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FSO System Performance Enhancement: Receiver Impact

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ABSTRACT

The atmospheric conditions such as fog and humidity are the main causes of attenuation of the free space optical (FSO) communication link. This leads to a reduction in the received power which can cause a drop in the performance of FSO link. This paper investigates the performance of an FSO system at different wavelengths 850, 950and 1550 nm at a distance up to 1 km under the effect of fog and humidity. Different transmitter divergence angles and receiver aperture diameters are studied using PIN photodiode and avalanche photodiode (APD). The obtained results show a remarkable improvement achieving maximum power received, data rate and signal to noise ratio (SNR) and minimum bit error rate (BER) for nonreturn-to-zero on-off keying(NRZ-OOK) modulation technique.

1. Introduction

Free Space optics (FSO) is one of leading optical communication technology. FSO is used to overcome the obstacles which face fiber optic networks such as difficult terrains, bottleneck speed problem or can be a backup link in case of breakdown of the main optical fiber link as a result of any damage [1]. There are a lot of influential atmospheric factors that affect the propagated optical beam.

The performance of an FSO link is affected by scattering and absorption phenomena. Fog is the most adverse factor that affects the FSO link due to scattering [2]. Humidity and temperature are important factors leading to absorption [3]. Most of the previous studies did not concentrate on the humidity and temperature in the calculations of the attenuation. This paper takes this factor into account in the calculations of the attenuation because of its high value through the year in the Middle East region leading to high attenuation. The FSO link can overcome most of the atmospheric challenges by choosing the suitably transmitted wavelength, divergence angle, receiver aperture diameter and the appropriate photodetector type.

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This paper investigates the performance of the FSO system by proposing a model that is affected by the attenuation due to fog, humidity and temperature. The model uses NRZ-OOK modulation technique. The study compares the performance of the system by using PIN and APD photodiodes and tries to reach to the maximum power received, data rate and achieve a high SNR and low BER by changing the transmitted divergence angle of the laser beam and the receiver aperture diameter.

2. Attenuation Model

The fractional relation between transmitted power, P_T, and the received power, P_R, is used to calculate the overall attenuation of the FSO link. Beer-Lambert law shows that beam power has an exponential decay relation with the propagation distance, L [4]

$$\tau(\lambda, L) = \tau_s + \tau_a = \frac{P_R}{P_T} = e^{-\gamma T(\lambda)L} \quad (1)$$

where $\tau(\lambda,L)$ is the transmittance of the atmosphere at a wavelength λ, $\gamma_T(\lambda)$ is the total attenuation in (dB/km),τ_s and τ_a are the scattering transmittance and the absorptive transmittance, respectively. The atmospheric attenuation occurs as a result of two individual processes; scattering and absorption [5].The total attenuation is the sum of the several partial attenuation factors [6].

2.1 Attenuation due to fog

Fog is the most influential factor on the atmospheric attenuation that affects the performance of the FSO link. Fog can be modeled by the Mie scattering mechanism that occurs when the particle size is comparable to the wavelength of the radiation [6]. The used wavelength band in FSO systems is (0.5 µm - 2 µm) which compares very much with the fog particles. This makes the fog is the most dominant scatterer in the atmospheric attenuation. The scattering transmittance is given by [6]

$$\tau_s = e^{-\gamma fog^L} \quad (2)$$

where γ_{fog} is the attenuation due to fog which is given by [7]

$$\gamma_{fog}(\lambda) = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-\delta} \quad (3)$$

where V stands for visibility in km, λ stands for wavelength in nm and the parameter δ is visibility dependence. There are four models to calculate δ: Kruse model [8], Kim model [8], Al Naboulsi advection model [9] and Al Naboulsi radiation model [9]. In this study, Kruse model has been chosen in the calculation of the attenuation in the simulation because it depends on the changing in the wavelength [2].

