ANALYSIS OF BIT ERROR RATE IN FREE SPACE OPTICAL COMMUNICATION SYSTEM

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ABSTRACT

During the past five years, the commercial use of free space optics has grown exponentially because the technology offers the potential to connect at extremely high bandwidths and provide many other applications. The main objective of this paper is to find the behaviour of signal in free space optic in different atmospheric conditions, specifically the analysis of the bit error rate with the change in average signal-to-noise ratio SNR (dB). Although Free Space Optics (FSO) has received a great deal of attention lately both in the military and civilian information society due to its potentially high capacity, rapid deployment, portability and high security from deception and jamming.

Keywords: Atmospheric Turbulence, Bit Error Rate (BER), Free-Space Optical Communication (FSO), Gamma Gamma Channel Model, Nakagami-M Channel Model.

I INTRODUCTION

Free-space optical communication (FSO) systems (in space and inside the atmosphere) have developed in response to a growing need for high-speed and tap-proof communication systems. Links involving satellites, deep-space probes, ground stations, unmanned aerial vehicles (UAVs), high altitude platforms (HAPs), aircraft, and other nomadic communication partners are of practical interest. Moreover, all links can be used in both military and civilian contexts. FSO is the next frontier for net-centric connectivity, as bandwidth, spectrum and security issues favour its adoption as an adjunct to radio frequency (RF) communications [1]. Applications range from short-range wireless communication links providing network access to portable computers, to last-mile links bridging gaps between end users and existing fiber optic communications backbones, and even laser communications in outer-space links [2]. Indoor optical wireless communication is also called wireless infrared communication, while outdoor optical wireless communication is commonly known as free space optical (FSO) communication.

The modulation of the source data onto the electromagnetic wave carrier generally takes place in three different ways: amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), each of which can be theoretically implemented at any frequency [3]. For an optical wave, another modulation scheme is also often used, namely intensity modulation (IM). Intensity is defined as flow energy per unit area per unit time expressed in W/m, and is proportional to the square of the field's amplitude. The light fields from laser sources then pass beam forming optics to produce a collimated beam. This practice is equivalent to providing antenna gain in RF systems.

II SYSTEM AND CHANNEL MODEL

We consider a FSO communication system with single users as depicted in Fig. 2 and in which the central node is equipped with single apertures and the users are only equipped with single apertures.[4]. A multi-hop free space optical (FSO) communication system with intensity modulation/direct direction links-hops using on-off keying is considered. In this work we are considering the channel model where both the turbulence-induced fading and path-loss are included. For one link between the transmitter and receiver.

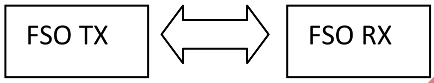

Fig.1 FSO Link For Duplex Communication

In this work we are considering the channel model where both the turbulence-induced fading and path-loss are included. For single link between the aperture at the transmitter and the user at the receiver, the channel with distance d can be modeled as [4].

For N =1 link.

$$h_1 = L\,(d_1)\,\tilde{h}_1, \tag{1}$$

where, h denoted as Turbulence fading, $\tilde{h}$ is the Atmospheric fading, L(d) path loss. The path loss, L (d) and can be written as:

$$L\,(d) = \frac{D_R^2}{(D_T + \theta_T d_1)^2} e^{-v d_1} \tag{2}$$

where, D_R and D_T are Receiver and Transmitter Aperture diameters respectively, v denotes Weather dependent attenuation coefficient and θ_T is opticalbeam's divergence angle. From Eq. (1), the instantaneous signal to noise (SNR) can be defined as

$$\gamma = \tilde{\gamma}\,|\tilde{h}|^2 \tag{3}$$

III GAMMA GAMMA DISTRIBUTION MODEL

For strong atmospheric condition, the channel fading can be modeled using the well-known gamma-gamma distribution [5], [6]. Thus, PDF of $|\tilde{h}|$ can be given by

$$f_{|\tilde{h}|}^{GG}(x) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} x^{\frac{\alpha+\beta}{4}-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta x}\right), \tag{4}$$

where Γ (°) is a gamma function α and β are re the fading parameters related to the effective atmospheric conditions of the link and depend on the Rytov variance, and $K_v(x)$ is the modified Bessel function of the second kind of order v. More specifically, from [7], the values of α and β can be expressed as where $\alpha = \exp\left[\left(0.49\delta^2/(1+0.18L^2+0.56\delta^{12/5})^{7/6}\right)-1\right]^{-1}$ and

