SIMO/FSO System using QAM over Gamma Exponential Atmospheric Turbulence Channel

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Abstract: This paper proposes a new channel model known as Gamma-Exponential channel model for Single Input Single Output(SISO) and Single Input Multiple Output(SIMO) free space optical communication system(FSO) using QAM modulation. As a part of analyzing turbulence in FSO, probability density function and bit error rate of FSO over turbulence channel is derived using Gamma-Exponential channel model. The derived BER is analyzed considering the effects of various turbulence conditions, link distance and refractive index structure parameter. SIMO-FSO system uses PFS multiuser scheduling algorithm to transmit signal from single user to selected user of multiple output. The performance of proposed channel model is compared using QAM and QPSK modulation with Mach-Zehnder Modulator (MZM). Simulation results show that BER of FSO improves if the system undergoes QPSK modulation with EAM and QAM modulation with MZM.

Key words: Bit Error Rate, Gamma-Exponential Channel Model, SIMO, Multiuser Scheduling, QAM

1. INTRODUCTION

FSO systems refers to optical wireless communication have high bandwidth, permitting optical transmission at higher data rates. Optical transmission takes place through optical carriers such as visible, infrared band etc (Ghassemlooy, 2013).

In free space optical communication, the received signal is affected by fading, scintillation etc. In case of shortest scintillation can be reduced by enhancing transmission power. But for longest distance it is difficult to increase power of transmission due to laser safety (Grabner, 2011). In such case it is essential to implement a technique to reduce fading.

One of the most efficient techniques is describing turbulence fading using channel model. The most commonly used model to describe the probability distribution function (pdf) of irradiance is log-normal distribution. It was based on Rytov approximation of order one. This distribution is well suited for weak turbulence conditions under strong turbulence conditions. The log normal distribution doesn’t matter with experimental data (Maaref, 2009).

To overcome the drawback of lognormal distribution, many more models have been developed for describing turbulence under various conditions. The channel model for describing pdf of strong turbulence conditions were negative exponential and K-distribution (Jakeman, 1978). Rayleigh distribution has been employed for modelling severe atmospheric turbulence.

Efforts have been made to develop a channel model that well suits for all turbulence conditions. As a result based on stochastic theory of scintillation, some channel models have been proposed which describes irradiance fluctuation as a product of small and large scale fluctuation.

K-distribution that well suits for weak turbulence has been extended to I-K (Churnside, 1989) distribution. But the problem is I-K distribution doesn’t maters with experimental data. Following this other channel models that have been developed based on doubly stochastic theory of scintillation are exponentiated Weibull, log-normally modulated exponential, log-normal Rice and Gamma-Gamma distribution(Al-Habash, 2001).

Of these the widely accepted is Gamma-Gamma distribution. It provides best fit to simulation data and well suited for weak and strong turbulence condition. Another doubly stochastic model that has been widely accepted is double Weibull distribution (Chatzidiamantis, 2010). It has good accuracy and particularly well suited for moderate turbulence condition.

Recently a new channel model is known as double Gamma-Gamma model is developed (Kashani, 2013) based on doubly stochastic theory. It was shown that double Gamma-Gamma distribution is more superior to Gamma-Gamma distribution, especially under moderate turbulence condition.
The proposed channel model is Gamma-Exponential channel model. This model describes irradiance fluctuation as the product of small and large. It combines Gamma distribution and exponential distribution. The proposed model describes turbulence for all ranges from weak to strong.

The effects of fading can be minimized by using two or more lasers and photo detectors in the transmitter section and receiver section respectively. This paper proposes Single Input Multiple Output (SIMO) FSO system to reduce the effect of fading (Bayaki, 2009 and Brands-Pearce, 2005). Signal from single user is transmitted to selected user among multiple users at the output using multiuser scheduling algorithm known as proportional fair scheduling algorithm.

The modulation techniques preferred in FSO system are OOK and PPM modulation. OOK modulation requires exact threshold value and PPM modulation requires narrow pulse to improve its efficiency. To overcome this drawbacks subcarrier intensity modulation scheme such as Quadrature Amplitude Modulation is preferred.