The visibility δ is given by [8]

$$\delta = \begin{matrix} 1.6 & V > 50km \\ 1.3 & 6km < V < 50km \\ 0.58V^{1/3} & V < 6km \end{matrix} \quad (4)$$

2.2 Attenuation due to humidity and temperature

Humidity and temperature cause absorption to the propagated optical beam which occurs as a result of the effect of water, CO_2 and ozone molecules. The absorption can be calculated by assuming that the changes in the water content of the atmosphere cause the variation in the transmission of light. The absorptive transmittance is given by [6]

$$\tau_a = e^{\left(-A_i \omega^{1/2}\right)} \qquad \omega < \omega_i$$

$$\tau_a = k_i \left(\frac{\omega_i}{\omega}\right)^{\beta_i} \qquad \omega > \omega_i \tag{5}$$

where ω is the perceptible water in (mm) given by [10]

$$\omega = 10^3 L\rho \tag{6}$$

where L is the link distance and ρ is the absolute humidity in (g/m^3) which is given by[10]

$$\rho = 2.16679\, P_W/T \tag{7}$$

where T is temperature in (°C) and P_w is the water vapour pressure in (Pa) given by [10]

$$P_W = A10^{\left(\frac{m\times T}{T+T_n}\right)} RH/100\% \tag{8}$$

Where RH is the relative humidity percentage, A, m and T_n are constants of values 6.116441, 7.591386 and 240.7263, respectively [11].The typical values of the constants A_i, k_i, β_i and ω_i are equal to 0.0305, 0.8, 0.112 and 54, respectively, for 850 nm wavelength, and 0.0363, 0.765, 0.134 and 54, respectively, for 950 nm wavelength and for 1550 nm are equal to 0.211, 0.802, 0.111 and 1.1, respectively.

3. Communication Link Model

In order to evaluate the performance of the proposed FSO system, the optical power received, data rate, SNR and BER are mentioned using PIN and APD photodetector.

3.1 Optical power received of FSO

The received optical power, P_r, for an FSO communication link is given by [12]

$$P_r = P_t \frac{D^2}{\theta_{div}^2 L^2} 10^{-\gamma L/10} \tau_{trans} \tau_{rec} \tag{9}$$

where P_t is the transmitted power, L is the link length, $D$is the receiver diameter, ϑ_{div} is the full divergence angle, γ is the total attenuation factor in (dB/km) and τ_{trans} and τ_{rec} are the transmitter and receiver optical efficiencies, respectively.

3.2 Data rate

The achievable data rate, R, can be obtained as [12]

$$R = \frac{4}{\pi E_p N_b} P_r \quad (10)$$

where E_p is the photon energy and N_b is the receiver sensitivity.

3.3 Signal to noise ratio

The SNRof a PIN photodiode is given by [5]

$$SNR_{PIN} = \frac{(P_r R_{PIN})^2}{2qB(I_P + I_D) + 4kT_{PIN} B F_n / R_L} \quad (11)$$

where R_{PIN} is the responsivity of the photodetector, I_P is the average photocurrent, q is the electron charge, B represents the bandwidth, I_D is the dark current, k is Boltzmann constant, T_{PIN} is the absolute photodiode temperature (= 298 K), $F_n$is the PIN photodiode noise figure (=1.0 for PIN photodiode), R_L is the PIN load resistor.

The SNR of an APD photodiode is given by [13]

$$SNR_{APD} = \frac{(R_0 P_{rec} M)^2}{2q(R_0 P_{rec} + I_D) M^{x+2} + 2qI_L B + 4kT_{APD} B F_T / R_{eq}} \quad (12)$$

where R_o denotes the primary sensitivity of the APD, M is the APD gain (= 100), I_D is the bulk dark current, I_L is the surface leakage current, x is the excess noise factor (= 0.5), B is the equivalent noise bandwidth, R_{eq} is the equivalent circuit resistance, T_{APD} is the system temperature (= 290 K) and F_T is the APD photodiode noise figure of the electric circuit.

3.4 Bit error rate

To calculate BER of the system, the modulation technique must be considered first. The OOK modulation technique is mostly used in FSO communication systems. Accordingly, the BER is given by [5]

$$BER_{NRZ-OOK} = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \quad (13)$$

4. Results and Discussion

Simulation is carried out by using MATLAB to study the effect of fog with visibility at a distance of 1 km, temperature of 20 ^oC and humidity of 67.9 % on FSO system performance. The NRZ-OOK modulation technique is applied in the transmitter and both PIN and APD photodiodes at the receiver are considered. The performance evaluation of FSO system was performed through calculating the optical power received, achieved data rate, SNR and BER. The values of the parameters used for the proposed systems are illustrated in Table 2 [3, 14].

Figure 1 shows the received power against the receiver aperture diameter and against the transmitter divergence angle. It is clear that, increasing the receiver aperture diameter yields an increase in the received power. Also, increasing divergence angle leads to a decrease in the received power. Higher values of received power are achieved at 1550 nm than the other values of wavelengths in both cases.