$\beta = \exp\left[\left(0.51\delta^2/(1+0.9L^2+0.62\delta^{12/5})^{5/6}\right)-1\right]^{-1}$.

By applying a simple variable transformation, PDF of γ can be given by

$$f_\gamma^{GG}(\gamma)=\frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)}\gamma^{\frac{\alpha+\beta}{4}-1}K_{\alpha-\beta}\left(2\sqrt{\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}}}\right), \tag{5}$$

and its corresponding Cumulative distribution function, CDF

$$F_\gamma^{GG}(\gamma)=\frac{1}{\Gamma(\alpha)\Gamma(\beta)}G_{1,3}^{2,1}\left[\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}}\,\middle|\,\begin{matrix}1\\ \alpha,\beta,0\end{matrix}\right] \tag{6}$$

$G_{1,3}^{2,1}$ is the Meijer's G-function [8]. Let denote the order statistics obtained by arranging the random variables assume that in an increasing order of magnitude. For tractable analysis, we are independent and identically distributed, i.e., for all users. The CDF and PDF for single user having single aperture denoted by K, hence, PDF and CDF $\gamma_{1,1}$ are given as [8].

$$F_{\gamma 1,1}(\gamma) = \left[F_\gamma(\gamma)\right], \tag{7}$$

$$f_{\gamma 1,1}(\gamma) = f_\gamma(\gamma), \tag{8}$$

IV STATISTICAL CHARACTERISTICS

In this subsection, we will derive the resulting CDF and PDF expressions for both log normal and gamma gamma distribution [9].

$$Q(x) \approx \frac{1}{12}\exp\left(-\frac{x^2}{2}\right)+\frac{1}{4}\exp\left(-\frac{2x^2}{3}\right) \quad x \geq 0 \tag{9}$$

Note that for K ≥ 2, using the exact CDF formulas Eq. (6) and Eq (7) to evaluate the system performance is very complicated. Therefore, we need to find approximate expressions the CDF and PDF in strong turbulence conditions.

V STRONG TURBULENCE CONDITION

We are focusing on the gamma- gamma distribution model and the CDF can be evaluated by using, the CDF in Eq. (4.9) can be rewritten as

$$F_\gamma^{GG}(\gamma)=\frac{1}{\Gamma(\alpha)\Gamma(\beta)}\frac{\pi}{2\sin((\alpha-\beta)\pi)}\sum_{s=0}^{\infty}\left[\frac{2}{(s+\beta)\Gamma(\beta-\alpha+1+s)s!}\left(\frac{\alpha\beta}{\sqrt{\bar{\gamma}}}\right)^{s+\beta}\gamma^{\frac{s+\beta}{2}}-\left(\frac{\alpha\beta}{\sqrt{\bar{\gamma}}}\right)^{s+\beta}\gamma^{\frac{s+\beta}{2}}\right] \tag{10}$$

It should be noted that $\beta-\alpha$ is not an integer in Eq. (10). Substituting Eq. (10) into Eq. (7), we get the CDF of the SNR of a gamma-gamma modeled FSO system can be written as:

$$F_{\gamma_{1,1}}^{GG}(\gamma)=\sum_{j=0}^{M(1-j)}\sum_{p=0}^{M(1-j)}\sum_{q=0}^{Mj}\binom{1}{j}(-1)^j\eta_p\eta_q\frac{1}{\Gamma(\alpha)\Gamma(\beta)}\cdot\left\{\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}}\right\} \quad (11)$$

