Performance of FSO Communication System under Various Weather Condition

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Abstract

In this paper, the performance FSO communication under different weather condition is theoretically analyzed, using L-PPM modulation technique and a Si PIN photodiodes receiver over FSO channels. Based on the attenuation coefficient of different weather and impacts on a received signal power, SNR, BER, and channel are analyzed. Simulation results indicate that the performance of 16-PPM is more suited for FSO communication.

Keywords: Communications, FSO Communications, Bit Error Rate, Channel Capacity.

I. Introduction

Free Space Optics (FSO) communication is widely used for the transmission of large volumes of data at high speed due to its excellent transmission performance and huge bandwidth [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]

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

While Kim model defines δ as [7]:

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

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:

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

The attenuation coefficient for advection fog is given by:

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

The specific attenuation coefficient for both types of fog is given by $\gamma_{specific}(\lambda)\left(\frac{dB}{km}\right) = \frac{10}{\ln(10)}\gamma(\lambda)$

(9)

The new proposed model for the prediction of the attenuation due to fog and smoke can be presented as [21]:

$$\beta_{\lambda}(dB / km) = \frac{17}{V\ (km)}\left(\frac{\lambda}{\lambda_0}\right)^{-q(\lambda)} \qquad (11)$$

Where, the wavelength with a range 550nm < λ < 1600 nm is valid for the visibility range of 0.015 km < V < 1 km. The function for q(λ) for the fog and smoke is defined as:

$$q(\lambda) = \begin{cases} 0.1428\lambda - 0.0947, & Fog \\ 0.8467\lambda - 0.5212, & Smoke \end{cases} \qquad (12)$$

III. Signal to Noise Ratio& Bit Error Rate

The first features of an FSO communication system are the signal to noise ratio SNR. When transmitted optical signals arrive at the receiver, they are converted into 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 [22]. For the PIN photodiode the signal to noise ratio (SNR) is given by [23]:

$$SNR = \frac{I_p^2}{2qB(I_p + I_D) + 4KTBF_n / R_L} \qquad (13)$$

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 [24]

$$I_p = P_r.R \qquad (14)$$

Where Pr is the average optical power received by the photodetector, R is the responsivity of the photodetector.
A second feature of FSO communication systems is the bit error rate BER [25]. The effect of fog on the Bit

Error Rate BER of an FSO link is reported in [26] 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 [27]. The relation BER and SNR for NRZ-OOK modulated signal is as follow [28]:

$$BER_{NRZ-OOK} = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}} \sqrt{SNR} \right) \tag{15}$$

And for RZ-OOK modulated signal is given by:

$$BER_{RZ-OOK} = \frac{1}{2} erfc\left(\frac{1}{2} \sqrt{SNR} \right) \tag{16}$$

While BER for L-PPM modulated signal is given by [28, 29]:

$$BER_{L-PPM} = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}} \sqrt{SNR \frac{L}{2} \log_2 L} \right) \tag{17}$$

4. Channel capacity

The channel capacity (C_s) is defined as a maximum rate of information data stream within the communication channel. The maximum rate of 1 bit per channel use can be achieved but only when the SNR is infinite. The capacity of the channel gives a theoretical limit for the transmission rate of (reliable, i.e., error-free) data from a transmitter of given power, over channel with a given bandwidth, operating in a given noise environment [30]. The channel capacity per symbol is given by [31]

$$C_S = 1 + BER \log_2 BER + (1 - BER) \log_2 (1 - BER) \tag{18}$$

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).

1. Received signal power as a function of distance

Let us first see the effect of the distance on the received optical power Pr. It is shown in Fig. (1) curves of Pr as a function of distance for different weather condition. Let us assume a tolerable loss of −150 dB.km beyond which the signal is not detectable at the receiver. We notice that, for heavy fog, the transmission range is limited to 0.3 km. When the weather is improvement (light fog, and thin fog) increases dramatically these ranges, obviously, it allows range limits increases to 0.6 km, and 0.8 km for light and thin respectively, and but 1.1 km for haze weather. When the weather is clear, the wavelength 650nm can be working at long ranges exceeded to 5 km.

