International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Bit Error Rate Analysis of Different Modulation Schemes in Free Space Optics Link using Gamma-Gamma Turbulence Model

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Abstract*: *Free Space Optical (FSO) link using gamma-gamma channel model has been studied in this paper. Comparison of the probability density function of gamma-gamma distribution under weak and strong turbulence regime has been performed. Performance of Bit error rate (BER) using different subcarrier-intensity modulation (SIM) schemes such as binary phase shift keying (BPSK), M-ary phase shift keying (M-PSK) and quadrature amplitude modulation (QAM) have been also investigated. Using MATLAB software, the BER is plotted with respect to normalized signal to noise ratio (SNR) and the link distance. All the analysis has been done using the Gamma-Gamma distribution model. In this work we found that the effectiveness of each modulation technique depends on the environment.

Keywords* : *Free Space Optics; bit-error-rate; Gamma-Gamma distribution; Subcarrier-Intensity Modulation (SIM).

I. INTRODUCTION

Free space optics (FSO) technology has become an attractive area of research [1-2]. Compared with the traditional radio frequency (RF), it has many advantages. This technology offered much larger capacity or bandwidth, about 300GHz range of frequency used and high data rate transmission [3]. It also consumes less power and provides greater protection against interference. In FSO systems, the data laden light is transmitted through the atmosphere over a short or long distance and then the light is collected at a receiver side. However, FSO technology suffer from the variation in the index of refraction caused by the random change in air pressure and temperature [1], [4]. In addition, there are a spatial and temporal spatial change within the light intensity or irradiance in contrast to the effect of fading in wireless communication systems. It is called scintillation [5]. Atmospheric turbulence can be described by three principal statistical models which are Log-normal distributed channel model [6-7], the K-distributed channel model [8-9] and the Gamma-Gamma distributed model [10-11]. In this paper, we have used Gamma-Gamma distributed model because it is suitable for modeling the irradiance of free space optical link over a weak turbulence region to strong turbulence region [12].

For the transmission of data, the intensity, phase or polarization of the optical field can be used in turbulence channel. Moreover, FSO technology has used on-off keying (OOK) modulation in many different commercial applications. The implementation of OOK modulation is simple but it is very difficult to fix the threshold required [13]. Pulse position modulation (PPM) is also another modulation scheme used by FSO communications. PPM has a very good power efficiency however its bandwidth is not efficient. To overcome those problems, a new technique known as subcarrier intensity modulation (SIM) has been proposed [1], [14], [4]. W. Huang *et al*. has shown in their work that Phase-shift keying subcarrier-intensity has good performance compared to OOK in the presence of turbulence in atmosphere [15]. In this paper we have studied three types of modulation schemes based on Subcarrier-intensity modulation (SIM). BPSK-SIM, 64-PSK-SIM and QAM-SIM.

II. GAMMA- GAMMA DISTRIBUTION

Propagation problems which involve intensity in gamma-gamma turbulence model are approximated very well. In this channel model, the fluctuation of light intensity can be divided into the large-scale (refraction) and the small-scale (scattering) atmospheric effects [16] and they follow gamma distribution. The probability density function (PDF) of the received irradiance I in FSO system is given by [16-18].

$$f(I)=\frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)}I^{\frac{\alpha+\beta}{2}-1}K_{\alpha-\beta}(2\sqrt{\alpha\beta I})\qquad I>0 \tag{1}$$

Here $K_n(\cdot)$ is the modified Bessel function of second kind and of order n, and $\Gamma(\cdot)$ is the Gamma function. In case the radiation from optical source is considered to be plane wave, the positive parameters α and β represent respectively the large- and small-scale optical wave intensity.

Manuscript published on November 30, 2019.

