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A Gamma-Exponential Distribution Channel Model for Turbulence in Free Space Optical Communication

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Abstract: Now a day's various type channel modeling are proposed in communication medium. In this paper introduces a new channel model known as gamma-exponential distribution for turbulence vanishing in free space optical communication. The proposed model acquires the probability density function and bit error rate of received Quadrature Amplitude Modulation (QAM) modulated optical power in Free Space Optical and (FSO) communication. This method acts well under weak, moderate and strong turbulence conditions. This model is related with existing channel models, Rayleigh fading channel model, gamma distribution channel model and gamma-gamma distribution channel model.

Key words: Gamma channel, QAM, free space optical, rayleigh fading, turbulence

INTRODUCTION

Many researchers are focused on the Free Space Optical (FSO) communication (Sandalidis *et al*., 2008). It is a hopeful technology opted to beat the bandwidth shortage existing in awash wireless marketplace (Gappmair *et al*., 2010; Wang *et al*., 2009). The accuracy of communication system lay on probability of detection and fade. For this we acquire knowledge of Probability Density Function (PDF) for the received optical power (Popoola and Ghassemlooy, 2009). The main flaw in FSO technology is that the optical wave agitates during its propagation through tempestuous atmosphere. Various techniques have been introduced to define turbulence fading in atmosphere channel. Standard authorized and distributions are Rayleigh fading channel model, log-normal distribution and gamma-gamma distribution (Ansari *et al*., 2011; Hasan, 2011; Peppas, 2011). Rayleigh model has a step density in the low amplitude region governing a huge impact on system performance. Gamma-gamma model achieves good for all domains from weak to strong turbulence zones. The negative exponential model is attested for the equivalent-verge of Gamma-gamma model on the other hand its peak value occurs at the negative region.

Log normal distribution displays large derivations under energetic turbulence. Thus this technique can be fitted only for weak turbulence conditions. To overcome the detriment of log-normal distribution, certain models are introduced to model turbulence over atmospheric channels. The performance of BER (Bit Error Rate) on communication systems employing subcarrier BPSK (Binary Phase shift Keying) modulation is finer than the consistent systems using OOK (On Offset Keying) modulation with or without tip-tilt compensation.

Literature review: Henniger and Wilfert (2010) proposed method is easily implemented and used channel model is established based on the received power measurement statistics from a land-mobile link maritime mobile link and satellite downlink. The systems handling intensity modulation with direct detection can only implement this model.

Aghajanzadeh and Uysal (2010) figures out the error probability on free space optical communication for diverse methods using Q-ary PPM (Pulse Position Modulation). It is concluded that Rayleigh model has a significant density in the low amplitude region (Ahmad *et al*., 2008). Balakrishnan propose a latest model called Double-Weibull distribution which is based on the theory of doubly stochastic reinstallation. Observing at the cases of moderate and strong turbulence, Double weibell appears more distinct than Gamma-gamma model (Balakrishnan and Kocherlakote, 1985). Ahmad and Yanikomeroglu (2010) proposed and Exponentiated Weibull (EW) distribution applies well for conditions like weak and moderate turbulence as well as for point like apertures is seen on (Ahmad and Yanikomeroglu, 2010). In another distribution is based on doubly stochastic theory of scintillation and produced through the product of 2 Generalized Gamma (GG) distributions. This was named Double Generalized Gamma (Double GG) and is proposed in (Krasniqi and Shabani, 2010).

Next new model named as gamma-exponential distribution for the irradiana funtuation in FSO links under atmospheric turbulence was proposed and the bit error

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probability is calculated. The conductions indicate that the proposed model is authorized andfor weak, moderate and strong turbulence conditions. Based on the simulation data gained from this method is correlated with (Ahmadi and Yanikomeroglu, 2010; Atapattu *et al*., 2011). The result states that the present model is exponential to other models.