Table 1. System parameters used in the simulation [24, 32, 33, 34]

Table (2) System parameters used in the simulation

Parameter		Value
Transmission Wavelength (λ)		650 nm
Transmitter power (P_T)		0.5 mw
Laser beam divergence angle		5 mrad
Receiver aperture area		10 cm
Electrum charge (q)		$1.6x10^{-19}$c
PIN load resistance(R_L)		1 kΩ
Boltzmann constant (k)		$1.38x10^{-23}$J.k
Temperature (T)		298K
Dark current(I_D)		10 nA
Responsively (R)		0.6 A/w
Bandwidth (B)		0.5 GH_Z
Attenuation	Clear	0.7 (dB/km)
	Haze	7.77 (dB/km)
	Thin	10.5(dB/km)
	Light	15.96(dB/km)
	Heavy	34.69(dB/km)

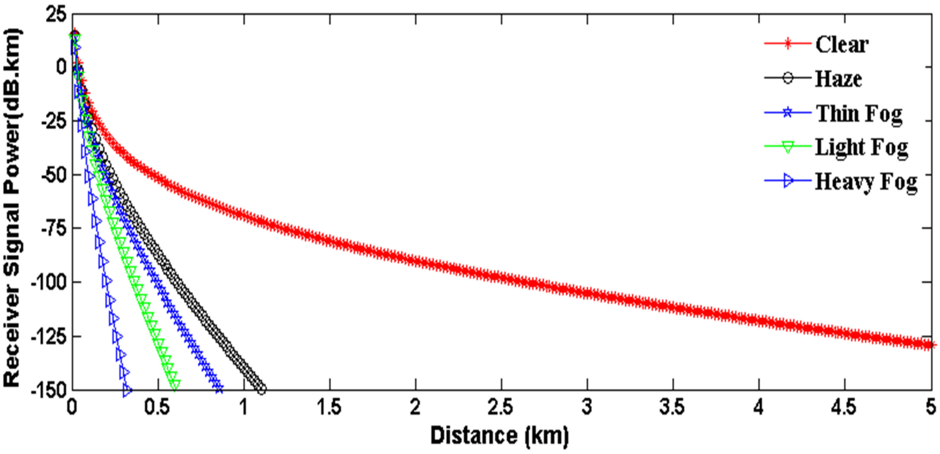

Fig (1) Received Signal Power versus distance

2. SNR as a function of distance

The SNR of different weather conditions is compared in Fig. (2). The SNR decreases with increasing distance. It is achieved that a clear sky has presented the highest SNR compared with the other conditions under the same wavelength. On the other hand, it can be seen that the fog and haze are more sensitive to the wavelength 650nm.

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 FSO under different weather condition. It is considered that NRZ-OOK, RZ-OOK, and L-PPM modulation techniques on the transmitter side because of its simplicity and resilience in the FSO communication system.

Let us consider the BER performance as a function of the distance. Fig. (3) shows the BER for NRZ-OOK under different weather condition. In this case, it is noticed that for BER 10^{-10}, the distance transmission is limited to 2.45 km, and 0.6 km for clear, and haze weather, and it decreases for fog weather, it becomes about 0.5 km, 0.4 km, and 0.2 km for thin, light, and heavy fog respectively. In fig. (4) An improvement increase occurs when an RZ-OOK is used as a modulation technique, where the distance of data transmission increases and reaches 2.7 km for a clear sky. In this case, the data of the transmission does not exceed 0.6 km for haze, thin, light, and heavy condition.

