Performance Analysis of Fog Effect on Free Space Optical Communication System

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Abstract: *In this paper, the attenuation of FSO communication systems operating at selected wavelengths of 650nm, 850nm, 950nm and 1550nm in fog models is theoretically analyzed, using 16-PPM and NRZ-OOK modulation techniques over fog channel. Four fog models are employed for optical beam propagation horizontally at different wavelengths. The received signal power, SNR is analyzed. The characteristics of bit error rate BER for 16-PPM and NRZ -OOK optical modulation techniques are studied. Simulation results show that the performance of 1550nm is more suited for an FSO communication system. On the other hand, we discuss the suitability of modulation techniques under these fog models.*
Keywords: *Fog models, modulation, FSO, 16-PPM, NRZ-OOK.*

I. Introduction

Free Space Optics (FSO) communication is a technology that uses light as its carrier to transmit data between two points in the atmosphere channel [1]. Free space optics (FSO) are sensitive to weather conditions – primary to fog and precipitation – may face with substantial loss of its power during passing through channel[2, 3] The effect of absorption and scattering of the light carrier signal (i. e. Laser) can be described by the path – dependent attenuation coefficient [4]. A laser communication system is advantageous to radio frequency communication systems for the following reasons: (i) no licensing requirements or tariffs are required for its utilization; (ii) its large bandwidth allows very high data rates; (iii) the system is light weight, small, and has compact dimensions; (iv) it operates with low power consumption. On the other hand, unlike radio frequency systems, laser communication systems have a very narrow laser beam divergence angle as well as a very narrow receiver field of view [5]. The proposed model for the prediction of attenuation due to fog is reported in [6-14]. One of the keys of any communication system is the selection of a suitable modulation technique; pulse position modulation L-PPM can provide higher power efficiency at the expense of increased bandwidth requirement. On the other hand, on – off – key (OOK-NRZ) is the simplest and widely used modulation scheme in free space optical communication due to its simplicity in the implementation. OOK-NRZ offers similar power efficiency to the 2-PPM [15].

II. Attenuation by Fog

For a terrestrial FSO link transmitting optical signal through the atmosphere, the received signal power at a distance, L from the transmitted signal power for FSO is given by [16]

$$p_r = P_t \frac{A_r}{(\theta.L)^2} \exp(-\gamma_{fog}.L) \tag{1}$$

Where A is the receiver area, θ is the full divergence angle; γ_{fog} is the fog attenuation factor (dB/km).

The function of $\gamma_{fog}(\lambda)$ is the total extinction coefficient per unit length, which represents the attenuation of the transmitted light. It is composed of terms for scattering and absorption, and general it is the sum of the following terms [17]

$$\gamma(\lambda) = \alpha_m(\lambda) + \alpha_a(\lambda) + \beta_m(\lambda) + \beta_a(\lambda) \tag{2}$$

The first two terms represent the molecular and aerosol absorption coefficients, respectively; while the last two terms are the molecular and aerosol scattering coefficients respectively. The wavelengths used in FSO are basically chosen to coincide with the atmospheric transmission windows [7, 18], resulting in the attenuation coefficient being dominated by scattering the attenuation is reduced to:

$$\gamma_{specific}(\lambda) \cong \beta_a(\lambda) \tag{3}$$

Attenuation coefficient based on empirical measurement data was calculated by the following empirical model [19]

$$\beta_a(\lambda) = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-\delta} \tag{4}$$

Where V is the visibility in (km), λ represent the wavelength in (nm). The parameter δ depends on the visibility distance range, according to Kruse model δ is given as [6]

$$\delta = \begin{cases} 1.6, & if \ V \succ 50km \\ 1.3, & if \ 6km \succ V \succ 50km \\ 0.585V^{1/3}, & if \ V \prec 6km \end{cases} \tag{5}$$

While Kim model defines δ as [7]:

$$\delta = \begin{cases} 1.6, & if \ V \succ 50km \\ 1.3, & if \ 6km \succ V \succ 50km \\ 0.16V + 0.34, & if \ 0.5km \prec V \prec 6km \\ V - 0.5, & if \ 0.5km \prec V \prec 1km \\ 0, & if \ V \prec 0.5km \end{cases} \tag{6}$$

Al-Naboulsi proposed expressions to predict the wavelength dependent fog attenuation coefficient for the convection and advection fogs for wavelengths from 690 to 1550 nm [20]. The attenuation coefficient for convection fog is given by:

$$\gamma_\lambda(con) = \frac{0.11478\lambda + 3.8367}{V(km)} \tag{7}$$

The attenuation coefficient for advection fog is given by:

$$\gamma_\lambda(adv) = \frac{0.18126.\lambda^2 + 0.13709 + 3.7205}{V(km)} \tag{8}$$