This paper uses SISO/SIMO-FSO system with QAM modulation to enhance performance over Gamma-Exponential channel model.

In the following section II describes proposed system block diagram. Section III gives probability density function of proposed channel model, section IV gives BER of SISO-FSO system with gamma-exponential channel model. Section V explains multiuser diversity in SIMOFSO system and it’s BER. Section VI gives results and discussions and is followed by conclusion in section VII.

2. PROPOSED SYSTEM DESCRIPTIONS

This section describes sub carrier intensity modulation (SIM) free space optical communication systems. Consider a SISO-FSO system with a single transmitter and single receiver as shown in fig.1. The basic principle behind SIM-OSM is, the base band signals gets converted into different carrier frequency by QAM modulation. The modulated signal is given to optical source drive circuit to get sub carrier intensity modulated optical signal. It is transmitted in free space.

The power of transmitted optical signal is expressed as

\[ P_o = P_i \cdot (1 + v(t)) \]  

Where \( P_i \) is the power of unmodulated carrier signal and \( v(t) \) is the modulating signal (QAM signal)

\[ I(t) = I_p \cdot P \cdot (1 + v(t)) \]  

Where \( P \) denotes multiplication factor and \( I_p \) is the photo current of unmodulated carrier

The photocurrent in terms of mean square signal current is given as

\[ i_{sig}^2 = (I_p \cdot P)^2 \cdot (2(a)) \]  

Where \( P_t \) is the total power of \( v(t) \).

The total power \( P_t \) in terms of spectral density of QAM signal \( v(t) \) having bandwidth \( B \) is given as

\[ P_t = \frac{1}{2\pi} \int_{-2\pi B}^{2\pi B} S_v(\omega) d\omega \]  

The mean square noise current at the receiver is expressed as

\[ i_{n}^2 = 2eB \cdot (I_p + I_d) \cdot P^2 \cdot v(P) + \frac{4KT\beta_n}{B_L} \]
Where $F_n$ denotes noise figure, $B$ denotes past detection bandwidth, $K$ denotes Boltzmann constant, $T$ denotes absolute temperature, $e$ denotes charge on an electron, $R_L$ denotes load resistance, $I_d$ denotes dark current.

Using mean square signal power and noise power, the signal to noise ratio is expressed as
\[ \frac{S}{N} = \frac{r^2 g}{i^2} \] (5)
\[ \frac{S}{N} = \frac{(I_p + P_t)^2 P_t}{2 \pi (I_p + P_t)^2 (P_t + R_y) + R_L} \] (6)

The above expression gives signal to noise ratio of SIM-FSO.

### 3. Gamma – Exponential Channel Model

The probability density function (pdf) of Gamma Distribution function is expressed as [12]

\[ f_{I_g}(I_g) = \frac{I_g^{k-1} e^{-\frac{I_g}{\sigma_1}}}{(k-1)\sigma_1} \] (7)

Similarly the pdf of exp distribution is exponential

\[ f_{I_e}(I_e) = \frac{e^{\frac{k^2}{\sigma_2}}}{\sigma_2} \] (8)

Combining equations (7) & (8), the pdf of Gamma – exponential channel model is

\[ f_I(I) = \int_0^\infty f_{I_g}\left(\frac{I}{l_e}\right) f_{I_e}(I_e) dI_e \] (9)

\[ f_{I_g}\left(\frac{I}{l_e}\right) = \frac{I_g^{k-1} e^{-\frac{I_g}{\sigma_1}}}{I_g (k-1) (k)} \exp\left(-\frac{I_g}{\sigma_1}\right) \] (10)

\[ f_I(I) = \int_0^\infty \frac{I_g^{k-1} e^{-\frac{I_g}{\sigma_1}}}{I_g (k-1) (k)} \exp\left(-\frac{I_g}{\sigma_1}\right) \frac{e^{\frac{k^2}{\sigma_2}}}{\sigma_2} \] (11)

Using Meijers-G function the above equation can be simplified as

\[ f_I(I) = \frac{q}{f(k)} q^{-k-1, I} -1 G_p^{0,0} \left[ \sigma_1^2 q \sigma_2^2 P_k^k \right] \frac{2}{I_g^{k-2}} \frac{2}{\sigma_1^2} \Delta(q: 1-k) \Delta(p: 1-k) \] (12)

Where $I_g$ & $I_e$ are irradiances under gamma and exponential distribution respectively. $G_p^{m,n}$ is the Meijer G-function, $\sigma_1^2$ and $\sigma_2^2$ are Rytov variances. Equation (12) gives the pdf of Gamma-Exponential channel model.