η_p, η_q are the coefficient of $(\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}})^p$ and $(\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}})^q$ in the expansion of

$$\sum_{s=0}^{M}\left[\frac{2}{(s+\beta)\Gamma(\beta-\alpha+1+s)s!}\left(\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}}\right)^s\right]^{1-j}$$

and $\sum_{s=0}^{M}\left[\frac{2}{(s+\beta)\Gamma(\beta-\alpha+1+s)s!}\left(\alpha\beta\sqrt{\frac{\gamma}{\bar{\gamma}}}\right)^s\right]^j$ respectively.

VI BER ANALYSIS

The mean BER can be calculated using CDF-based method as:

$$P_e = E_x\left\{F_\gamma\left(\frac{X^2}{2}\right)\right\} \quad (12)$$

where X is a random variable with standard Normal distribution. Substituting Eq. (11) into Eq. (12), we obtain the approximate BER expressions for the gamma gamma modeled FSO system with the low SNR and high SNR[10].

To evaluate the above integrals, we define two integrals as

$$I_1(A, B) = \frac{2}{\sqrt{\pi}}\int_0^\infty \exp\{-A(\ln(x)+B)^2\}\, e^{-x^2}dx, \qquad A>0 \quad (13)$$

$$I_1(A,B,\lambda) = \frac{2}{\sqrt{\pi}}\int_\lambda^\infty \exp\{-A(\ln(x)+B)^2\}\, e^{-x^2}dx, \qquad A>0 \quad (14)$$

Using the above results from the above equation of I_1 and I_2, we obtain closed form expressions for Eq. (13) and Eq. (14) as the average BER over the gamma-gamma modeled optical channel with the Nth best user selection can be obtained as

P_e^{GG}=

$$\sum_{j=0}^{i}\sum_{p=0}^{M(i-j)}\sum_{q=0}^{Mj}\sum_{t=0}^{1-i}\sum_{r=0}^{t}\sum_{a=o}^{M(t-r)}\sum_{b=0}^{Mr}\binom{1}{i}\binom{i}{j}\binom{1-i}{t}\binom{t}{r}(-1)^{j+t+r}\left(\frac{1}{\Gamma(\alpha)\Gamma(\beta)}\cdot\frac{\pi}{2\sin((\alpha-\beta)\pi)}\right)^{i+t}\times$$
$$\eta_a\eta_b\lambda_a\lambda_b\left(\frac{\alpha\beta}{\sqrt{\bar{\gamma}}}\right)^{\beta(i-j+t-r)+\alpha(j+r)+p+q+a+b}\times\frac{1}{2\sqrt{\pi}}\Gamma\left(\frac{\beta(i-j+t-r)+\alpha(j+r)+p+q+a+b+1}{2}\right) \quad (15)$$

VII RESULT AND ANALYSIS

The bit error rate (BER) performance of free space optical (FSO) communication systems employing on-off keying (OOK) modulation format is derived. The improvement is different for different turbulence strength i.e for strong turbulence strengths and modulation formats. Based on the gamma–gamma distribution and the BER performances for intensity modulation direct detection with OOK formats has been derived. For OOK modulation format, the BER performance employing an optimal threshold is superior to that employing a fixed threshold.