MATERIALS AND METHODS

Block diagram of proposed system with gamma-exponential channel model: The signal generated by associate an optical supply is required to be modulated within the transmitter before to transmission over the optical fiber link. The Fig. 1 shows the block diagram of sub carrier intensity modulation FSO system model. It consists of transmitter section, free space channel and receiver section. In the transmitter section analog baseband signals are modulated using QAM modulation. The QAM modulated electrical signal is applied to optical source drive circuit. The resultant signal is QAM modulated optical signal. This is transmitted in free space channel. There is a chance of turbulence iatrogenic attenuation in free space channel. Such turbulence iatrogenic attenuation in free space is delineate mistreatment using gamma exponential channel model.

At the receiver section the transmitted signal undergoes direct detection prior to electrical QAM demodulation to obtain originally transmitted baseband signal.

BER of gamma-exponential channel model: In general in presence of noise, the signal at the receiver is not well outlined (Kashani *et al*., 2015). This is shown in Fig. 2. The signal in presence of noise at the detector is also in terms of the probability density operate. The arithmetic mean of the signal within the two transmitted standing specifically, 0 and 1 square measure is indicated by p_0 (U,V) and p_1 (U,V) respectively.

When the additive noise is assumed to possess a Gamma exponential distribution, the PDF of the two statuses will also be Gamma exponential. The Gamma exponential PDF that is continuous outlined as:

$$P(u,v) = P.\frac{1}{\Gamma(k)\sigma^k}u^{K-1}\exp(\frac{-u}{\sigma}) + (1-P)\frac{v}{\sigma}\exp\left(\frac{-v}{\sigma}\right) \quad (1)$$

Where ‘σ’ and is standard deviation of the distribution. If P (u,v) describes the probability of detection a noise current or voltage, ‘σ’ represents to the rms value of that current or voltage. If P(1) and P(0) are the probabilities of transmission for binary ones and zeros respectively, then the total probability of error P(e) may be expressed as:

$$P(e) = P(1)P(0/1) + P(0)P(1/0) \quad (2)$$

The decision threshold is kept at D = i_D. At time when a binary 1 is transmitted, the noise current is negative such that:

$$i_N < (i_{sig} - i_D) \quad (3)$$

Hence the resultant current i_{sig}+i_N will be minimum i_D and then an error may occur. The corresponding probability of the transmitted signal 1 being received as a 0 may be written as:

$$P(0/1) = \int_{-D}^{i_D} P(i,i_{sig})di \quad (4)$$

Hence:

$$P_1(u,v) = P(i,i_{sig}) \quad (5)$$

$$P_1(u,v) = P\frac{1}{\Gamma(k)(i_N)^K}(i-i_{sig})^{k-1}\exp\left\{-\left[\frac{(i-i_{sig})^2}{i_N^2}\right]\right\} + (1-P)\frac{1}{i_N}\exp\left[\frac{-(i-i_{sig})}{i_N}\right] \quad (6)$$

$$P_1(u,v) = Gam\_\exp[i,i_{sig},i_N] \quad (7)$$

Where:
I = The actual current
i_{sig} = The peak signal at binary 1 and
i_N = The mean square noise current

can be expressed as:

$$P(0,1) = \int_{-D}^{i_D} Gam - \exp[i,i_{sig},i_N].di \quad (8)$$

Same way, the possibility when binary 1 will be received when ‘0’ is transmitted is a chance that received current will be higher at times during ‘0’ bit interval. It is given by:

