}{\lambda}$ *is the wave number*
λ: is the wavelength

C_n^2: is the structural constant of atmosphere refraction coefficient, it depends on temperature, relative humidity and wind speed.
R: is the distance to the emission source

$$C_n^2 = a_1 W + b_1 T + c_1 R_H + c_2 R_H^2 + c_3 R_H^3 + d_1 W_S + d_2 W_S^2 + d_3 W_S^3 + e \qquad (4)$$

Where a1, b_1, c_1, …..,e are numerical regression coefficients; W is temporal hour weight; T is the temperature(kelvin); R_H is relative humidity (%); W_S is wind speed (ms^{-1}).

3.2. Absorption Attenuation

Absorption attenuation can be happened when a laser beam travels in the atmospheric channel, it encounters with many gas molecules which, present in the atmosphere. This attenuation can be given by [7]:

$$a = -0.000545\,\lambda^2 + 0.002\,\lambda - 0.0038 \qquad (5)$$

$$b = 0.00628\lambda^2 - 0.0232\lambda + 0.0439 \qquad (6)$$

$$c = -0.028\lambda^2 + 0.101\lambda - 0.18 \qquad (7)$$

$$d = -0.228\lambda^3 + 0.922\lambda^2 - 1.26\lambda + 0.719 \qquad (8)$$

$$\tau' = a \cdot h_E^3 + b \cdot h_E^2 + c \cdot h_E + d \quad \text{km}^{-1} \qquad (9)$$

$$A_S = \frac{4.3429\,\tau'}{\sin(\theta)} \qquad 0 \; (10)$$

where a, b, c, d are the empirical coefficients, h_E is the height of the earth station above mean sea level (km), λ is the wave length in μm, τ` extinction ratio,**θ** is the elevation angle in degrees, A_S is the atmospheric attenuation due to absorption. Absorption attenuation can be given by [6]:

$$T_{absorption}(\lambda) = \exp(-As\,R) \qquad (11)$$

3.3Scattering Attenuation

Scattering can happen when the size of atmospheric particle is smaller than the wavelength, when size of particle and wavelength are equal, scattering occurs. The various atmospheric conditions that produce these types of losses are clear, rain and fog weathers. Clear and fog weathers are dependent on wavelength and visibility. As visibility increasesthe attenuation decreases, but rain is dependent on the rate of rainfall. Scattering attenuation can be given by [8]:

$$T_{Scattering}(\lambda) = \exp(-\alpha R) \qquad (12)$$

Where α is the atmospheric attenuation due to scattering.

- **Clear Weather**

In clear weather case; the attenuation is very small,Clear weather can found when the visibility is high and the attenuation is low, the amount of attenuation in the clear weather is from 0 to 3 dB/km. Scattering attenuation at clear weather can be given by[1]:

$$\alpha(\lambda) = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-\frac{1}{3}} \qquad (13)$$

Where V is the visibility by (Km). It must be greater than 10Km, λ is the wavelength by nm.

- **Fog Weather**

Fog is the most important attenuation factor, because it results in both scattering and absorption so, it will make the transmission distance decreases. Under dense fog, visibility is reduced to 50m and attenuation is increased to 350dB/km, which limits the FSO performance. The attenuation due to fog can be given by [3]:

$$\alpha(\lambda) = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-P} \qquad (14)$$

Where p is the particle size coefficient.Value of P is given by:

$$P = \begin{cases} 1.6 & V > 50\text{ Km} \\ 1.3 & 6\text{ Km} < V < 50\text{Km} \\ 0.1V + 0.34 & 1\text{Km} < V < 6\text{ Km} \\ V-0.5 & 0.5\text{ Km} < V < 1\text{ Km} \\ 0 & V < 0.5\text{ Km} \end{cases} \qquad (15)$$

- **Rain Weather**

Rain droplets are larger in size as compared to the wavelength used in FSO communication, it depends on the rate of rainfall.Attenuation due to rain can be given by [9]:

$$\alpha_r = 1.076 * R_n^{2\backslash 3} \qquad (16)$$

Where R_n is the rate of rainfall (mm/h) it has range from 0.25 mm/h to 25 mm/h.

