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PERFORMANCE ANALYSIS OF FSO COMMUNICATION SYSTEM WITH DIFFERENT MODULATION SCHEMES

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ABSTRACT

Free-space optical communication (FSO) is a technology which use optical signals to transmit data wirelessly, providing a viable alternative to conventional wired systems. The Free Space Optical (FSO) communication system has emerged as an attractive option due to its large license free bandwidth, high security and low cost It is one of the very promising technologies for wireless communication. However, the sensitivity to weather conditions is one of the major disadvantage of FSO systems. Weather factors, such as rain, fog, snow, and dust, can significantly attenuate the optical signals, which can lead to a reduction in signal strength and it can affect potentially data transmission reliability. Present work focusses on two key performance parameters Average Bit Error Rate (ABER) and Outage Probability (OP) which is of much importance due to the adverse impact of weather factors on FSO communication system. For the present study the OP and ABER performance are analysed over Gamma- Gamma (G-G) fading for FSO links in the presence weak and moderate atmospheric turbulence with four different modulation schemes. The CDF functions for the channel model has been derived and MATLAB codes are used to predict the OP and ABER performance for the FSO communication system.

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INTRODUCTION

The increased demand for larger bandwidth and greater mobility has led to a rapid development of broadband wireless communications. Free space optical wireless communication is a technologythat can be used to bridge the gap in existing high data rate fiber network and also for easy deployable mobile wireless communication system. Free space optics provides the capability to send large amounts of data securely without the expense of laying fiber optic cable. FSO system has been widely used in transport communication, under water communication, deep space and satellite communication.Free space optical communication systems is seen as an alternative to Radio Frequency (RF) communication because of its large bandwidth, low cost of implementation, very excellent security etc. [1]. One of the disadvantage of FSO system is the degradation in performance by the atmospheric turbulence induce-fading [2]. FSO communications clearly has more advantages when compared to RF communications w.r.t data transfer rate, massive bandwidth availability, cost-effectiveness, and license-free. By adopting adaptive modulation, coding for error control and aperture averaging, the communication system can be made more efficient [3]. Many mathematical models with different levels of success like lognormal [4], and gamma – gamma [5] have been proposed. Atmospheric turbulence over the FSO link was characterized by various statistical models using log normal model for weak turbulence regime within a distance less than 1 km [6]. Negative exponential and K-distribution models have been proposed for a very strong turbulence over long distances [7]. Several authors have presented the performance evaluation of RF-FSO system using decode-and- forward (DF) or amplify –and-forward (AF) protocols [8]-[10]. Conventional On/Off Key (OOK) modulation is widely adopted to improve the FSO system performance due to its low cost and simplicity in implementing it practically [11]. Pulse Position Modulation (PPM) was investigated [12] for FSO link impairments. Many researches have proved that better performance metric can be achieved with SIM modulation as mitigation technique against turbulence for FSO systems [13]. Good amount of work has been carried out with different models for different turbulence regimes such as GG [14], double Weibull [15], and extended generalized K (EGK) [16]. For the current work the gamma-gamma distribution has been chosen, because moderate-to-strong turbulence situations are accurately reproduced by this approach [17], [18], [19]–[24]. In the present work, average bit error rate and outage probability is derived with different modulation schemes and turbulence parameters. The CDF functions for the channel model has been derived and MATLAB codes are used to predict the OP and ABER performance for the FSO communication system.

System and Channel Modelling

System Model: In this system, the FSO link is characterized by Gamma –Gamma Fading channel model. Both weak and moderate turbulence effects have been studied with four modulations schemes coherent binary frequency shift keying (CBFSK), coherent binary phase shift keying (CBPSK), non-coherent binary frequency shift keying (NBFSK), and differential binary phase shift keying (DBPSK).

FSO Channel Model: For FSO transmissions, we have used Gamma –Gamma fading model including pointing errors. The PDF is given by [14, eq. (1)]

$$f(I) = \frac{\zeta^2 \; I^{-1}}{\Gamma(\alpha)\Gamma(\beta)} G_{1,3}^{3,0}\left(\alpha\beta \frac{I}{i^L} \Big|_{\zeta^2 \; ,\alpha,\beta}^{\zeta^2 \; +1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

ξ- pointing error coefficient

α - large-scale fading parameters related to atmospheric turbulence effects.

β- small-scale fading parameters related to atmospheric turbulence effects.