$$P(1/0) = \int_{i_D}^{D} P(i,0) \quad (9)$$

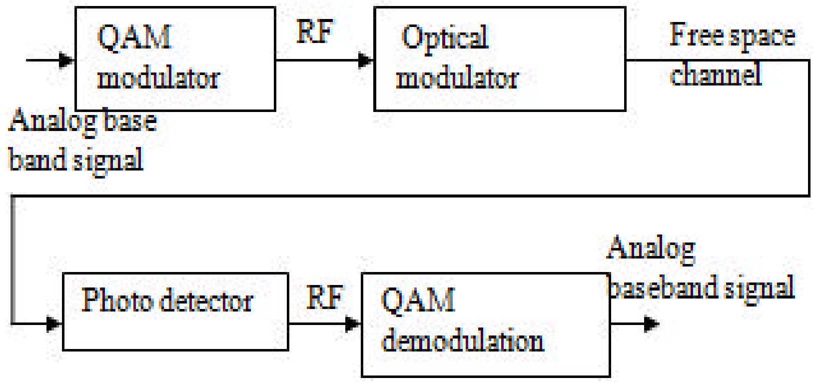

Fig. 1: Sub carrier intensity modulation of FSO system model

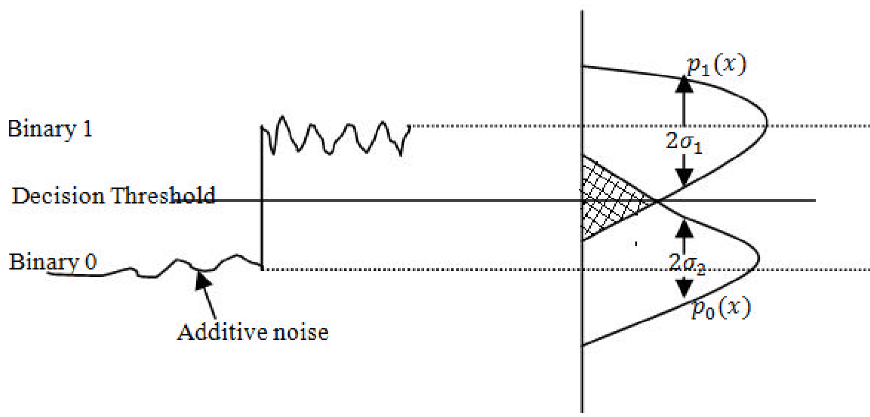

Fig. 2: Probability density functions for the binary signal

Assuming the mean square noise current in the zero state is equal to the mean square noise current in the one state $(\bar{i}_N^2)$:

$$P_o(U,V) = P(i,0) = P\frac{1}{\Gamma(k)(i_N)^K}(i-o)^{k-1}$$

$$\exp\left\{-\left[\frac{(i-o)^2}{i_N^2}\right]\right\} \qquad (10)$$

$$+(1-P)\frac{1}{i_N}\exp\left[\frac{-(i-o)}{i_N}\right]$$

$$P_0(U,V) = \text{Gam}-\exp[i,0,i_N] \qquad (11)$$

Hence Eq. 9 becomes:

$$P(1,0) = \int_{i_D}^{D}\text{Gam}-\exp[i,o,i_N]\,di \qquad (12)$$

The integrates of Eq. A and B can be written interns of error function as:

$$\text{erf}(u) = \frac{2}{\sqrt{\pi}}\int_0^u \exp(-z^2)dz \qquad (13)$$

and the complementary error function is:

$$\text{erfc}(u) = 1-\text{erf}(u) = \frac{2}{\sqrt{\pi}}\int_u^\infty \exp(-z^2)dz \qquad (14)$$

Hence, Eq. 8 becomes:

$$p(0/1) = \frac{1}{2}\text{erfc}\left(\frac{i_{sig}-i_D}{\Gamma(k)i_N^K}\right)+\frac{1}{2}\text{erfc}\left(\frac{i_{sig}-i_D}{i_N}\right) \qquad (15)$$

Similarly Eq. 12 becomes:

$$p(1/0)=\frac{1}{2}\text{erfc}\left(\frac{-i_D}{\Gamma(k)i_N^K}\right)+\frac{1}{2}\text{erfc}\left(\frac{-i_D}{i_N}\right) \quad (16)$$

The net probability of error:

$$P_e=\frac{1}{2}\left[p(0/1)+p(1/0)\right] \quad (17)$$

$$P_e=\frac{1}{2}\left[\frac{1}{2}\text{erfc}\left(\frac{i_{sig}-i_D}{\Gamma(k)i_N^K}\right)\right]+\frac{1}{2}\text{erfc}\left(\frac{i_{sig}-i_D}{i_N}\right)+ \frac{1}{2}\text{erfc}\left(\frac{-i_D}{\Gamma(k)i_N^K}\right)+\frac{1}{2}\text{erfc}\left(\frac{-i_D}{i_N}\right) \quad (18)$$