4.Results and Discussions

The results of given free space optical communication system can be taken out by using the following parameters for transmitter: power = 25mw, gauss pulse mean =35nsec, standard deviation=13nsec, beam divergence =3mrad andtransmitter diameter=30mm,forlink atmospheric:wavelength=780,1046,1550nm, and structural constant of reflection coefficient=$52 * 10^{-17}$. and for receiver:receiver diameter =30mm, focal distance =40mm, band width =33MHz, photodiode sensitive area diameter =0.5 mm and receiver diameter =30mm.

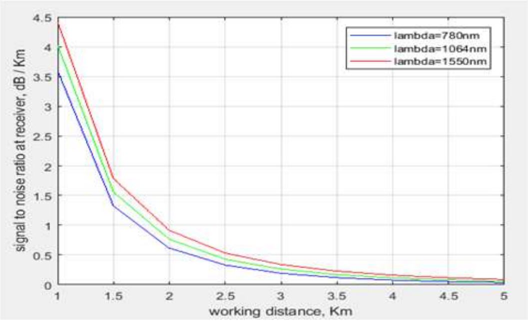

Figure 2: Signal to Noise Ratio with Working Distance for different wavelengths.

Figure2. Illustrates the relation between the signal to noise ratio and the working distance at clear weather case at different operating wavelengths. Basically, the graph shows that wavelength with1550nm gives less effect of atmospheric attenuation than 780nm and1064nm, at wavelength 1550nm, maximum range is 1.9 Km but at wavelength 780nm, maximum range is 1.7 Km, so 1550nm will give the best performance [2].

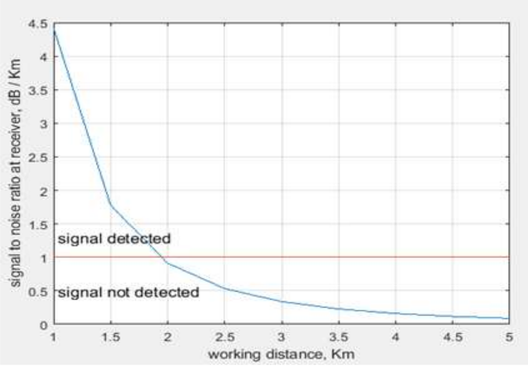

Figure 3. Signal to Noise Ratio with Working Distance at clear weather

Figure3. depicts the simulation of SNR with working distance at clear weather. It has been observed that when the SNR over one the receiver will be detected the transmitted signal, otherwise the signal will not be detected. In this figure at clear weather the signal will be detected maximum up to 2Km.

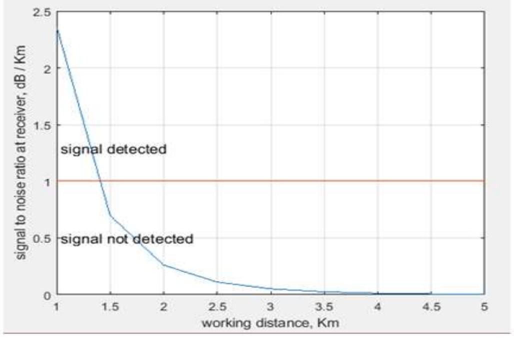

Figure 4. Signal to Noise Ratio with Working Distance at Fog weather

Figure 4. depicts the simulation of SNR with working distance at fog weather. It has been observed that the signal will be detected when the SNR above one. In this case the maximum range will be 1.2Km.