The expression for instantaneous and average received SNRs is given by [25, eq. (6, 9)]

$$\gamma = \frac{(\eta PGI)^2}{\sigma^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\bar{\gamma} = \frac{(\eta PGKI)^b}{\sigma^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where $k = \zeta^2/\zeta^2+1$

Using eqn 1,2 and using the power transformation of random variables, the unified pdf of the instantaneous SNR for IM/DD and HD is obtained as [25, eqn. (2)]

$$f_\gamma(\gamma) = \frac{\zeta^2 \; \gamma^{-1}}{b\Gamma(\alpha)\Gamma(\beta)} * \; G_{1,3}^{3,0}\left(\alpha\beta k \left(\frac{\gamma}{\mu}\right)^{1/b} \frac{\zeta^2+1}{\zeta^2,\alpha,\beta}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where μ,b represents the average electrical SNR, which is linked to γ,b as

$$\mu_1 = \bar{\gamma}_1$$

$$\mu_2 = \frac{\alpha\beta\zeta^2 \; (\zeta^2+2)}{(\alpha+1)(\beta+1)(\zeta^2+1)^2} \gamma_2$$

where subscript 1 and 2 represent intensity modulation and direct detection (IM/DD) and heterodyne detection (HD). In the present work, the results are presented for HD technique.

Using equation 4 and [27, eq. (07.34.21.0084.01)], the cdf of γcan be obtained after certain algebraic expressions as

$$F_\gamma(\gamma) \; = X_g G_{b+1, \; 3b+1}^{3b, \; 1}\left(\varepsilon \frac{\gamma}{\mu_2} \Big|_{B^2 \; ,0}^{1,B^1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where $X_g = \frac{2^{\alpha+\beta-2}\zeta^2}{2\pi\Gamma(\alpha)\Gamma(\beta)}$

$$\varepsilon = \left(\frac{\alpha^2\beta^2 \; k^2}{16}\right)$$

$$B^1 \;\; = \left(\frac{\zeta^2 \; +1}{2}, \frac{\zeta^2 \; +2}{2}\right)$$

$$B^2 \;\; = \left(\frac{\zeta^2}{2}, \frac{\zeta^2 \; +1}{2}, \frac{\alpha}{2}, \frac{\alpha+1}{2}, \frac{\beta}{2}, \frac{\beta+1}{2}\right)$$

Here b =2 as we are dealing of HD technique

Performance Analysis: In this section, analytical expressions are derived for outage probability and Bit Error Rate of different binary modulation schemes where the FSO link is modelled by Gamma – Gamma Fading channel model.

Outage Probability (OP): OP is an important performance parameter which is defined as the probability that instantaneous SNR, γ_z, is less than a specified threshold value γ_{th}, is a value of SNR above which the channel quality is satisfactory. The Outage probability for the FSO link can be written as

$$P_{out} = F_\gamma(\gamma_{th}) \; = X_g G_{b+1, \; 3b+1}^{3b, \; 1}\left(\varepsilon \frac{\gamma}{\mu} \Big|_{B^2 \; ,0}^{1,B^1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

For the present case, b=2 as the detection technique used is HD.

Average BER for binary modulation techniques

The BER for various binary modulation techniques of a communication link can be computed using [28, Eq.(12)] is given by

$$P_e = \frac{v^u}{2\Gamma(u)} \int_0^\infty \gamma^{u-1} \exp(-v\gamma) \, F_\gamma \, (\gamma) d\gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where u and v are the BER parameters describing binary modulation techniques, coherent binary frequency shift keying (CBFSK), coherent binary phase shift keying (CBPSK), non-coherent binary frequency shift keying (NBFSK), and differential binary phase shift keying (DBPSK) as shown in Table 1 and $F_\gamma \, (\gamma)$is the CDF of the communication link.

Table 1. BER parameters for various modulation techniques

Modulation scheme	u	v
CBFSK	0.5	0.5
CBPSK	0.5	1
NBFSK	1	0.5
DBPSK	1	1

Table 2. Fading parameters of the FSO link under different turbulence conditions

Turbulence regime	α	β
Weak turbulence	2.296	2
Moderate turbulence	4.2	3

Table 3. Simulation parameters for FSO link [25]

Switching threshold	γ_{th}	10 dB
Pointing error coefficient	ζ	5.2
Optical to electrical efficiency	η	0.8

Substituting eqn (5) in eqn (7) we get

$$P_e = \frac{v^u}{2\Gamma(u)} \int_0^\infty \gamma^{u-1} \exp(-v\gamma) \, F_\gamma \, (\gamma) d\gamma$$

$$P_e = \frac{v^u}{2\Gamma(u)} \int_0^\infty \gamma^{u-1} \exp(-v\gamma) \; X_g G_{b+1, \; 3b+1}^{3b, \; 1}\left(\varepsilon \frac{\gamma}{\mu_2} \; \Big|_{B^2 \; ,0}^{1,B^1}\right) \quad \ldots..(8)$$