Using Meijer G-function the cumulative distribution function of Gamma-Exponential channel model is expressed as,

\[ f_I(I) = \frac{q}{f(k)} q^{-k-1,I} -1 G_p^{0,0+q+1} \left[ \sigma_1^2 q I_g \right] \frac{2}{I_g^{k-2}} \frac{2}{\sigma_1^2} \frac{1}{\sigma_2^2} \Delta(q: 1-k) \Delta(p: 1-k) \] (13)

The channel capacity SIM FSO can be expressed as

\[ \frac{C}{B} = \int_0^\infty \log_2(1 + \gamma) F_I(I) dI \] (14)
Upon simplifying the above expression using Meijer G-function, the resultant expression is

\[
\frac{c}{b} = \log_2(1 + y) \frac{q^{k-1}}{\Gamma(k_1)} p^{k_2-1} I^{k_1-1} G_{p+q,0}^{0,m+n} [\sigma_1^2 q^k \sigma_2^2 p^{k_2} \frac{\sigma_2^{k_2}}{\Gamma(k_2)} | \Delta(q: 1 - k_1), \Delta(p: 1 - k_2)]
\]  

(15)

\[
\frac{c}{b} = \frac{q^{k-1}}{\Gamma(k_1)} p^{k_2-1} I^{k_1-1} \frac{1}{p+q,0} \left[ \sum_{i=0}^{\infty} q^{i} G_{p+q,0}^{0,m+n} \left[ \sigma_1^2 q^k \sigma_2^2 p^{k_2} \frac{\sigma_2^{k_2}}{\Gamma(k_2)} | \Delta(1, k_1 + q + m, k_1 + 1 - k_1 + m) \Delta(1, 1 - k_2) \right] dI \right]
\]

(15(a))

The above expression gives channel capacity of SIM FSO Gamma-Exponential channel model.

4. BIT ERROR RATE OF SISO-FSO GAMMA-EXPONENTIAL CHANNEL MODEL

The correlation time of channel model is of the order of milliseconds. This is very much greater than the QAM symbol duration. Due to this reason, the channel has to be modelled, considering fading process as a slower one (Aladeloba, 2012).

The average bit rate over turbulence channel can be expressed as

\[
P_e = \int_0^\infty f_I(I) P_e(y) dI
\]

(16)

Where \( P_e(y) \) is the bit error probability of QAM signal. It is expressed as

\[
P_e(k) = \frac{1}{\sqrt{\pi}} \sum_{i=0}^{(1-2^k)\sqrt{\pi}-1} \left\{ w(i, k, M) \sqrt{I} e^{-f(c)} \left( 2i + 1 \right) \frac{3 \log_2 M y^2}{2(M-1)} \right\}
\]

(17)

Substituting (17) in (16) and simplifying using Meijer G function, the bit error rate is expressed as

\[
P_e = \int_0^\infty \frac{q^{k-1}}{\Gamma(k_1)} p^{k_2-1} I^{k_1-1} G_{p+q,0}^{0,m+n} \left[ \sigma_1^2 q^k \sigma_2^2 p^{k_2} \frac{\sigma_2^{k_2}}{\Gamma(k_2)} | \Delta(q: 1 - k_1), \Delta(p: 1 - k_2) \right] dI
\]

(18)

Simplifying the above expression using Meijers G-function (Mohammadreza A. Kashani, 2015), the resultant solution is given in equation (19).

\[
P_e = \frac{q^{k-1}}{\Gamma(k_1) 2 \pi M y^2} p^{k_2-1} I^{k_1-1} G_{p+q,0}^{0,m+n+1} \left[ \sigma_1^2 q^k \sigma_2^2 p^{k_2} \frac{\sigma_2^{k_2}}{\Gamma(k_2)} | \Delta(1, k_1 + q + m, 1, k_1 + 1 - k_1 + m) \Delta(k_2 + p, 1) \right]
\]

(19)

The above expression is the generalized BER. By assigning particular values for \( k_1, k_2, \sigma_1^2 \) and \( \sigma_2^2 \) the BER of various channel models can be obtained (Karagiannidis, 2009).