The specific attenuation coefficient for both types of fog is given by

$$\gamma_{specific}(\lambda)\left(\frac{dB}{km}\right) = \frac{10}{\ln(10)}\gamma(\lambda) \tag{9}$$

III. Signal to Noise Ratio& Bit Error Rate

The first features of an FSO communication system is the signal to noise ratio SNR. When transmitted optical signals arrive at the receiver, they are converted to electronic signals by photo detectors. There are many types of photo detectors in existence, photodiodes are used almost exclusively in optical communication applications because of their small size, suitable material, high sensitivity, and fast response time [21]. For the PIN photodiode the signal to noise ratio (SNR) is given by [22]:

$$SNR = \frac{I_p^2}{2qB(I_p + I_D) + 4KTBF_n / R_L} \tag{10}$$

Where I_p is the average photocurrent, q is the charge of an electron(C), B represents the bandwidth, I_D is the dark current, T is the absolute photodiode temperature (K), F_n is the photodiode figure noise equal to 1 for PIN photodiode, R_L is the PIN load resistor. The average photocurrent I_p can be expressed as [23]

$$I_p = P_r.R \tag{11}$$

where Pr is the average optical power received to the photodetector, R is the responsivity of the photodetector.

A second feature of FSO communication systems is the bit error rate BER [24]. The effect of fog on the Bit Error Rate BER of an FSO link is reported in [25] which correlate the atmospheric transmission with the BER. However, RZ-OOK and NRZ-OOK modulation schemes are widely used in commercial FSO communication systems because of their ease of implementation, bandwidth efficiency and cost effectiveness [26]. The relation BER and SNR for NRZ-OOK modulated signal is as follow [27]:

$$BER_{NRZ-OOK} = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \tag{12}$$

While BER for L-PPM modulated signal is given by [27, 28]:

$$BER_{L-PPM} = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR\frac{L}{2}\log_2 L}\right) \tag{13}$$

IV.   Numerical Results

In this section, using the above mentioned formulations, the simulation presents the results of analyzing the performance of FSO communication systems due to fog attenuation channel employing NRZ-OOK, and L-PMM modulation techniques in the transmitter and Si PIN in a receiver. The values of the simulation parameters and constants are given in table (1).

Table 1. System parameters used in the simulation [23, 29, 30, 31]

Parameter	Value
Visibility	1 km
Transmitter power (P_T)	50 mw
Receiver Area (A)	10cm
Laser beam divergence angle θ	1mrad
Electron charge (q)	1.6×10^{-19} C
PIN load resistance (R_L)	1kΩ
Boltzmann constant (k)	1.38×10^{-23} J.k
Temperature (T)	298K
Dark current (I_D)	10nA
Responsivity (R)	0.6A/W`
Bandwidth (B)	0.5GHz