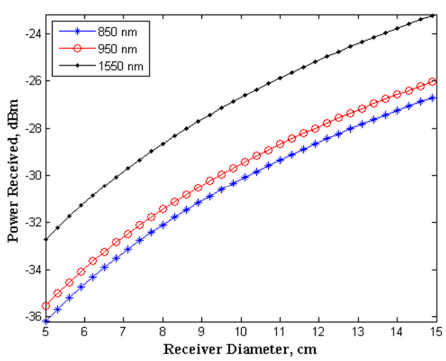
Table 1
Operating parameters of FSO system

Operating parameter	Value
Transmitter power (P_t)	5 mW
Transmitter efficiency (τ_{trans})	0.9
PIN photodiode	
PIN load resistance (R_L)	1 kΩ
Dark current (I_D)	10 nA
Responsivity (R_{PIN})	0.6 A/W
Electrical bandwidth (B)	0.5 GHz
APD photodiode	
Bulk dark current (I_D)	0.05 nA
Electrical bandwidth(B)	25 MHz
Surface leakage current (I_L)	0.001 A
Noise figure (F_T)	3 dB
Equivalent resistance (R_{eq})	50 kΩ

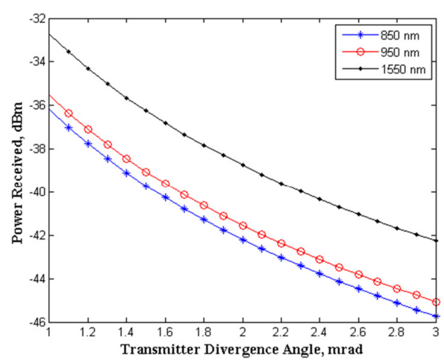
A data rate of 10 Mbps can be achieved at a receiver diameter greater than 7.5 cm for all the wavelengths as shown in Fig. 2. It is also observed that the data rate is an inverse relationship with the divergence angle.

Figure 3 displays the SNR when a PIN photodiode is used, where the 1550 nm wavelength gives higher SNR values than other wavelengths. SNR reaches 30 dB at 15 cm receiver diameter. The SNR decays with increasing the divergence angle for all wavelengths and the highest value (11 dB) is achieved at 1 mrad divergence angle.

The same procedure is repeated in Fig. 4 when an APD photodiode is used, where higher SNR values are obtained with the same behavior like Fig. 3. SNR reaches its highest value 48.2 dB at 15 cm receiver diameter and 38.5 dB at 1 mrad divergence angle.

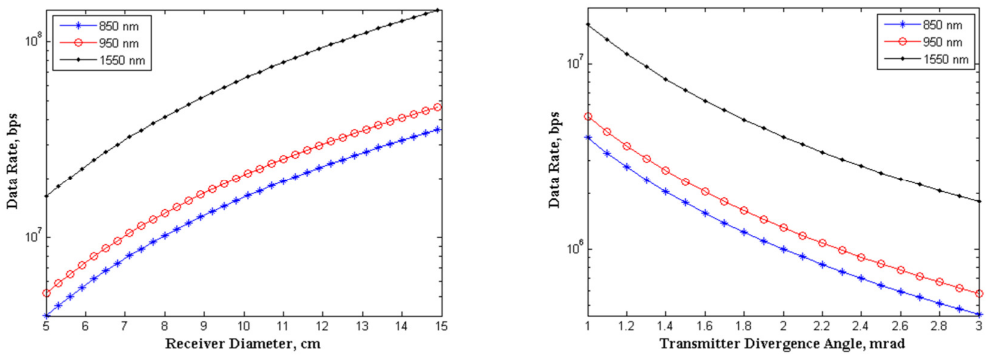


(a)



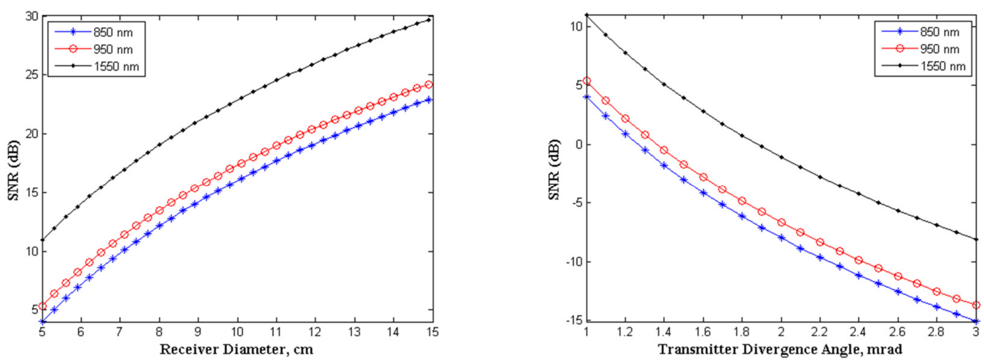
(b)