Integrating the above eqn (Wolfram eqn:07.34.21.0088.01) and doing algebraic manipulations, the equation for the probability of error is obtained as

$$P_e = \frac{v^u}{2\Gamma(u)} \left[X_g \, v^{-\alpha} \, G_{4,7}^{6,2} \left(\frac{\varepsilon}{\mu v}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

1-u,1,ζ^2+1/2,ζ^2+2/2,

ζ^2/2, ζ^2+1/2, α/2,α+1/2,β/2,β+1/2,0

NUMERICAL RESULTS

This section highlights the numerical results of the FSO system with G-G fading channel and characterized by weak to moderate turbulence levels and pointing error (ζ=5.2). For the present case, MATLAB code was used to derive the performance. Four modulation schemes have been used to study its impact on the performance of the FSO system (Table 1). The fadingparameters used for the FSO link is provided in Table 2. The outage probability and Bit Error Rate versus average SNR graphs are plotted forvarious scenarios. Fig.1, 2 show the OP versus average Signal to Noise Ratio (SNR) with γ_{th}= 10dB, 15dB with turbulence ranging from weak turbulence and moderate turbulence andpointing parameter, ζ= 5.2.

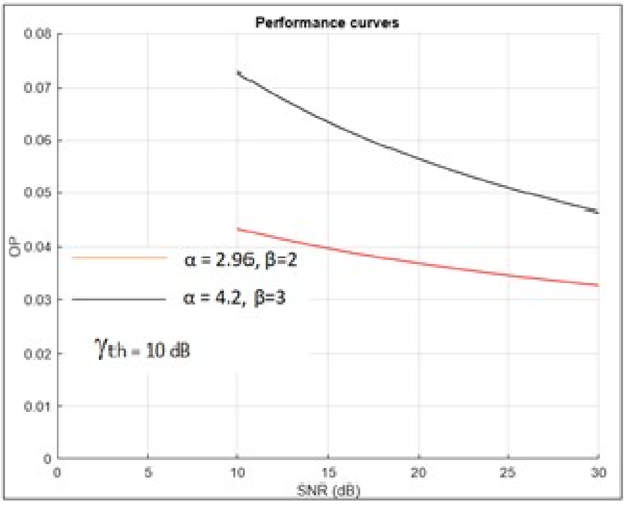

Fig. 1. OP vs SNR (γ_{th} = 10 dB)

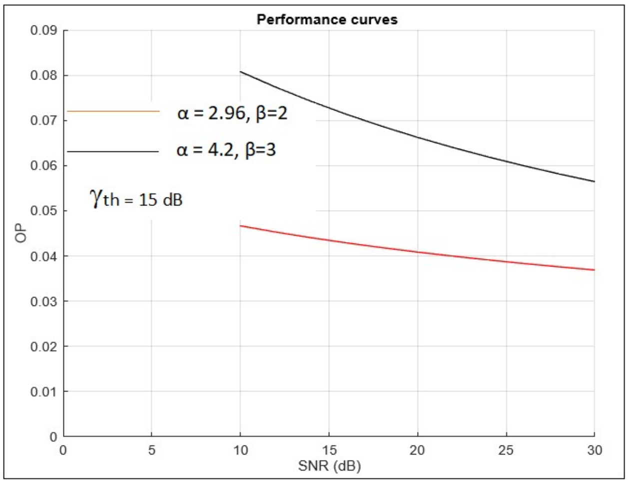

Fig. 2. OP vs SNR (γ_{th} = 15 dB)

It can be seen from the figures that as the effectof atmospheric turbulence decreases, the performance ofthe system improves and vice versa. With increase in threshold value, the outage probability increases. Fig. 3 to 6 show the BER vs SNR for the four modulation schemes with pointing error ζ=5.2.