1. Received signal power as a function of distance

Let us first see the effect of the distance on the received optical power P_r, it is considered that the visibility is 1 km. It is shown in Fig. (1-4) curves of P_r as a function of distance for four fog model types and four extreme cases of wavelengths. Let us assume a tolerable loss of −50 dBm beyond which the signal is not detectable at the receiver. We notice that, for λ =650 nm, the transmission range is limited to 0.5 km for the fog models under study. When the wavelength is increasing (λ = 850, 950 nm) increases dramatically these ranges, obviously, it allows range limits increases to 0.58 km for 850nm and but 0.6 km for 950nm when Kim & Kruse models are applied. When the wavelength 1550 nm is used, Kim & Kruse models can be working at long ranges reached to 0.72 km and 0.78km, respectively. But for AL-Naboulsi models (Advection & convection) stay about 0.5 km for the wavelengths applied in simulation.
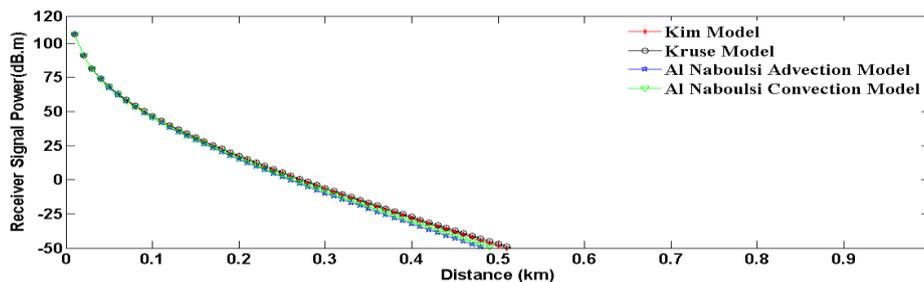
Fig (1) Received Signal Power for 650nm
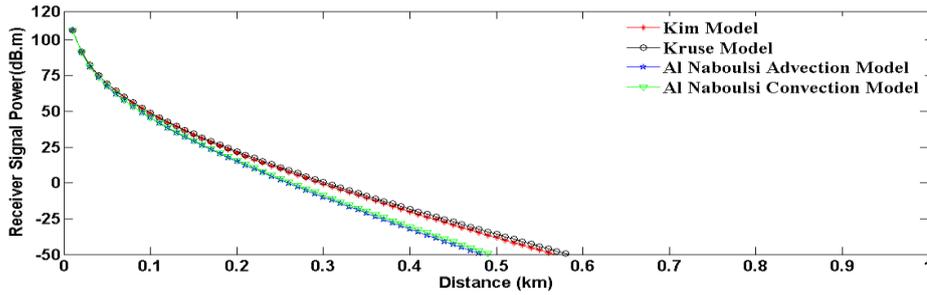
Fig (2) Received Signal Power for 850nm
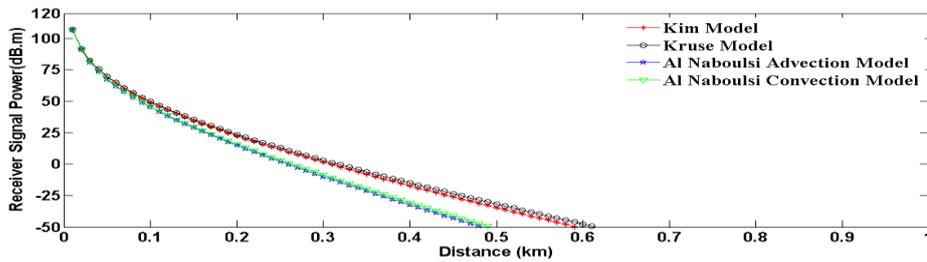
Fig (3) Received Signal Power for 950nm
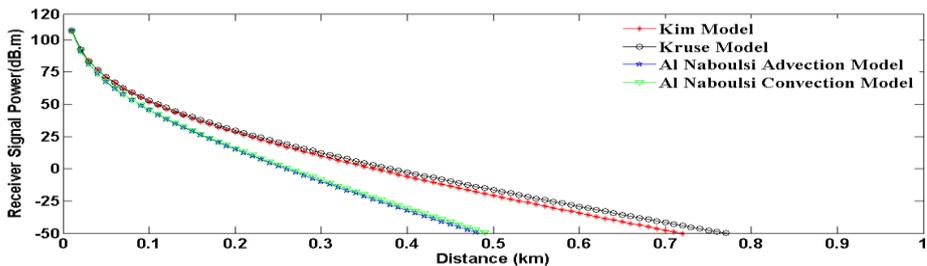
Fig (4) Received Signal Power for 1550nm