Analyzing asymptotical performance of BER, it comes to know that it is dominated by origin pdf. Thus using series expansion of Meijers G-function, the BER of gamma exponential channel model can be expressed as a single polynomial (Castillo-V’azquez, 2012) and is given in equation (20)

\[
P_e = \prod_{\kappa=1}^{m} \frac{\Gamma(\alpha+\kappa)}{\Gamma(\alpha+\kappa+1)} \prod_{\kappa=1}^{n} \frac{\Gamma(1-n-\kappa)}{\Gamma(1-n-\kappa+1)} \left[ \sigma_1^2 q^k \sigma_2^2 p^{k_2} \frac{\sigma_2^{k_2}}{\Gamma(k_2)} \right]^{\alpha-1} \frac{2 \pi M y^2}{2(M-1)}
\]

(20)

5. SIMO-FSO SYSTEM

In single input multiple output FSO system, there is a single transmitter and a multiple receiver. Consider a common node in the transmitter section with many transmit aperture and N nodes in the receiver section. At a particular time slot only one transmit aperture remains active. So that each user (receiver) is equipped with the corresponding transmit aperture. Such configuration gives the name SIMO-FSO system(Kashani, 2013 and Kashani, 2013).
The signal may get affected by turbulence during its transmission from one end to another end. The proposed fading model to describe turbulence condition is gamma exponential channel model.

5.1. FSO System with Multiuser Diversity

This can be achieved by means of multiple transmitters and/or multiple receivers. In this work single transmitter single receiver is extended to single transmitter multiple receivers. There exist many multiuser diversity schemes. This work uses Proportional Fair Scheduling with Exponential Rule as a multiuser diversity scheme for improving system performance.

5.1.1. Proportional Fair Scheduling

The main aim of multiuser scheduling is to determine a way for users to achieve maximum throughput and minimum latency. In PFS the scheduler at central node selects best user at the optical receiver based on their channel condition (Jamshid Abouei, 2012). At time slot $n$ the best user at the optical receiver is selected by the scheduler based on the expression

$$i^*_n = \arg \max_{1 \leq i \leq N} \frac{R_{i,n}}{R_{i,n}}$$  \hspace{1cm} (21)

Where $R_{i,n}$ represents average throughput and $R_{i,n}$ is the achievable throughput.

The average throughput per slot basis is represented as

$$\bar{R}_{i,n+1} = \left\{ \left(1 - \frac{1}{t_c} \right) \bar{R}_{i,n} + \frac{1}{t_c R_{i,n}}, i_n = i^*_n \right\}$$  \hspace{1cm} (22)

$$\bar{R}_{i,n+1} = \left\{ \left(1 - \frac{1}{t_c} \right) \bar{R}_{i,n}, i_n \neq i^*_n \right\}$$  \hspace{1cm} (23)

Where $t_c$ is a parameter which findout the tradeoff between throughput and latency in point to multipoint system. If $t_c = 1$, the PFS scheduler acts as Round robin scheduling scheme. Similarly if $t_c$ tends to infinity, the PFS scheduler acts as a greedy scheduling algorithm.