TABLE

Comparison of BER for weak and strong Turbulence

Average SNR (dB)	BER (Strong Turbulence)
10	1
20	0.9998
30	0.9834
40	0.8057
50	0.3904
60	0.09278
70	0.1157
80	0.009323
90	5.369×10^{-5}
100	2.54×10^{-6}

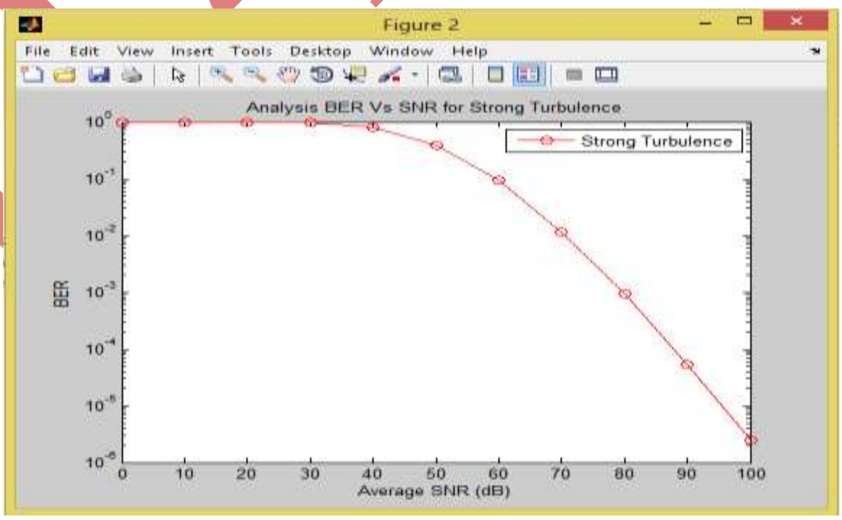

Fig. 2 Analysis for Strong Turbulence

The performance of Bit error rate (BER) with respect to Average Signal to Noise Ratio (SNR) [dB] is shown in Fig 2. The above figure shows that in free space optic system, when the signal propagates in the strong turbulence medium, the behaviour of SNR is inverse proportional to that of Bit error rate. In other words, as the SNR [dB] is increasing the BER is decreasing.

VIII CONCLUSION & FUTURE WORK

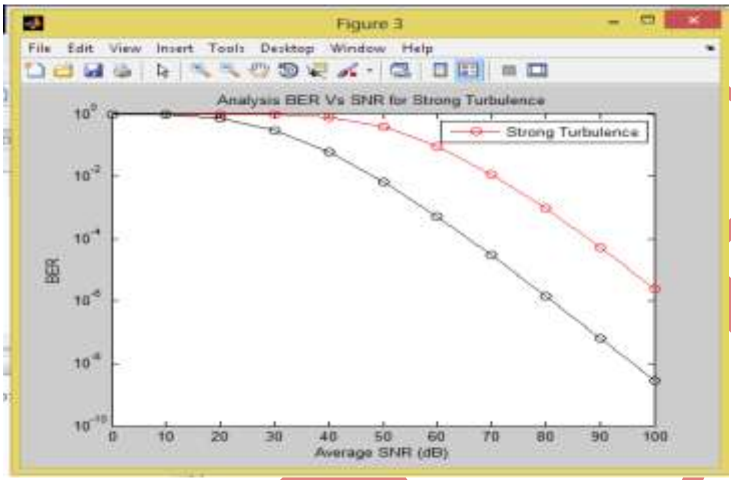

Fig.3. Analysis for Strong Turbulence and Weak Turbulence

The performance of Bit error rate (BER) with respect to Average Signal to Noise Ratio (SNR) [dB] is shown in Fig 3. The above figure shows the comparison of the signals propagating in both the strong and weak turbulence medium respectively.

It may be noted that as the signal to noise ratio increases the bit error rate decreases in both the turbulence conditions. Due to this decrease in BER the system performance increases. It is also noted that in weak turbulence condition, BER is less as compared with strong turbulence conditions. Hence, weak turbulence condition will provide better performance of the FSO system in different applications.

We derived a comprehensive performance analysis or the FSO communication systems with single user diversity for strong atmospheric turbulence in this paper and compared it with Weak turbulence. We derived some approximate expressions for the BER analysis strong atmospheric turbulence. Results show that the approximate analysis is quite accurate. In this a practical channel model for IM/DD FSO communications links was proposed and verified using the experimental FSO link. We can also use PPM, BPSK modulation scheme.

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