Assuming a Gamma_exponential distribution for noise and substituting:

$$i_D=\frac{i_{sig}}{2}$$

$$P(e)=\frac{1}{2}\left[\begin{array}{l}\frac{1}{2}\text{erfc}\left(\frac{i_{sig}/2}{\Gamma(k)i_N^K}\right)+\frac{1}{2}\text{erfc}\left(\frac{-i_{sig}/2}{i_N}\right)+\\ \frac{1}{2}\text{erfc}\left(\frac{1-i_{sig}/2}{\Gamma(k)i_N^K}\right)+\frac{1}{2}\text{erfc}\left(\frac{-i_{sig}/2}{i_N}\right)\end{array}\right] \quad (19)$$

$$P(e)=\frac{1}{2}\left[\text{erfc}\left(\frac{i_{sig}}{\Gamma(k)i_N^K}\right)+\frac{1}{2}\text{erfc}\left(\frac{-i_{sig}}{2i_N}\right)\right] \quad (20)$$

$$p(e)=\frac{1}{2}\text{erfc}\left(\frac{i_N(S/N)1/2}{\Gamma(k)i_N^K+i_N}\right) \quad (21)$$

Equation 21 gives the expression bit error probability of Gamma_exponential distribution.

Gamma exponential channel model: Consider a statistically independent random processes l_U andl_V due to large and small turbulence. The probability density equation of l_U due to Gamma (u, K, σ) distribution is:

$$f_{I_u}(I_u)=\frac{I_u^{K-1}}{\Gamma(k)\sigma^k}\exp\left(\frac{-I_u}{\sigma}\right) \quad (22)$$

The probability density function of i_v due to exponential (v,k,σ) distribution is:

$$f_{I_v}(I_v)=\frac{I_v^{K-1}}{v}\exp\left(\frac{-I_v}{\sigma}\right) \quad (23)$$

Where v_i>0,u_i>0,k_i>0 and I = 1,2 are Gamma and exponential parameters respectively. The probability density of Gamma exponential distribution can be expressed as:

$$f_I(I)=\int_0^{\omega} f_{I_u}(I/I_v).f_{I_v}(I_v).dI_v \quad (24)$$

Where:

$$f_{I_u}(I/I_v)=\frac{\left(\frac{I}{I_v}\right)^{K-1}}{\Gamma(k)\sigma^k}\exp\left(-\left(\frac{I}{I_v}\right)\frac{1}{\sigma}\right) \quad (25)$$

Hence:

$$f_I(I)=\int_0^{\alpha}\frac{\left(\frac{I}{I_v}\right)^{K-1}}{\Gamma(k)\sigma^k}\exp\left(-\left(\frac{I}{I_v}\right)\frac{1}{\sigma}\right)\frac{I_v^{K-1}}{v}\exp\left(\frac{-I_v}{\sigma}\right)dI_v. \quad (26)$$

The mean value of random variable (u,v) is expressed as:

$$E(u,v)=\int_{\omega}^{\omega}\int_{\omega}^{\omega} f(u,v)F_{uv}(u,v)dudv \quad (27)$$

Where:

F_{uv} (u,v) = The joint probability density function. The two random variables
u and v = Statistically dependent
if F F_{uv} (u,v) = $F_u(u).F_v(v)$

Hence:

$$E(u,v)=\int_{\omega}^{\omega}\int_{\omega}^{\omega} f(u,v)\left[\begin{array}{l}p\frac{1}{\Gamma(k)\sigma^k}u^{K-1}\exp\left(\frac{-u}{\sigma}\right)+\\ (1-p)\frac{v^{K-k}}{\sigma}\exp\left(\frac{-v}{\sigma}\right)\end{array}\right]du.dv \quad (28)$$