Fig. 1. Power received with (a) receiver diameter and (b) divergence angle



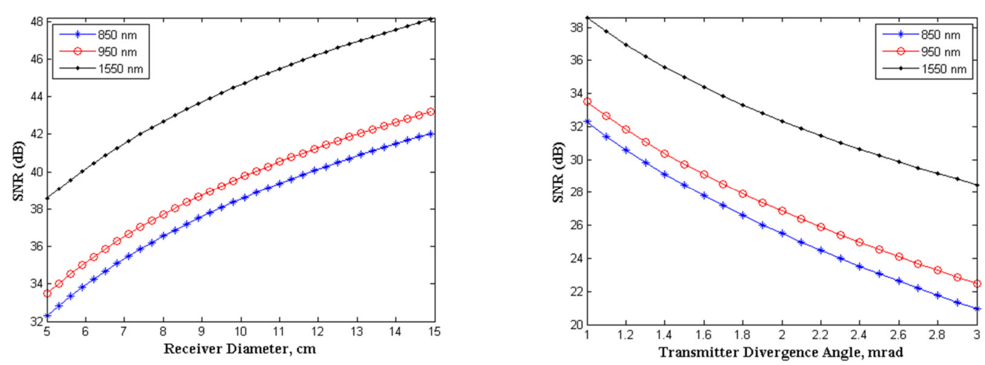
(a) (b)

Fig. 2. Data rate with (a) receiver diameter and (b) divergence angle



(a) (b)

Fig. 3. SNR for PIN with (a) receiver diameter and (b) divergence angle

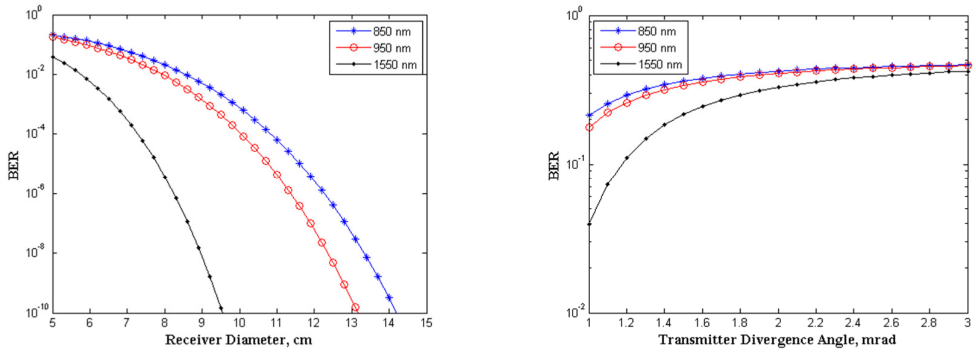


(a) (b)

Fig. 4. SNR for APD with (a) receiver diameter and (b) divergence angle

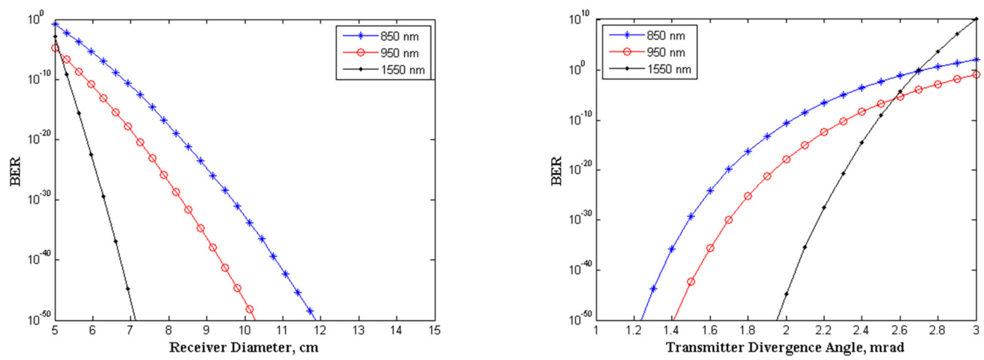
Figure 5 displayed the BER against receiver diameter and against transmitter divergence angle using a PIN photodiode. Better values of BER are obtained at greater receiver diameter, where BER can reach to 10^{-10} as shown. BER increases with the divergence angle and then becomes almost constant.