2. SNR as a function of distance

The SNR of different fog models is compared in Fig. (5-9). The SNR increases with increasing wavelengths. It is achieved that 1550 nm has presented the highest SNR compared with the other wavelengths under the same operating conditions. On the other hand, it can be seen that the Kim & Kruse Models are more sensitive to foggy weather, while AL–Naboulsi models (Advection and convection) are having value about 0.85 km for different wavelengths under study.
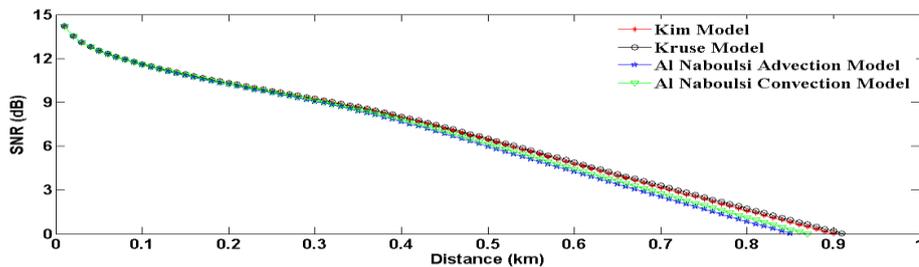
Fig (5) SNR for 650 nm
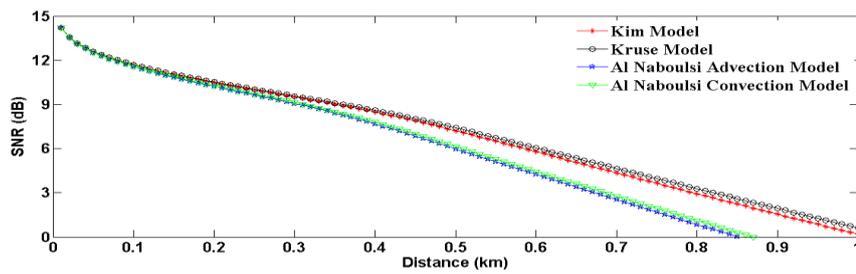
Fig (6) SNR for 850 nm
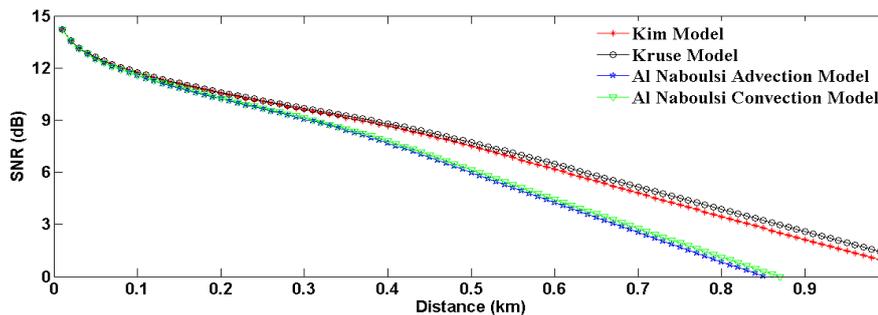
Fig (7) SNR for 950 nm
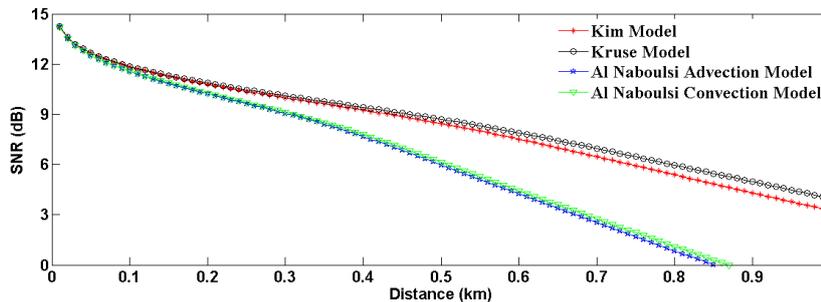
Fig (8) SNR for 1550 nm

3. BER Characteristics for FSO Communication

BER plays an essential function in an optical communication system. We present here simulation results to compare the performance of fog attenuation under different mathematical models. It is considered that 16-PPM and NRZ-OOK modulation techniques in the transmitter side because of its simplicity and resilience in the FSO communication system.

3. 1 The Impact of the distance

Let us consider the BER performance as a function of the distance. Fig (9) shows that BER for NRZ-OOK and 16-PPM modulation format under different fog models when a 650nm is used. In this case, we notice that for BER 10^{-10}, when 16-PPM is applied the distance about 0.85 km for Kruse and Kim models, and its decrease for Al-Naboulsi model becomes about 0.8 km. On the other hand, when NRZ-PPM is applied the distance is about 0.78 for Kruse and Kim Models, and its decrease for Al –Naboulsi model becomes about 0.73 km. It is observed from Fig. (10) a significant increase in the distance can be achieved by 850nm. For Kruse and Kim model are utilized the maximum data rate is about 1 km and 0.98km, respectively when 16-ppm is used. While for Kruse and Kim models becomes 0.89 km and 0.88 km when NRZ-OOK is used. On the other hand, AL-Naboulsi (Advection and Convection) has the same values remember in fig. (9). Another important simulation was evaluated the performance of the BER for 950nm. In Figure (11) a significant improvement in the distance can be achieved by using 950nm, for the BER 10^{-10}, when 16-PPM is applied; the maximum data transmission is about 1.1 km for Kruse and 1 km for Kim while its about 0.9 km and 0.85 km for Kruse and Kim