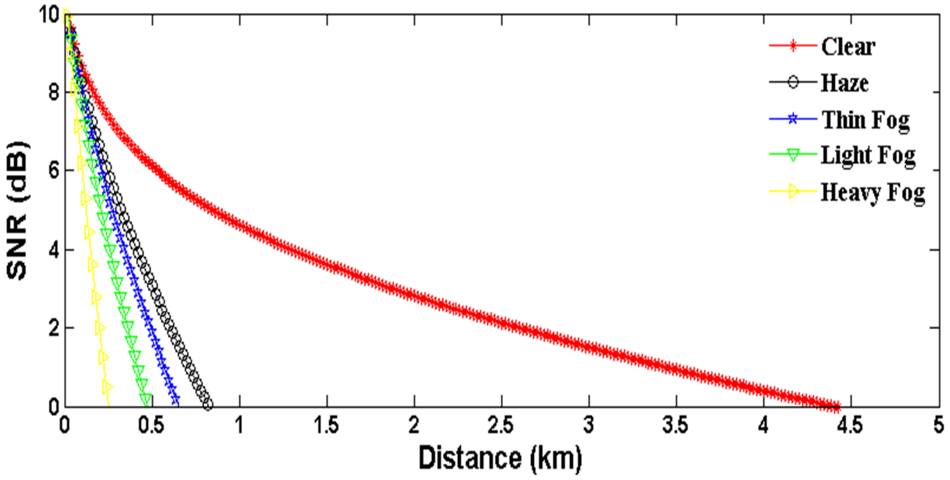

Fig. (2) SNR versus distance

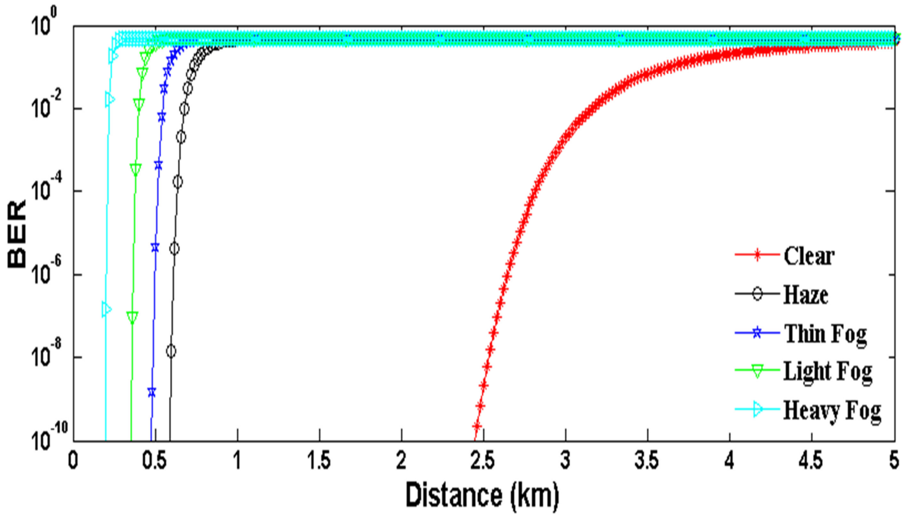

Fig (3) BER versus distance link for NRZ-OOK

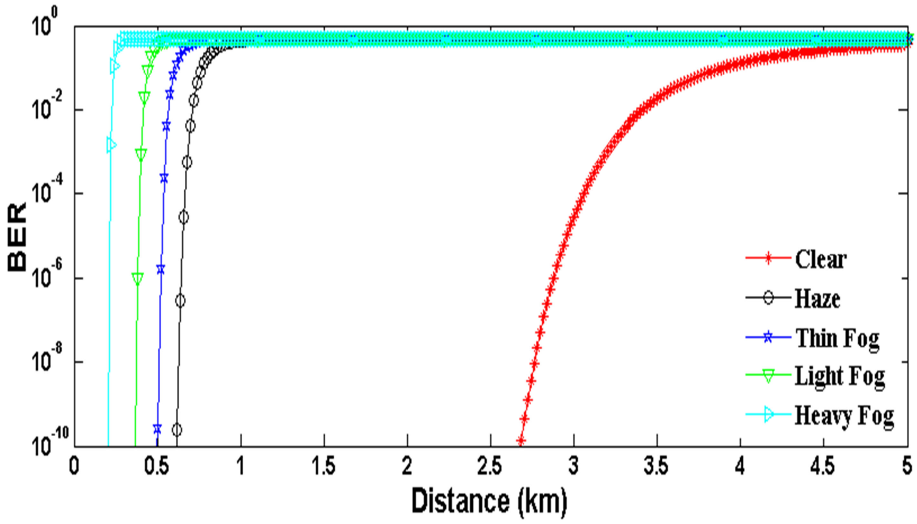

Fig (4) BER versus distance link for RZ-OOK

Another important simulation to evaluate the performance of BER for L-PPM. Fig (5) shows that BER for 4-PPM modulation format under different weather conditions when a 650nm is used. In this case, we notice that for BER 10^{-10}, when 4-PPM is applied the distance about 0.2 km for heavy fog, and its increase for light and thin fog becomes about 0.4 km, and 0.5 km, respectively. On the other hand, when the system is applied in haze weather condition, the distance is about 0.6 km, and its increase for clear sky becomes about 2.9 km. It is observed from Fig. (6) a significant increase in the distance can be achieved by 8-PPM. The maximum data rate is the same values of 4-PPM under the condition such as: heavy, light, thin, and haze conditions but for clear sky about 3.4 km. While for 16-PPM modulation technique becomes 3.8 km for the clear sky as shown in fig. (7)