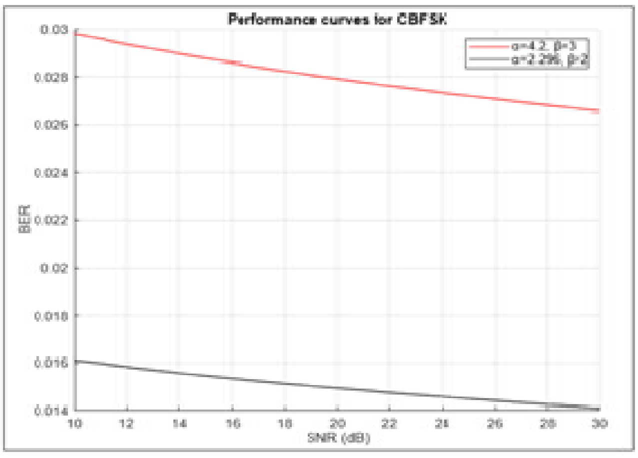

Fig. 3. BER vs SNR (CBFSK modulation)

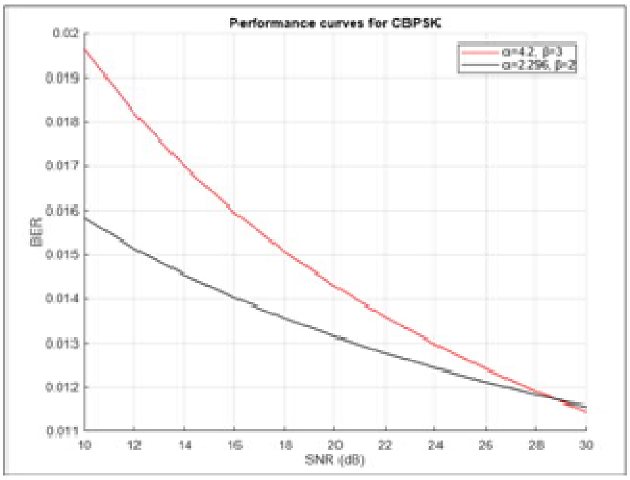

Fig. 4. BER vs SNR (CBPSK modulation)

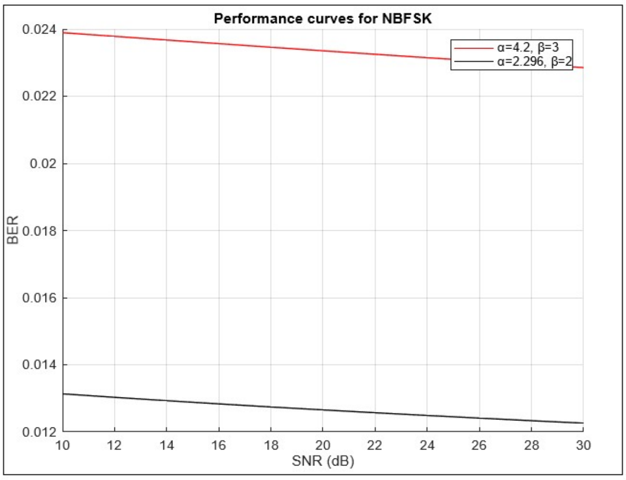

Fig. 5. BER vs SNR (NBFSK modulation)

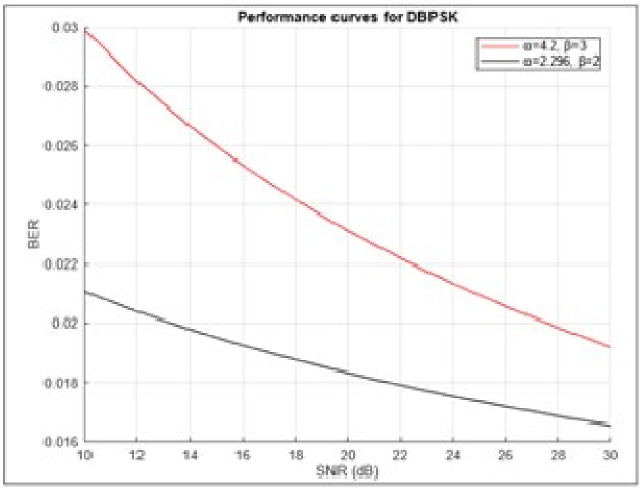

Fig. 6. BER vs SNR (DBPSK modulation)

It can be inferred seen from the plots of average BER versus SNR (with four modulation schemes), with weak turbulence, the BER decreases with SNR. For SNR=10, the BER was lowest with CBFSK technique under moderate turbulence whereas the NCBFSK technique had the lowest BER for weak turbulence.

CONCLUSIONS

In this work, the Meijer G function based closed form expression was obtained for BER for the FSO communication system. The CDF function was substituted in the Probability error equation through which the BER for various binary modulation techniques Coherent binary frequency shift keying (CBFSK), coherent binary phase shift keying (CBPSK), non-coherent Binary frequency shift keying (NBFSK), and differential binary phase shift keying (DBPSK)was evaluated.. It is observed that a system with lesser atmospheric turbulence is having a better BER performance. It is also the outage probability increases with increase in threshold value which is line with the expectation.

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