model respectively; under NRZ-OOK modulation technique. It is observed that in fig. (12), the maximum data transmission is increasing for 1550nm for Kruse and Kim Model. The maximum data transmission reached to 1.3 km and 1.25km for Kruse and Kim models respectively, for 16-PPM, while reaching to 1.13 and 1.19 km for Kruse and Kim model when applied NRZ-OOK modulation technique. An approximately occurs in the BER performance for Al-Naboulsi model compared with the other wavelengths.
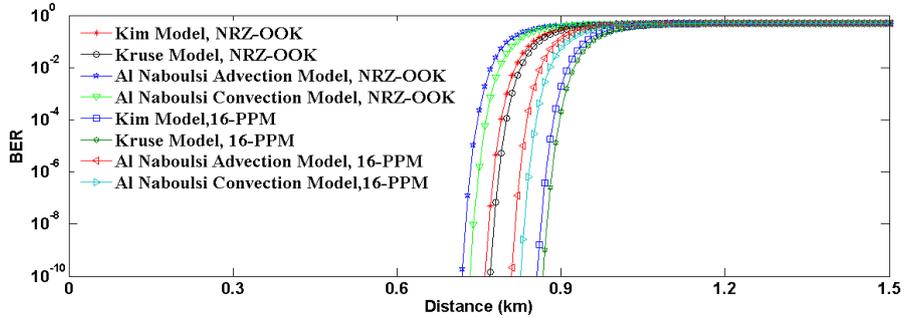
Fig (9) BER for 650 nm
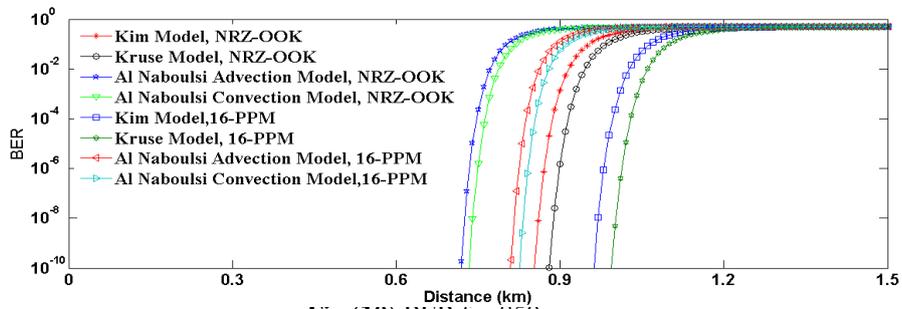
Fig (10) BER for 850 nm
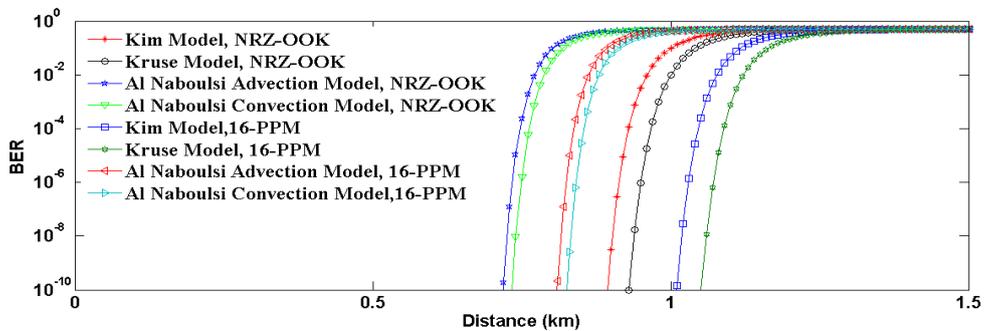
Fig (11) BER for 950 nm
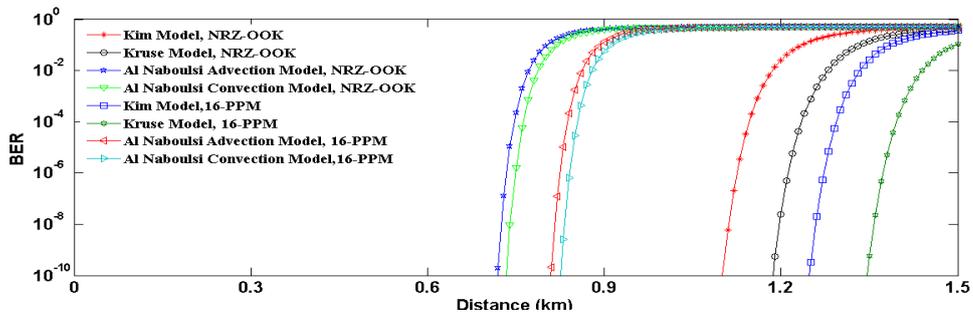
Fig (12) BER for 1550 nm

3.2 The Impact of the transmitted power

It has investigated the effect of transmitter power on BER under fog weather condition. We compare the performance of the fog models when an NRZ-OOK and 16-PPM used as a modulation format under a PIN photodiode. Fig. (13) shows BER versus the transmitter power when a distance and visibility are 1 km. If we consider required 10^{-10}, when used a 16-PPM modulation format and 650 nm as a carrier signal the transmitter power about -7dBm and -5dBm, for Kruse and Kim models respectively, while the decrease for Al-Naboulsi model reached to 3dBm and 6 dBm for convection and advection models. When a NRZ-OOK applied as is evident in fig. (13). A decrease occurs in the BER leads to increase in the transmitter power reached to 10 dBm and 13 dBm for Kruse and Kim models, while reached to 20 dBm and 23dBm for Al-Naboulsi model, convection and advection respectively.