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Their relations to the scintillation index are given by [19].

$$\alpha = \left\{ \exp\left(\frac{0.49\sigma_R^2}{(1+1.11\sigma_R^{12/5})^{7/6}}\right) - 1 \right\}^{-1} \qquad (2)$$

$$\beta = \left\{ \exp\left(\frac{0.51\sigma_R^2}{(1+0.69\sigma_R^{12/5})^{5/6}}\right) - 1 \right\}^{-1} \qquad (3)$$

where $\sigma_R^2 = 0.5C_n^2 k^{7/6} L^{11/6}$ is Rytov variance and it is the log-irradiance variance in which C_n^2 is the structure index of refraction parameter, $k = 2\pi/\lambda$ is the wave number, and L represents distance between the transmitter and the receiver. In Gamma-Gamma channel model, weaker to stronger turbulence scenarios can be cover [12].

Eq.1 contains two special cases. The first is K -distribution ($\alpha > 0$ and $\beta = 1$) and it is used in a channel with strong turbulence conditions [16],[18]. The second used in extremely strong turbulence is the negative exponential distribution ($\alpha \to \infty$ and $\beta = 1$).

III. SERIES REPRESENTATION OF GAMMA-GAMMA DISTRIBUTION

Performance analysis in Multivariate Free Space Optical communications systems using gamma-gamma distribution is sometimes hard because of the presence of the modified Bessel function of 2nd kind. In order to avoid its use , we have base our work on a generalized power series representation given by [20].

$$K_v(x) = \frac{\pi}{2\sin(\pi v)}\left[\sum_{j=0}^{\infty}\frac{1}{\Gamma(j-v+1)\,j!}\left(\frac{x}{2}\right)^{2j-v} - \sum_{j=0}^{\infty}\frac{1}{\Gamma(j+v+1)\,j!}\left(\frac{x}{2}\right)^{2j+v}\right] \qquad (4)$$

Which can be valid only if $v \notin \mathbb{Z}$ and $|x| < \infty$. We note that the simple power series representation does not exist in case v is an integer. Therefore, combination of Eq. 1 and Eq. 4 leads to

$$f(I) = \sum_{j=0}^{\infty}\left(a_j(\alpha,\beta) I^{j+\beta-1} + a_j(\beta,\alpha) I^{j+\alpha-1}\right) \qquad (5)$$

Where $(\alpha - \beta) \notin \mathbb{Z}$ and

$$a_j(\alpha,\beta) \triangleq \frac{\pi(\alpha\beta)^{j+\beta}}{\sin[\pi(\alpha-\beta)]\Gamma(\alpha)\Gamma(\beta)\Gamma(j-\alpha+\beta+1)\,j!} \qquad (6)$$

IV. SUBCARRIER MODULATION AND BIT ERROR RATE ANALYSIS

In this work BPSK-SIM, 64-PSK-SIM and 16-QAM modulation technique has been studied in the Gamma-Gamma channel model.

A. *BPSK-SIM*

The conditional bit error rate of BPSK-SIM while considering equi-probable data transmission is given by [21]:

$$P_c = Q\left(\sqrt{\gamma I^2}\right) \qquad (7)$$

where γ is the signal to noise ratio at the demodulator input. Consequently, the unconditional bit error rate over the fading gain is given by:

$$P_e = \int_0^{\infty} P_c f(I)\,dI$$

$$P_e = \int_0^{\infty} Q\left(\sqrt{\gamma I^2}\right) f(I)\,dI \qquad (8)$$

Where $f(I)$ is the probability distribution of I . Therefore, by using the series representation of Eq. 5, in Eq. 8 we obtain the average of BER in Gamma-Gamma fading.

$$P_e = \sum_{j=0}^{\infty}\left(a_j(\alpha,\beta) X\left(\sqrt{\gamma}, j+\beta\right) + a_j(\beta,\alpha) X\left(\sqrt{\gamma}, j+\alpha\right)\right)$$

$$P_e = \sum_{j=0}^{\infty}\left(\xi_j(\alpha,\beta)\gamma^{-\frac{j+\beta}{2}} + \xi_j(\beta,\alpha)\gamma^{-\frac{j+\alpha}{2}}\right) \qquad (9)$$