5.1.2. BER of SIMO

To improve the performance of SISO, multiple receivers or transmitters can be used. Assuming multiple receivers in the receiver section the BER of SIMO is derived. Considering in phase and quadrature component the BER of QAM modulated signal is expressed as

$$p_e(\gamma) = \left[ 2q(M_i)Q(A_Q\sqrt{\gamma}) + 2q(M_Q)Q(A_Q\sqrt{\gamma}) - 4q(M_i)q(M_Q)Q(A_I\sqrt{\gamma})Q(A_Q\sqrt{\gamma}) \right]$$  \hspace{1cm} (24)

This section discusses the BER of SIMO-FSO system. The average BER of SIMO-FSO system is expressed as

$$P_e(\gamma) = \frac{1}{L} \int_I \left[ F_I(i) p_e(\gamma) \right] dI$$  \hspace{1cm} (25)

$$P_e(\gamma) = \int_I \left[ F_I(i) \left( 2q(M_i)Q(A_Q\sqrt{\gamma}) + 2q(M_Q)Q(A_Q\sqrt{\gamma}) - 4q(M_i)q(M_Q)Q(A_I\sqrt{\gamma})Q(A_Q\sqrt{\gamma}) \right) \right] dI$$  \hspace{1cm} (26)

Where $P_e(\gamma)$ is the probability of subcarrier intensity QAM signal, which is given as

$$P_e(\gamma) = 2q(M_i)Q(A_Q\sqrt{\gamma}) + 2q(M_Q)Q(A_Q\sqrt{\gamma}) - 4q(M_i)q(M_Q)Q(A_I\sqrt{\gamma})Q(A_Q\sqrt{\gamma})$$  \hspace{1cm} (27)

Where $M_I$ is inphase component and $M_Q$ is quadrature component.

$$A_I = \frac{6}{\sqrt{[(M_I^2-1)+r^2(M_Q^2-1)]}}$$  \hspace{1cm} (28)
$$A_Q = \sqrt[6r^2]{\frac{1}{(m_1^2-1)+r^2(m_0^2-1)}}$$  \hspace{1cm} (29)$$

Here \( r = \frac{d^0}{dt} \) is the quadrature to in-phase decision ratio. Simplifying equation (26)

$$P_e = 2q(M_0) \int I Q(Q_{\gamma}) F(I) I dI + 2q(M_0) \int I Q(Q_{\gamma}) F(I) I dI - 4q(M_0)q(M_0) \int I Q(Q_{\gamma}) Q(Q_{\gamma}) F(I) I dI$$

\hspace{1cm} (30)

\hspace{1cm} (31)

\hspace{1cm} (32)

Hence equation (29) can be expressed as

$$P_e = 2q(M_0) + 2q(M_0) \frac{1}{12} \prod_{n=1}^N \Lambda(n,4) + \frac{1}{4} \prod_{n=1}^N \Lambda(n,3) - 4q(M_0)q(M_0) \frac{1}{12} \prod_{n=1}^N \Lambda(n,4) + \frac{1}{4} \prod_{n=1}^N \pi(n,3)$$ \hspace{1cm} (33)

Where \( \Lambda(n,4) \) is obtained from eqn(34) of [14].

6. RESULTS AND DISCUSSION

This section discusses the BER of proposed gamma-exponential channel model for various turbulence conditions and multiuser diversity scheduling for SIMO-FSO system. The parameters are chosen as follows, the link distance \( L \) was selected between 1000 to 6000m, the refraction index structure parameter was selected as \( 1 \times 10^{-15} m^{-2/3}, 9 \times 10^{-15} m^{-2/3} \) and \( 3 \times 10^{-14} m^{-2/3} \) respectively for weak, moderate and strong conditions.

Figure 2 gives average BER for various channel models using EAM optical modulator and QAM modulation under various turbulence conditions. It indicates that average BER of gamma exponential channel model is low under all turbulence conditions. It shows the superiority of proposed gamma exponential channel model.

Average BER for various channel models using EAM optical modulator and QPSK modulation under weak, strong and moderate turbulence conditions is shown in figure 3. It indicates that average BER of gamma exponential channel model is \( 10^{-3} \) at 19db. It proves that BER of gamma exponential channel model is lower than existing channel models.

Figure 4 shows average BER for gamma exponential channel model using EAM optical modulator with QAM and QPSK modulation for various values of \( C_0^2 \). It indicates that higher the value of \( C_0^2 \), lower the value of BER. Also it is evident from figure 4 that BER performance of QPSK modulation is better than QAM modulation. Average BER for gamma exponential channel model using EAM optical modulator with QAM and QPSK modulation for various values of \( L \) is shown in Figure 5. It proves that lowers the value of link distance \( L \), lower the value of BER. Also BER is lower for QPSK modulation than QAM modulation.