We performed the same calculations also for 850 nm under the same conditions. Fig (14) indicates an improvement occurs when applied 850 NM as a carrier signal. In this case, notice that for BER 10^{-10}, a decreasing occur in the transmitter power, for Kruse and Kim models the transmitter power reached to -30dBm and -25 dBm respectively; when 16-PPM is applied, while reached to -11 dBm and -8 when NRZ-OOK is applied. On the other hand, the transmitter power reached to 2dBm and 7dBm for Al-Naboulsi convection and advection model respectively; when 16-PPM is applied and over 20 dBm for NRZ-OOK is applied. In fig (15) assume that an FSO communication system operating under 1550 nm, it is clear that, for 16-PPM, the data of the transmission about -37 dBm for Kruse model and -30 dBm for a Kim model while reaching to -30 dBm. For NRZ-OOK is applied, the data of the transmission reached to -20 dBm for Kruse model and -14 dBm for Kim model. It is observed that, the AL-Naboulsi model have the same behavior compared with the wavelength 850nm. An improvement occurs when 1550 nm is used as a carrier wavelength as shown in fig. (16). The maximum data transmission reached to -70 dBm and -60 dBm for Kruse and Kim models respectively, for 16-PPM, while reaching to -50 dBm and -42 dBm for Kruse and Kim model when applied NRZ-OOK modulation technique. Also noticed that, the BER performance of the AL-Naboulsi model have the same behavior for 1550 nm compared with the other near infrared wavelengths (859 nm, 950 nm).
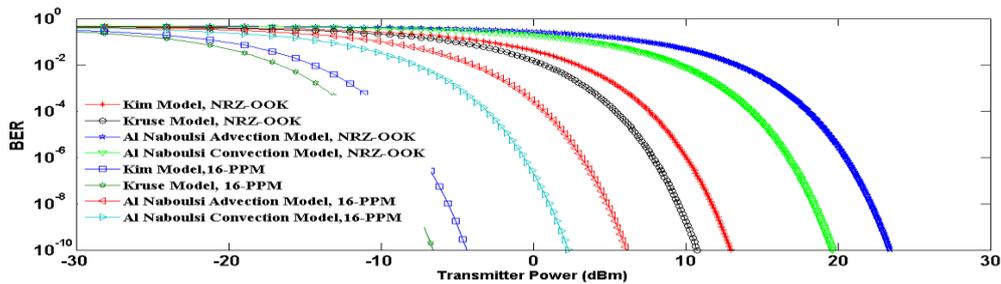
Fig. (13) BER versus Transmitter Power for 650 nm, V=1km, L=1km.
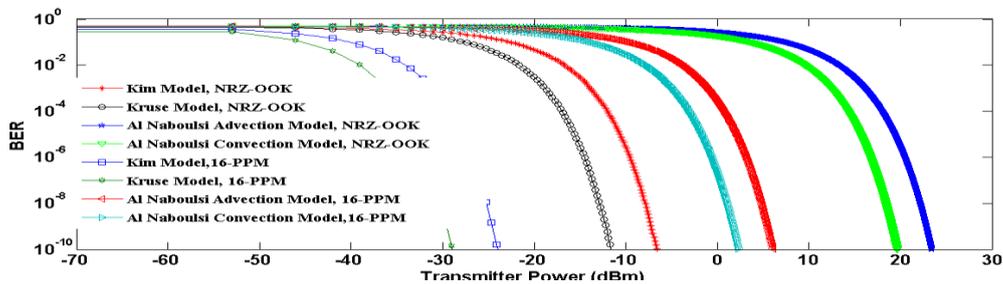
Fig. (14) BER versus Transmitter Power for 850 nm, V=1km, L=1km.
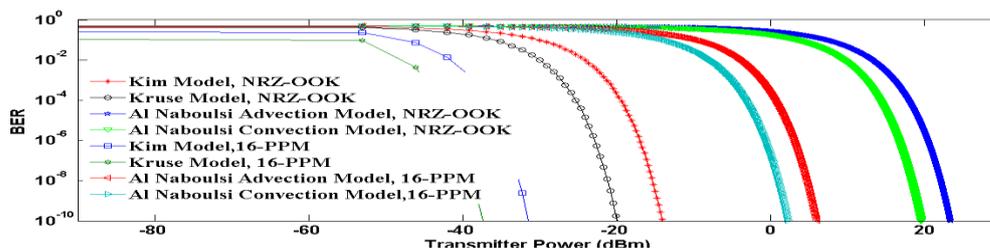
Fig. (15) BER versus Transmitter Power for 950 nm, V=1km, L=1km.
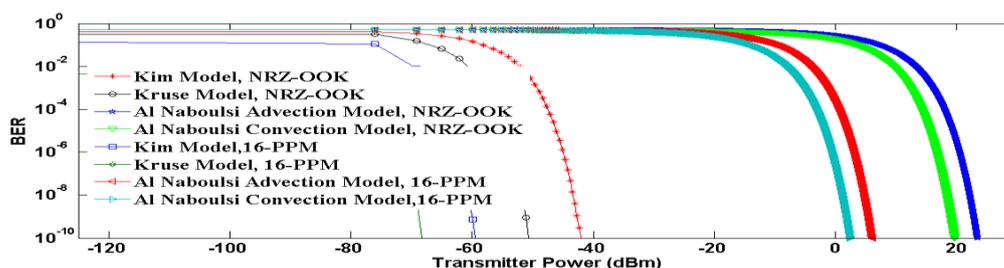
Fig. (16) BER versus Transmitter Power for 1550 nm, V=1km, L=1km.