Where $(\alpha - \beta) \notin \mathbb{Z}$ and

$$\xi_j(\alpha,\beta) \triangleq \frac{\sqrt{\pi}(\sqrt{2}\alpha\beta)^{j+\beta}\Gamma(\frac{j+\beta+1}{2})}{2\sin[\pi(\alpha-\beta)]\Gamma(\alpha)\Gamma(\beta)\Gamma(j-\alpha+\beta+1)(j+\beta)\,j!} \qquad (10)$$

B. *M-PSK SIM*

Conditional BER of M-PSK is given by [22]

$$P_c \approx \frac{2}{\log_2 M} Q\left(\sqrt{\log_2 M \gamma I^2}\sin(\pi/M)\right) \qquad (11)$$

The unconditional bit error rate of M-PSK can be obtained as

$$P_e = \frac{2}{\log_2 M}\int_0^{\infty} Q\left(\sqrt{\log_2 M \gamma I^2}\sin(\pi/M)\right) f(I)\,dI$$

$$P_e = \frac{2}{\log_2 M}\sum_{j=0}^{\infty}\left(\xi_j(\alpha,\beta)(\sqrt{\log_2 M}\gamma\sin(\pi/M))^{-\frac{j+\beta}{2}} + \xi_j(\beta,\alpha)(\sqrt{\log_2 M}\gamma\sin(\pi/M))^{-\frac{j+\alpha}{2}}\right) \qquad (12)$$

C. *M-QAM-SIM*

Quadrature amplitude modulation scheme increases power efficiency and the data rate however it is more effective in the presence of noise.

The conditional BER of M-QAM is expressed as [22]

$$P_c = \frac{2\left[1-1/\sqrt{M}\right]}{\log_2 M} Q\left(\sqrt{\frac{3\log_2 M}{2(M-1)}\gamma I^2}\right) \qquad (13)$$

Thus, the unconditional BER of M-QAM is obtained as :

$$P_e = \frac{2\left[1-1/\sqrt{M}\right]}{\log_2 M}\int_0^\infty Q\left(\sqrt{\frac{3\log_2 M}{2(M-1)}\gamma I^2}\right) f(I)dI$$

$$P_e = \frac{2\left[1-1/\sqrt{M}\right]}{\log_2 M}\sum_{j=0}^{\infty}\left(\xi_j(\alpha,\beta)\left(\sqrt{\frac{3\log_2 M}{2(M-1)}}\gamma\right)^{-\frac{j+\beta}{2}}\right.$$

$$\left. + \xi_j(\beta,\alpha)\left(\sqrt{\frac{3\log_2 M}{2(M-1)}}\gamma\right)^{-\frac{j+\alpha}{2}}\right) \qquad (14)$$

V. RESULTS AND DISCUSSION

We have studied in this work the probability density function of attenuation over Gamma-Gamma turbulence channel. We analyzed this PDF in weak turbulence region, $C_n^2 = 6.5\times10^{-15} m^{-2/3}$ and strong turbulence region, $C_n^2 = 6.5\times10^{-14} m^{-2/3}$ for a link range of 1000m at 1550 nm of wavelength.

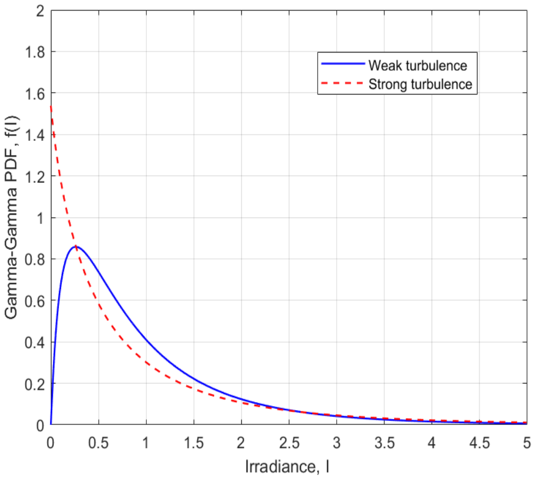

Fig. 1. Turbulence effects at different FSO link

beam and its signal strength is affected in this strong turbulence regime. FSO link should be installed at high altitudes in order to reduce this problem.