Average BER \( v_4 \) average SNR for various channel models using MZM optical modulator and QAM modulation under moderate turbulence condition is shown in Figure 6. It shows that at 19db BER is \( 10^{-3} \) for MZM optical modulator whereas for EAM optical modulator, BER is \( 10^{-3.7} \). From figure 4 it is clear that MZM modulator works well with QAM modulation than EAM modulator. Figure 7 shows average BER for various channel models using MZM optical modulator and QPSK modulation for moderate turbulence conditions. It shows that at 19db BER is \( 10^{-1} \). But for EAM optical modulator with QPSK modulation BER is \( 10^{-3} \). It indicates that EAM modulator works well with QPSK modulation than MZM modulator. Figure 8 and figure 9 shows average BER for gamma exponential channel model using MZM optical modulator with QAM and QPSK modulation for various values of \( C_0^2 \) and link distance \( L \) respectively. It is evident from figure 8 and figure 9 that BER is lower than QAM modulation than QPSK modulation.

Figure 10 shows the throughput of proportional fair scheduling for turbulence fading with gamma exponential channel model under various turbulence condition and for irradiance \( I_{0u} = I_{0v} = 0.5 \). The number of users is chosen as \( t_u = 20 \).

It indicates that PFS exhibits optimal throughput under low turbulence condition than medium and high turbulence condition. Throughput versus number of users using proportional fair scheduling and Greedy scheduling with gamma-exponential channel model for turbulence condition is shown in figure 11. It indicates...
that the throughput of PFS scheduling is more than Greedy scheduling for moderate and strong turbulence conditions and remains same for both greedy scheduling and PFS under weak turbulence condition.

Figure 2. Average BER $v_s$ average SNR for various channel models using EAM optical modulator and QAM modulation with $L = 1000m$ and $\mathcal{C}_n^2 = 1e - 15m^{-2/3}$

Figure 3. Average BER $v_s$ average SNR for various channel models using EAM optical modulator and QPSK modulation with $L = 1000m$ and $\mathcal{C}_n^2 = 1e - 15m^{-2/3}$

Figure 4. Average BER $v_s$ average SNR for gamma exponential channel model using EAM optical modulator with QAM and QPSK modulation for various values of $\mathcal{C}_n^2$

Figure 5. Average BER $v_s$ average SNR for gamma exponential channel model using EAM optical modulator with QAM and QPSK modulation for various values of $L$
Figure 6. Average BER $v_s$ average SNR for various channel models using MZM optical modulator and QAM modulation with $L = 1000m$

Figure 7. Average BER $v_s$ average SNR for various channel models using MZM optical modulator and QPSK modulation with $L = 1000m$ and $C_n^2 = 1e^{-15m^{2/3}}$

Figure 8. Average BER $v_s$ average SNR for gamma exponential channel model using MZM optical modulator with QAM and QPSK modulation for various values of $C_n^2$

Figure 9. Average BER $v_s$ average SNR for gamma exponential channel model using MZM optical modulator with QAM and QPSK modulation for various values of $L$

Figure 10. Throughput of FSO system using PFS for various turbulence condition

Figure 11. Comparison of throughput of FSO system for various turbulence conditions

7. CONCLUSION

This paper proposed QAM for SISO/SIMO FSO system. Fluctuations of irradiance over atmospheric channels for various turbulence conditions was described using a new channel model known as Gamma-
Exponential channel model. The closed pdf of Gamma-Exponential channel model have been determined. The proposed model has been compared with Gamma-Gamma distribution, Gamma distribution and Rayleigh fading distribution. Comparison results showed that the proposed channel model works well for all turbulence conditions than other channel models. Simulation results showed that the performance of QPSK with EAM and MZM has increased in presence of Gamma-Exponential atmospheric turbulence. In addition to providing accurate results, the proposed work helps in understanding performance and properties of QAM and QPSK with EAM and MZM in presence of atmospheric turbulence.

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