The moment of irradiance of Gamma exponential distribution can be expressed as:

$$E(I^2)=E(I_u^2).E(I_v^2)$$

Where:

$$E\left(I_u^2\right)=1+\sigma_u^2 \quad (29)$$

$$\sigma_u^2=E\left(I_u^2\right)-1 \quad (30)$$

The n^{th} moment of l_u is given as:

$$E(I_u^n)=\left(\frac{\sigma}{I_u}\right)^{\frac{n}{x_1}}\frac{\Gamma\left(K+\frac{n}{x_1}\right)}{\Gamma(K)} \quad (31)$$

Hence:

$$\sigma_u^2 = \left(\frac{\sigma}{I_u}\right)^{\frac{n}{x_1}} \frac{\Gamma\left(k+\frac{n}{x_1}\right)}{\Gamma(k)} - 1 \tag{32}$$

Similarly:

$$E\left(I_v^n\right) = \left(\frac{\sigma}{I_v}\right)^{\frac{n}{x_2}} \tag{33}$$

$$\sigma_v^2 = \left(\frac{\sigma}{I_v}\right)^{\frac{n}{x_2}} - 1 \tag{34}$$

The capacity of Gamma exponential Channel distribution can be expressed as:

$$C = B\log_2\left(1+\frac{(RP_0)^2 P_a}{8B_a \pi N_0}\right) \tag{35}$$

Consider a random variable u and v. The mutual information between random variables u and v can be expressed as:

$$I(u,v) = \int_{-\omega}^{\omega}\int_{-\omega}^{\omega} f_{u,v}(u,v)\log_2\left[\frac{f_U(u/v)}{f_U(u)}\right]dudv \tag{36}$$

Where:

f u,v (u,v) = The joint probability density function of

u and v and $f_u(u/v)$ = The conditional probability density function of U, given that V = v

The mutual information for gamma_exponential distribution can be expressed as:

$$I(u,v) = \int_{-\omega}^{\omega}\int_{-\omega}^{\omega} \frac{PI_v^{\,K-1}}{\Gamma(k)\sigma^K}\exp\left(\frac{-I_v}{\sigma}\right) + (1-p)\frac{I_\phi^{\,K-k}}{\phi}\exp\left(\frac{-I_v}{\sigma}\right) \log_2\left[\left(\frac{I}{I_v}\right)^{K-1}\exp\frac{\left(\frac{-I}{I_v}\right)\frac{1}{\sigma}}{\Gamma(K)\sigma^K}\right]du.dv \tag{37}$$

SISO FSO system: This section discusses BER analysis of FSO system with QAM modulation over proposed gamma exponential channel model. Consider the received optical signal as:

$$y = ax_i + n \tag{38}$$

where, α represents attenuation of propoagated signal, x_i represents information bits and n represents additive white Gaussian noise. The BER of QAM modulated optical signal for a given irradiance I is expressed as (Zhang and Letaief, 2005):

$$P_e(k) = \frac{1}{\sqrt{M}}\sum_{i=0}^{(1-2^{-k})}\sqrt{M-1} \left\{w(i,k,M)\,\mathrm{erfc}\left(2i+1\sqrt{\frac{3\log_2 M.\gamma.l^2}{2(M-1)}}\right\}\right. \tag{39}$$

An expression for the BER of an M-QAM for a gamma-exponential distribution fading channel is given as:

$$P_{ge}(k) = \int_{-\infty}^{\infty} f_l(l)P_e(k)dl \tag{40}$$

$$P_{ge}(k) = \int_0^{\infty}\frac{1}{\sqrt{M}}\sum_{i=0}^{(1-2^{-k})\sqrt{M-1}}\left\{w(i,k,M)\mathrm{erfc}(2i \int_0^{\infty}\frac{\left(\frac{1}{lv}\right)^{k-1}}{\Gamma(k)\sigma^{\varepsilon}}\exp\left(-\left(\frac{1}{lv}\right)\frac{1}{lv}\right)+1) \sqrt{\frac{3\log_2 M.\gamma.l^2}{2(M-1)}}\right)\right\}\frac{l_v^{k-1}}{V}\exp\left(\frac{-lv}{\sigma}\right)dl_v \tag{41}$$

Equation 17 gives the BER of QAM for gamma exponential channel model:

FSO system with multiuser diversity: When compared to frequency and time diversity techniques multiuser diversity techniques improve system performance (Zhang and Letaief, 2005). This can be achieved by means of multiple transmitters and/or multiple receivers. In this paper single transmitter single receiver is extended to single transmitter multiple receivers. There exist many multiuser diversity schemes. This study uses proportional fair scheduling with exponential rule as a multiuser diversity scheme for improving system performance.