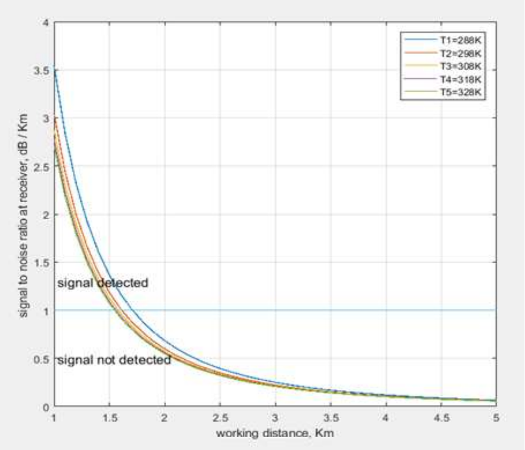

Figure5. Signal to Noise Ratio with Working Distance at different temperature

Figure 5. Shows the effect of changing temperature on signal to noise ratio, it was observed that at low temperature, signal to noise ratio increased and the signal can be detected at long distance, but at high temperature signal to noise ratio decreased because at low temperature the structural constant of refraction index decreased, so turbulent effect can be weak and attenuation can be decreased. But at high temperature the structural constant of refraction index increased, turbulent effect can be strong and attenuation can be increased [4].

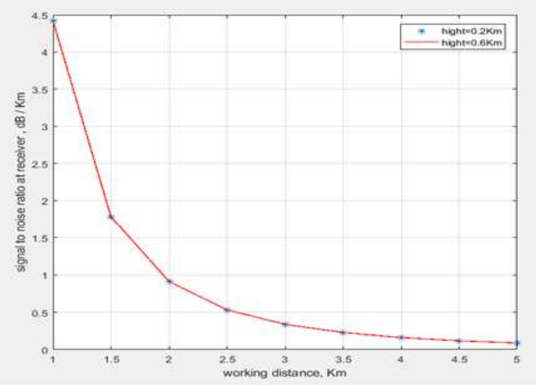

Figure 6. Signal to Noise Ratio with Working Distance at different height

Figure6.Illustrates the relation between signal to noise ratio and working distance at different heights , it was observed that the effect of absorption changed with very small value that not observed, which can be neglected[8].

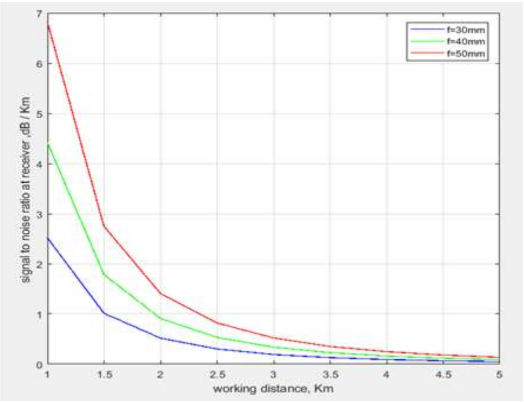

Figure 7. Signal to Noise Ratio with Working Distance at different focal lengths

Figure.7. depicts the simulation of SNR with working distance at different focal lengths. It has been observed that as focal length of the receiver increases the performance of detection will increase .For example, at focal length 30mm and working distance 1Km the SNR is 2.5, and at focal length 50mm and same working distance, SNR is 6.8. It was clear that for a reduction in background radiation, it is necessary to reduce the field of view of the receiver by increasing the focal length and reducing the dimension of sensing area of the photo detector [10]

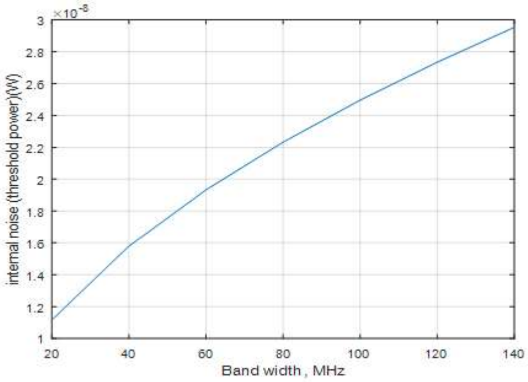

Figure 8. Threshold Power with Band Width

Figure8. depicts the simulation of SNR vs bandwidth. It has been observed that the spectral bandwidth of the optical filters should be as small as possible in order to decrease the level of the background radiation and to increase the detection range. And in addition to decrease the power threshold, to detect the lower signals.