V. Conclusion

In this paper, we have investigated a theoretical analysis of the effect of fog on the FSO communication performance using NRZ-OOK and 16-PPM modulation techniques in the transmitter, and Si PIN as a receiver with four mathematical models for fog attenuation. The specific attenuation coefficient of the laser beam through fog weather has a significant effect on the performance of FSO communication systems. Based on the fog attenuation model and the relation with visibility employed to study the effect of fog on a receiver signal power, SNR, and BER are investigated. The suitable selected of wavelength has a strong influence on the attenuation coefficient, which leads to long transmission in free space. When a distance has increased, this causes a decrease in receiving signal power. The BER characteristics of the NRZ and 16-PPM modulation techniques under different fog models are studied. The results show that the wavelength 1550nm has a greater advantages than the other wavelength, therefore, a 1550nm is a more suitable wavelength for FSO communications compared with the other wavelengths. Furthermore, the theoretical results showed that the performance of 16 - PPM is far better than the NRZ-OOK, the calculations indicate that Kim and Kruse models are able to work under long distances. It can be observed that the AL Naboulsi model (Advection and Convection) insensitive for IR wavelengths, therefore it has the same behavior when the simulation run to calculate the received signal power, SNR, and BER.

References

[1]. B. Barua, D. Barua, Channel Capacity of Mimo FSO system under strong Turbulent Condition, IJECS-IJENS, 11(2011)1-5.
[2]. M. Salem, A. Marzuki, E. Leitgeb, F. Nadeem, M. S. Khan, C. Capsoni, Weather effects impact on the optical pulse propagation in free space, IEEE 69th Vehicular Technology Conference, Barcelona, Spain. 2009, pp. 1-5.
[3]. E. J. McCartney, optics of the atmosphere: scattering by molecules and particles, J. Willey& Sons. The University of Califorinia, 1977.
[4]. F. D. Kashani, M. R. Hedayati Rad, et.al, Reliability analysis of an auto-tracked FSO link under adverse weather condition, Optik-International journal for light and electron optics, vol. 124, iss. 22, (2013) 5462-5467.
[5]. A. Shlomi, Performance of a laser microsatellite network with an optical preamplifier, Journal of the Optical Society of America A, vol. 22, no. 4, (2005)708-715.
[6]. P. W. Kruse, L. D. McGlauchlin, E. B. McQuistan, "Elements of infrared technology: Generation, transmission and detection," *J. Wiley and sons,* 1962.
[7]. I. I. Kim, B. McArthur, and E. Korevaar, "Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications," in *Proc. SPIE 4214*, Boston, MA, USA, 2001.
[8]. R. M. Pierce, J. Ramapras, and E. C. Eisenberg, "Optical attenuation in fog and clouds"," *Proc. SPIE 4530,* vol. 58 2001.
[9]. M. A. Naboulsi, H. Sizun, and D. F. Frédérique, "Wavelength selection for the free space optical telecommunication technology," *SPIE* vol. 5465 pp. 168-179, 2004.
[10]. M. A. Naboulsi, H. Sizun, and F. d. Fornel "Fog attenuation prediction for optical and infrared waves,," *Journal of Optical Engineering,* vol. 43, pp. 319-329, 2004.
[11]. K. W. Fischer, M. R. Witiw, and E. Eisenberg, "Optical attenuation in fog at a wavelength of 1.55 micrometers," *Atmospheric Research,* vol. 87, pp. 252-258, 2008.