RESULTS AND DISCUSSION

This study compares the simulation results of Bit error rate of gamma-exponential channel model with Rayleigh fading channel model, gamma channel model and gamma-gamma channel model. The turbulence fading is characterized by Rytov variance σ^2. Figure 3 shows the BER performance of subcarrier QAM modulated gamma-exponential channel model under weak turbulence condition with Rytov variances $\sigma^2_R = 0.5$. From Equations 32-34, the parameters of gamma-exponential distribution

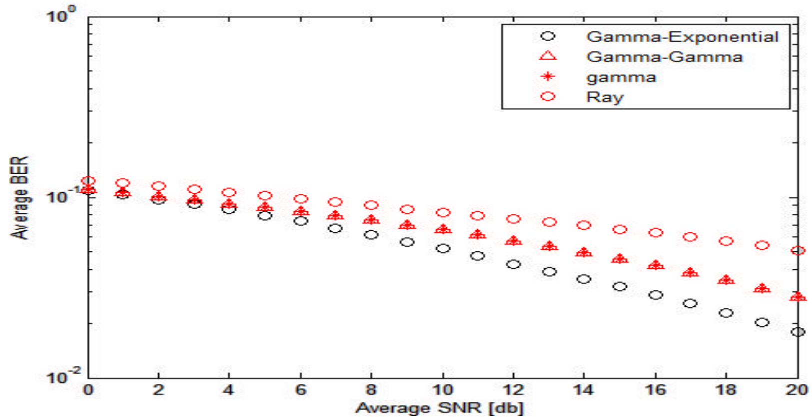

Fig. 3: Bit error probability of gamma exponential channel model under low turbulence condition with Rytov variance σ^2 R = 0.5

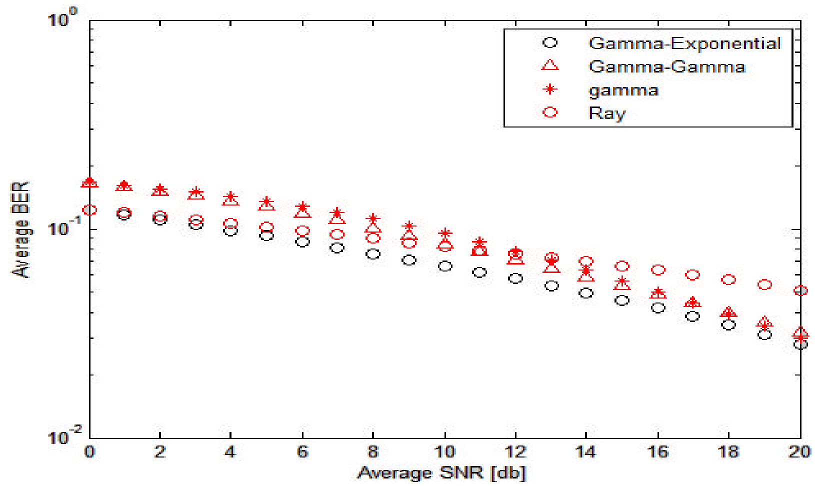

Fig. 4: Bit error probability of gamma exponential channel model under moderate turbulence condition with Rytov variance σ^2R = 5

under weak turbulence conditions are p = 0.1, irradiance $l_u, = l_v = 1, K = 4, x_1 2 and x_2 = 2$. The variances of fluctuations are calculated using Eq. 31 and 33. Figure 3 indicates that BER performance of gamma exponential channel model is better than gamma distribution and gamma-gamma distribution. At SNR = 20db BER is 10^{1-2} for Rayleigh distribution, 10^{1-6} for gamma and gamma-gamma distribution and 10^{-18} for gamma exponential distribution. From Fig. 3 it is inferred that gamma-exponential distribution fits best under weak turbulence condition.