In this paper, we have investigated the BER performance analysis using of BPSK-SIM, PSK-SIM and QAM-SIM methods with the help of MATLAB software. We have also compared them. In this work, the analytical and simulation is done in a Gamma-Gamma channel model. The error performance of the system is numerically simulated with respect to the normalized signal to noise ratio (SNR). The computation of BER expressed in Eq. 10, Eq. 12 and Eq. 13 for the three modulations schemes are shown in Fig. 2.

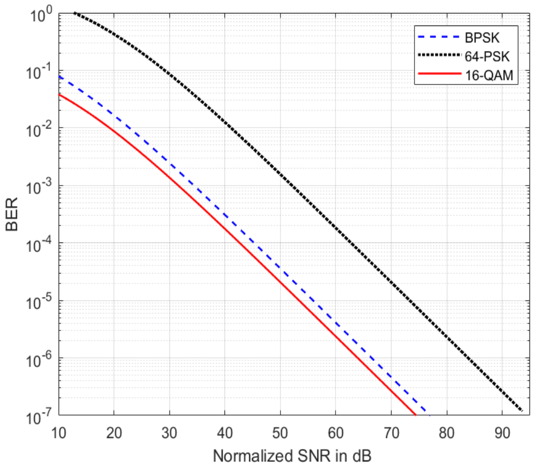

Fig. 2. BER versus Normalized SNR

The bit error rate falls with the rise the of signal to noise ratio values. To achieve a BER of 10^{-6} for QAM-SIM, the required SNR is about 64 dB and this grow to approximately 66 dB and 84 dB, respectively for BPSK-SIM and PSK-SIM. Fig. 3 illustrates the BER of the three modulations schemes with respect to the link distance L, which is the distance between the transmitter and receiver . Eq. 2 and Eq. 3 are computed, where $\lambda = 1550\,nm$, $C_n^2 = 1.7\times10^{-14} m^{-2/3}$ and the value of SNR is chosen to be 20dB in order to eliminate the effect of attenuation. Fig. 3 shows that BER of the three modulation in the FSO systems degrades with an increase in link distance since the value of α and β decrease. The obtained BER from the analysis predicts the performance of the simulation.

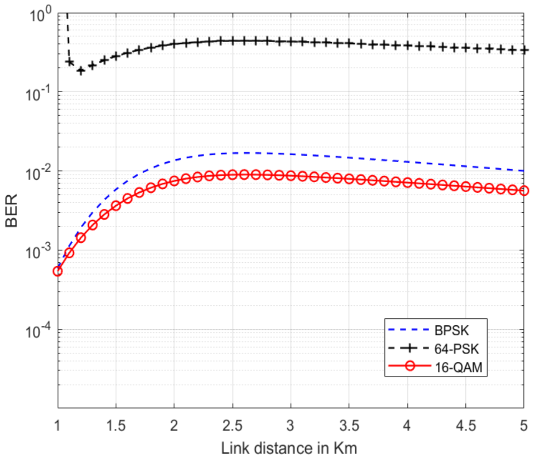

Fig. 3. BER versus Link distance

VI. CONCLUSION

Free space optical communication systems error performance analysis has been performed in this work while considering the gamma-gamma fading model. The analysis relied on the generalized power series representation of the modified Bessel function of the second kind which give an accurate performance evaluation. The bit error rate performance of M-QAM is better compare to the two other modulation schemes.

Retrieval Number: D8982118419/2019©BEIESP
DOI:10.35940/ijrte.D8982.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

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