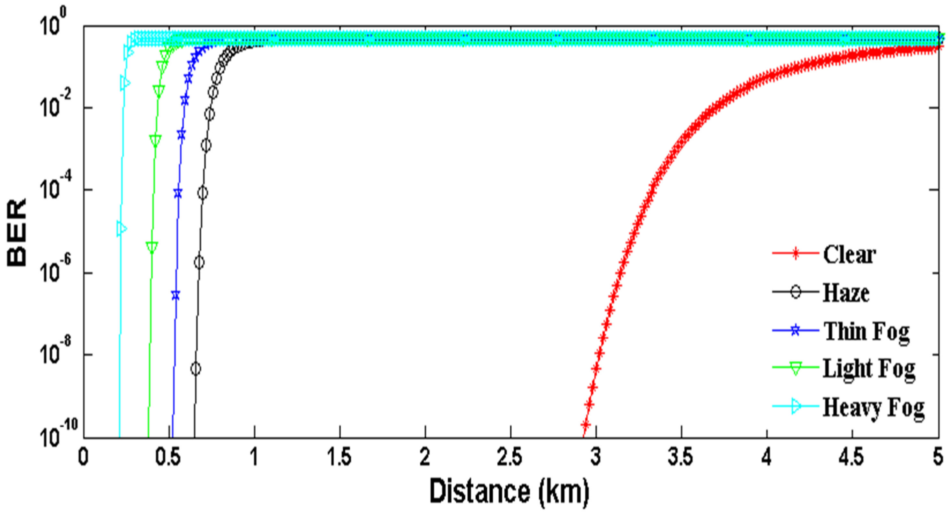

Fig (5) BER versus distance link for 4- PPM

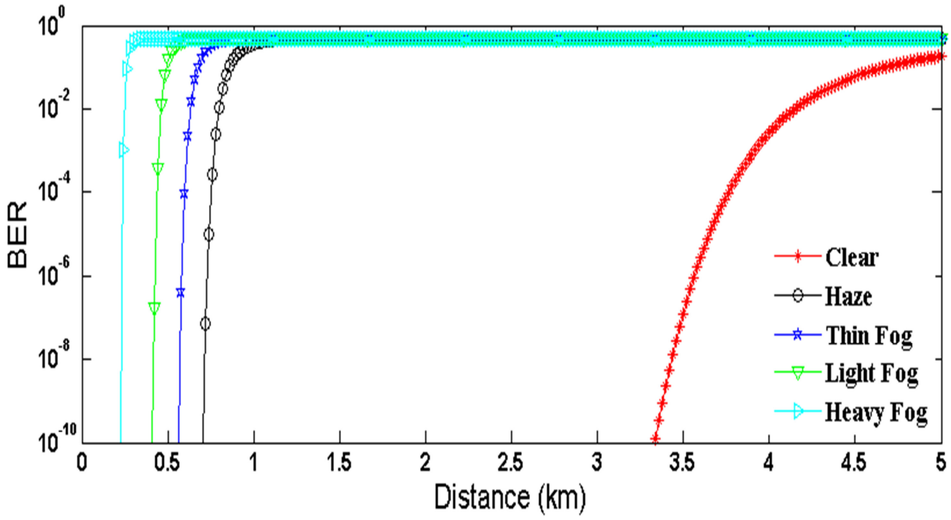

Fig (6) BER versus distance link for 8- PPM

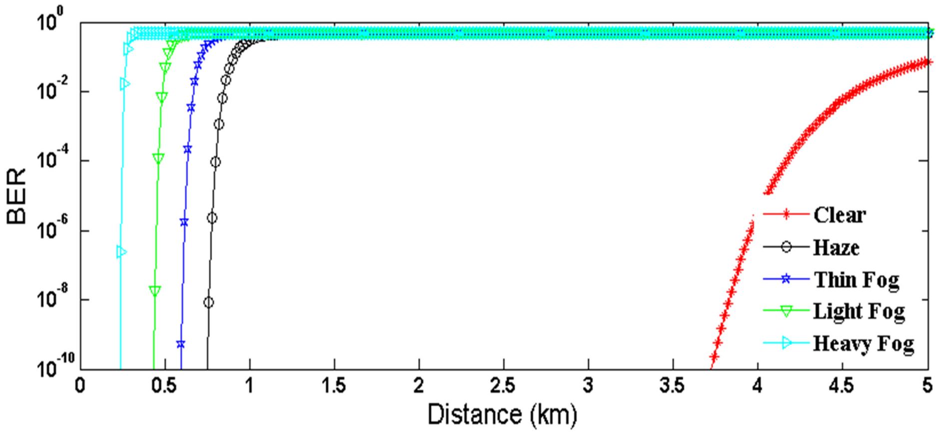

Fig (7) BER versus distance link for 16- PPM

4. Channel capacity

The channel capacity is presented in terms of BER of FSO communication, under different weather condition for various modulation techniques. In fig (8, 9), it is inferred that the information data increases along with distance decrease. The channel capacity can reach a maximum value of 1 (bits/sym), the information data not exceed 1 km for haze, thin, light, and heavy fog under NRZ, RZ-OOK. For clear sky the capacity about 1.4km, 1.6km for NRZ-OOK, and RZ –OOK. Fig (10) shows channel capacity against distance link when 16-PPM are applied. An improvement occurs in the channel capacity, where it is noticed that the information data reached 2.4km. It is intuitively clear that the increase in distance link leads to a reduction in the channel capacity.