BER performance of QAM modulated gamma exponential channel model under moderate turbulence condition is shown in Fig. 4. Here Rytov variances $\sigma_R^2 = 5$ Eq. 31and 33 helps in calculating variance under weak and strong fluctuation. The parameters of gamma exponential channel model under moderate turbulence condition are calculated using Equ. 32 and 34 . The obtained parameters are P = 0.1, irradiance l_{u}= l_v = 0.5, K= 1.4, x_1 = 2 and x_2 = 1. Under moderate turbulence for SNR = 20db BER is 10^{-16} for gamma exponential distribution, 10^{-15} for gamma distribution and gamma-gamma distribution and 10^{-13} for Rayleigh distribution. Figure 4 indicates that gamma exponential distribution fits well for moderate turbulence condition.

Figure 5 shows the BER of QAM modulated gamma exponential channel model under strong turbulence condition. The parameters of gamma exponential channel model under strong turbulence condition are calculated using Eq. 32 and 34. The calculated parameters are p = 0.1 irradiance l_u = l_v = 1, K = 0.8, x_1 = 1.9 and x_2 = 1.8. Figure 5 indicates that at SNR = 20 db, BER is $10^{-1.8}$ for gamma-exponential distribution, 10^{-17} for gamma-gamma distribution and $10^{-1.18}$ for gamma distribution for Rayleigh

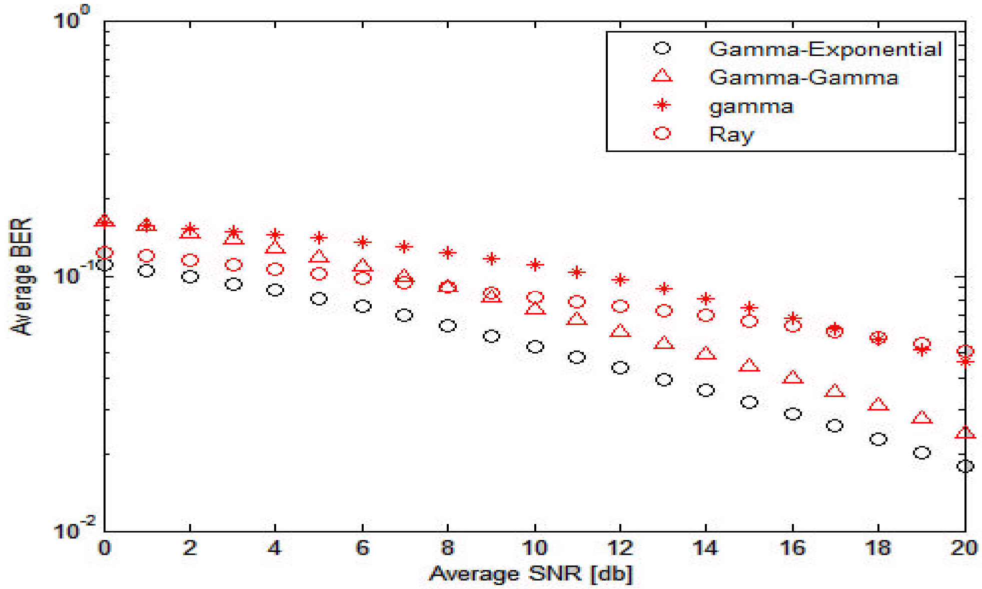

Fig. 5: Bit error probability of gamma exponential channel model under strong turbulence condition with Rytov variance $\sigma^2 R$ =25