[12]. E. Ferdinandov, Kalin dimitrov, A. Dandarov, and I. Bakalski, "A general model of the atmospheric scattering in the wavelength interval 300 - 1100nm," *Radio Engineering,* vol. 18, 2009.

[13]. F. Nadeem, T. Javornik, E. Leitgeb, V. Kvicera, and G. Kandus, "Continental fog attenuation empirical relationship from measured visibility data," *Radio Engineering,* vol. 19, 2010.

[14]. M. Grabner and V. Kvicera, "The wavelength dependent model of extinction in fog and haze for free space optical communication," *Journal of Optics Express,* vol. 19, pp. 3379-3386, 2012.

[15]. M. Ijaz, Experimental Characteristics and Modelling at Atmospheric Fog and Turbulence in FSO, Ph. D thesis, University of Northumbria, Newcastle, 2013.

[16]. S. Bloom, S. Hartley, the last – mile solution: hybrid FSO radio. http://www. Freespaceoptic.com/WhitePpers/Hybrid_FSO/pdf.

[17]. Hemati, H., Deep space optical communications, in deep space communications and navigation series California, 2005.

[18]. Bloom, S., Korevaar, E., Shuster, J., and Willebrand, H., understanding the performance of free-space optics, journal of networking, vol. 2, pp. 178-200, 2003.

[19]. Fadhil, H. A., Amphawan, A.H., Shamsuddin, A. B., Thanaa Hussein Abd, Hamza Al-Khafaji, M. R., Aljunid, S. A., and Nasim Ahmed, optimization of free space optics parameters: An optimum solution for bad weather conditions, Elsevier, Optik, vol.124, 3969-3973, 2013.

[20]. Naboulsi, M. A., Forne, F. D., Sizun, H., Gebhart, M., Leitgeb, E., Muhammed, S. S., Flecker, B. and Chlestil, C., measured and predicted light attenuation in dense coastal upslope fog at 650, 850, and 950 nm for free-space optics applications, journal of optical engineering, vol. 47, no. 3, 2008.

[21]. Keiser, G., optical fiber communications, McGraw-Hill Company, 2000.

[22]. Kharraz, O., Forsyth, D., PIN and APD photodetector efficiencies in the longer wavelength range 1300-1500nm, Elsevier, Optik, vol. 124, pp. 2574-2576, 2013.

[23]. Keiser, G., optical essential communications, McGraw-Hill Company, 2004.

[24]. Tyson, R. K., Bit-Error Rate for free – space adaptive optics laser communications, Journal of Optical Society of America A, vol.19, no. 4, pp. 753-758, 2002.

[25]. Strickland, B. R., Lavan, M. J., Woodbridge, E., and Chan, V., Effects of fog on the bit -error rate of a free space laser communication system, journal of applied optics, vol.38, pp. 424-431, 1999.

[26]. Liu, N., Zhong, W. D., He, Y., Heng, H., and Cheng, T. H., Comparison of NRZ and RZ modulations in laser intersatellite communication systems, proceedings of the 2008 international conference on advanced infocomm technology, Shezhen China, pp. 677, 2008.

[27]. Trisno, S., design and analysis of advanced free space optical communication systems, Ph. D thesis, University of Maryland, 2006.

[28]. W. O. Popoola, Z. Ghassemlooy, "BPSK subcarrier intensity modulated free-space optical communications in atmospheric turbulence", Journal of Lightwave technology, vol.27, no. 8, pp. 967-973, 2009.

[29]. Agrawal, G. P., Fiber-Optic communication system, John Wiley and Sons, 4th edition, 2010.

[30]. Mazin Ali A. Ali, Comparison of NRZ, RZ-OOK Modulation Formats for FSO Communications under Fog Weather Condition, vol. 108, no. 2, (2014)29-34.

[31]. Mazin Ali A. Ali, FSO Communication Characteristics under Fog Weather Condition, International Journal of Scientific and Engineering Research, Vol.6, Iss. 1, (2015)