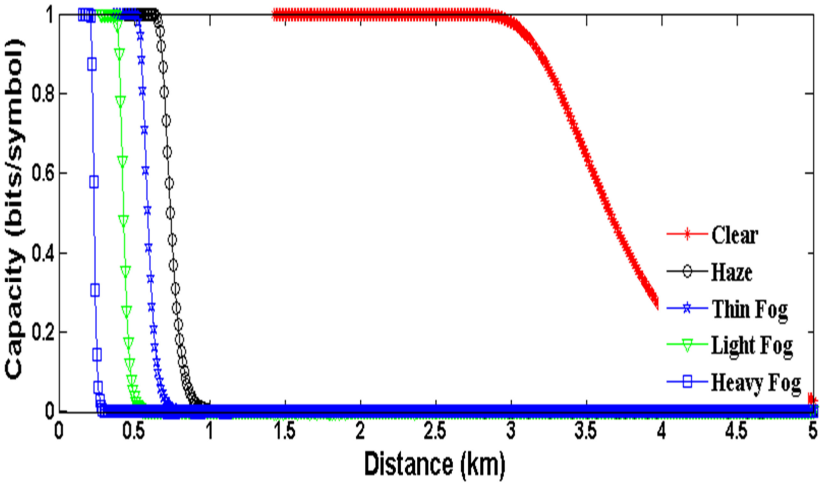

Fig (8) Channel Capacity versus distance link (m) for NRZ-OOK

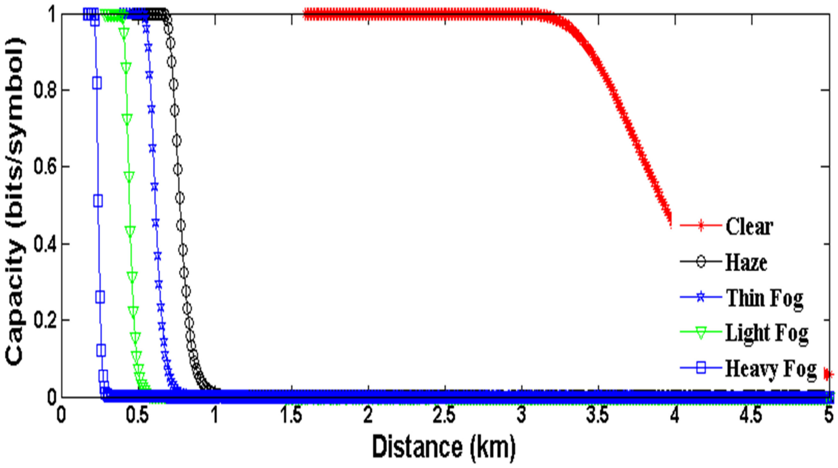

Fig (9) Channel Capacity versus distance link (m) for RZ-OOK

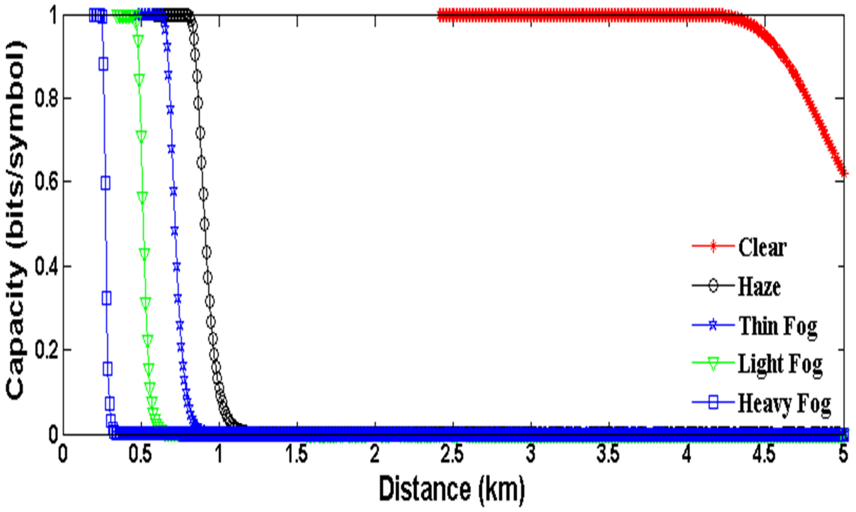

Fig (10) Channel Capacity versus distance link (m) for 16-PPM

Conclusions

In this paper, we have investigated a theoretical analysis of the effect of weather condition on the FSO communication performance using L-PPM modulation technique in the transmitter, and Si PIN as a receiver. The specific attenuation coefficient of the laser beam through free space has a significant effect on the performance of FSO communication systems. Based on the attenuation coefficients of weather conditions employed to study the effect on a receiver signal power, SNR, and BER. The suitable selected for 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 and channel capacity characteristics of L-PPM modulation technique under different weather condition are studied. The results show that the 16-PPM has a greater advantages than the other techniques, therefore, a 16-PPM is a more suitable wavelength for FSO communications compared with the other modulation techniques.

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