Figure 6 illustrates the obtained BER when an APD photodiode is used. Lower BER is achieved as compared with the case of PIN photodiode for all wavelengths with changing the receiver diameter. The only case that 1550 nm wavelength gives worst performance than the other wavelengths occurs when increasing the divergence angle more than 2.45 mrad. It reaches to 10^{10} at 3 mrad divergence angle.



(a) (b)

Fig. 5. BER for PIN with (a) receiver diameter and (b) divergence angle



(a) (b)

Fig. 6. BER for APD with (a) receiver diameter and (b) divergence angle

5. Conclusion

This paper represents a performance evaluation of an FSO communication system with attenuation due to fog, humidity and temperature. The obtained results compare the performance at 850, 950and 1550 nm with changing the transmitter divergence angle and the receiver aperture diameter when using PIN and APD photodiodes. It was shown that increasing the divergence angle makes the performance of the FSO system worse. On the other hand, increasing the receiver aperture diameter improves the performance of the system. This forces the system designer to choose the transmitter with the smallest divergence angle and the receiver with the largest aperture diameter. The 1550 nm wavelength gives a better performance than other wavelengths in all cases except for APD photodiode the BER with divergence angle more than 2.45 mrad that gives the worst performance of 1550 nm. The APD photodiode gives a better performance than PIN photodiode in all cases.

References

[1] Willebrand, Heinz, and Baksheesh S. Ghuman. *Free space optics: enabling optical connectivity in today's networks*. SAMS publishing, 2002.

[2] Kaur, Ajaybeer, and M. L. Singh. "Comparing the Effect of Fog and Snow Induced Attenuation on Free Space Optics (FSO) and RF Links 1." (2012).

[3] Ghoname, Sherif, Heba A. Fayed, Ahmed Abd El Aziz, and Moustafa H. Aly. "Performance analysis of FSO communication system: Effects of fog, rain and humidity." In *Digital Information Processing and Communications (ICDIPC), 2016 Sixth International Conference on*, pp. 151-155. IEEE, 2016.

[4] R. M. Gagliardi and S. Karp. Optical communications. 2nded., New York: John Wiley, USA, 1995.

[5] Ali, Mazin Ali A. "Performance analysis of fog effect on free space optical communication system." *IOSR Journal of Applied Physics* 7, no. 2 (2015): 16-24.

[6] Forin, Davide M., G. Incerti, GM Tosi Beleffi, A. L. J. Teixeira, L. N. Costa, PS De Brito Andrè, B. Geiger, E. Leitgeb, and F. Nadeem. "Free space optical technologies." In *Trends in Telecommunications Technologies*. InTech, 2010.

[7] Mohammed, Nazmi A., Amr S. El-Wakeel, and Mostafa H. Aly. "Pointing error in FSO link under different weather conditions." *Fog* 15, no. 33.961 (2012): 84-904.

[8] Nadeem, F., B. Flecker, E. Leitgeb, M. S. Khan, M. S. Awan, and T. Javornik. "Comparing the fog effects on hybrid network using optical wireless and GHz links." In *Communication Systems, Networks and Digital Signal Processing, 2008. CNSDSP 2008. 6th International Symposium on*, pp. 278-282. IEEE, 2008.

[9] Al Naboulsi, Maher C., Frederique De Fornel, Hervé Sizun, Michael Gebhart, Erich Leitgeb, S. Sheikh Muhammad, Benno Flecker, and Christoph Chlestil. "Measured and predicted light attenuation in dense coastal upslope fog at 650, 850, and 950 nm for free-space optics applications." *Optical Engineering* 47, no. 3 (2008): 036001.

[10] Weichel, Hugo. *Laser beam propagation in the atmosphere*. Vol. 3. SPIE press, 1990.

[11] Oyj, Vaisala. "Calculation Formulas for Humidity—Humidity Conversion Formulas." *Vaisala: Helsinki, Finland* (2013).

[12] Kaur, Ajaybeer, and M. L. Singh. "Performance evaluation of free space optics (FSO) and radio frequency communication system due to combined effect of fog and snow." In *International Conference on Recent Advances and Future Trends in Information Technology*, pp. 32-36. 2012.

[13] G. Keiser. Optical Fiber Communications. 3rded., New York,NY: McGraw-Hill, USA, 2000.

[14] H. Yong, C. Ying, Z. Qiang. "Free-space optical wireless communication using visible light." *Journal of Zhejiang University Science* A 8, (2007): pp. 186-191.