5.CONCLUSION

Atmospheric effects are the main challenge to design any FSO links as the transmission channel is free space. In this paper the system designed to simulate FSO system in different atmospheric conditions considering Clear, Foggy and Rainy weathers. The model has been designed to optimize the parameters which can improve the detection of the weak optical signals. First point in our design, for choosing the best wave length, the wavelength 1550 nm was detected to give the lowest attenuation. Second point was the maximum signal to noise ratio, first at clear weather was considering 4.4 dB/Km which give detection range 2 Km, second at fog weather the maximum signal to noise ratio was considering 2.3 dB/Km which gave detection range 1.2 Km. then considering the effect of atmospheric turbulence was discussed, it was observed that by increasing the temperature the attenuation will be increased. Next the effect of the absorption attenuation can be neglected due to its lower effect. Lastly for improving the detection, it was necessary to reduce the background radiation or reduce the threshold power. The background radiation depends on field of view of the receiver, it can be decreased by increasing the focal length, so as focal length of the receiver increases the performance of the detection will increase. Also, for reduce the threshold power, the spectral bandwidth of the optical filters should be small.

REFERENCES

[1] A. Kumar, A. Dhiman, D. Kumar, and N. Kumar, “Free Space Optical Communication System under Different Weather Conditions,” *IOSR J. Eng.*, vol. 3, no. 12, pp. 52–58, 2013.

[2] B. S. Naimullah *et al.*, “Comparison of wavelength propagation for free space optical communications,” *2008 Int. Conf. Electron. Des. ICED 2008*, pp. 4–8, 2008.

[3] R. Bajwa, “Effect of Different Atmospheric Conditions on the,” *2018 5th Int. Conf. Signal Process. Integr. Networks*, pp. 390–395, 2018.

[4] A. Touati, A. Abdaoui, F. Touati, M. Uysal, and A. Bouallegue, “On the Effects of Temperature on the Performances of FSO Transmission under Qatar’s Climate,” *IEEE Veh. Technol. Conf.*, vol. 2017–June, pp. 1–5, 2017.

[5] M. Al-Jaberi, M. Richardson, J. Coath, and R. Jenkin, “The simulation of laser-based guided weapon engagements,” 2006, p. 622814.

[6] D. Sadot, “Forecasting optical turbulence strength on the basis of macroscale meteorology and aerosols: models and validation,” *Opt. Eng.*, vol. 31, no. 2, p. 200, 1992.

[7] N. A. M. Nor, R. Islam, W. Al-khateeb, and A. Z. Suriza, “A TMOSPHERIC E FFECTS O N F REE S PACE E ARTH -T O -S ATELLITE O PTICAL LINK IN T ROPICAL C LIMATE,” vol. 3, no. 1, 2013.

[8] M. Ali and A. Ali, “Performance Analysis of Fog Effect on Free Space Optical Communication System,” *IOSR J. Appl. Phys.*, vol. 7, no. 2, pp. 16–24, 2015.

[9] S. A. Zabidi, W. Al Khateeb, M. R. Islam, and A. W. Naji, “The effect of weather on Free Space Optics communication (FSO) under tropical weather conditions and a proposed setup for measurement,” *Int. Conf. Comput. Commun. Eng. ICCCE’10*, no. May, pp. 11–13, 2010.

[10] M. Al-Jaberi, M. Richardson, J. Coath, and R. Jenkin, “The simulation of laser-based guided weapon engagements,” vol. 6228, p. 622814, 2006.