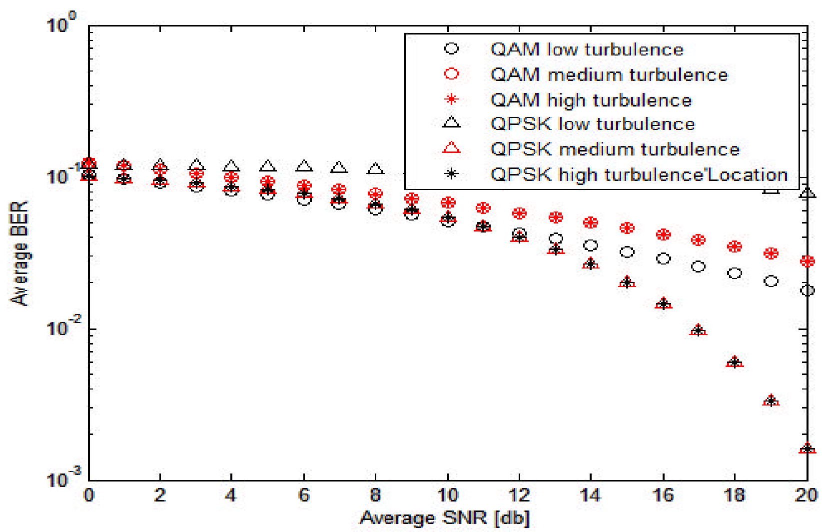

Fig. 6: BER of QAM and QPSK modulated gamma exponential channel model under various turbulence condition

distribution. From Fig. 5 it is concluded that gamma exponential distribution fits best under strong turbulence condition.

Comparison of average BER of QAM and QPSK modulated gamma exponential channel model under various turbulence condition is shown in Fig. 6. The parameters used for comparison are irradiance $l_u = l_v = 0.2$, p = 0.1 and the value of x_1, x_2 and K are chosen depends on turbulence condition. It shows that under low turbulence BER of QAM modulated is lower than QPSK modulated gamma exponential channel model. But under moderate and high turbulence condition BER of QPSK modulated is lower than QAM modulated gamma exponential channel model. Fig. 7 shows the throughput of proportional fair scheduling for turbulence fading with gamma exponential channel model under various turbulence condition and for irradiance It indicates that PFS exhibits optimal throughput under low turbulence condition than medium and high turbulence condition $l_u = l_v = 0.5$.

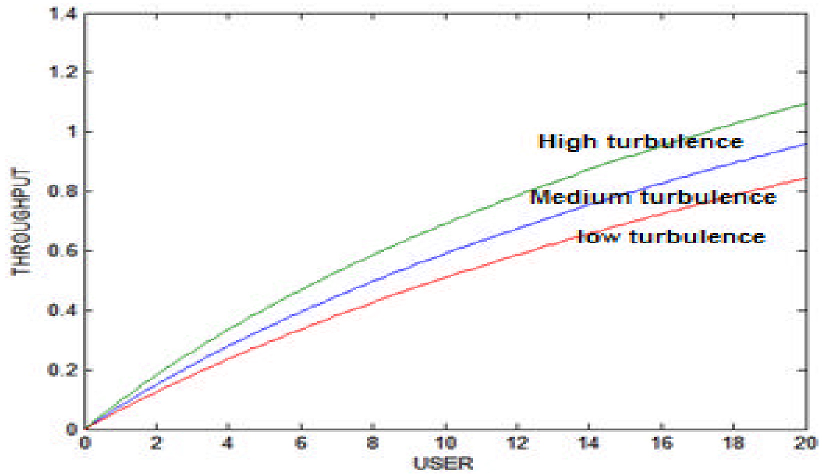

Fig. 7: Throughput of proportional fair scheduling for turbulence fading with gamma exponential channel model under various turbulence condition

CONCLUSION

In this study a new channel model known as gamma-exponential for turbulence fading in free space optical communication is proposed. Using the new channel model, closed-form expressions for the BER of QAM is derived. BER of QAM and QPSK were analysed using the proposed channel model under weak, moderate and strong turbulence condition. From simulation results it is inferred that the proposed channel model is very well suited under all turbulence conditions than gamma-gamma distribution.

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