jayesh final paper1

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Submission date: 23-Jun-2020 07:22PM (UTC+0530)
Submission ID: 1348575962
File name: jayesh_paper_edited.docx (269.85K)
Word count: 3132
Character count: 17454

MIMO FSO COMMUNICATION SYSTEM USING HYBRID SIM OVER DOUBLE GENERALIZED GAMMA DISTRIBUTION

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Abstract- **In this paper, we model the hybrid SIM with LPPM and MPSK modulation over Double Generalized Gamma (GG) distribution under moderate turbulence condition, to improve the Free Space Optical (FSO) communication system performance. We use the probability density function of the double GG distribution in its power series expansion form for both Single-Input Single-Output (SISO) and Multiple-Input Multiple-Output (MIMO). We use a new hybrid Subcarrier Intensity Modulation (SIM) with L-Pulse Position Modulation (LPPM) and M-ary Phase Shift Keying (MPSK) and analyze the average Symbol Error Rate (SER) performance of FSO communication system over double GG fading for average electrical SNR. We analyze the SER for both SISO and MIMO. We observe from the simulation results, the SER decreases for each M in MPSK with the increase in average length of the PPM symbol L under the moderate turbulence for both SISO and MIMO in the FSO communication system.**

Index Terms- *Double Generalized Gamma (double GG) distribution , Free Space Optical (FSO) communication, Signal to Noise Ratio (SNR), Multiple-Input Multiple-Output (MIMO) system,. Pulse position Modulation (PPM), Hybrid Modulation, Multi-path Fading, Bit-Error Rate (BER),*

1. INTRODUCTION

Free Space Optical (FSO) communication is evolved as new paradigm of modern communication system to fulfill the ever increasing demand of data rate in future 5G communication systems. In Free Space Optical Communication (FSO) technology, data is transferred as a light source in the free space which provides higher data rate as compared to the optical fiber [1]. FSO uses license free spectrum, which offers wireless connectivity at a low cost. FSO offers easy installation, quick implementation of communication link, high band-width provisioning, and it can be employed for both indoor and outdoor applications [2]. With their unique properties and advantages, FSO communication system has brought significant attention initially as a last mile solution and it can be used in a variety of applications, such as storage area network, fiber backup, metro-network extensions, cellular backhaul among microcells in future 5G systems, redundant link in disaster recovery and relief efforts among others. [3].

However, likewise any wireless system, in FSO wireless link is the weak link which introduces various impairments such as fading, scattering, atmospheric turbulence and absorption [3]. The major concern is atmospheric turbulence caused by change of refractive index due to heterogeneous nature of pressure and temperature variation. These random fluctuations result in the immense change in optical intensity & phase of received signal which sometimes causes the optical link failure in communication systems. [4]

In past years considering the effects of atmospheric turbulence, various statistical model [5] have been introduced such as Negative Exponential [6], Log Normal, I-k distribution. Nakagami-m /Exponential Weilbull and Gamma-Gamma distributions [7] In previous works Log-normal distribution has been used more often but it is limited for weak turbulence conditions only. Then the other dominant model is Gamma-Gamma fading distribution suitable for all weak to strong turbulence regimes. In this paper we have used Double Generalized Gamma fading distribution which is generalized distribution model used to cover all turbulence conditions [2].

Recent studies have shown that many mitigation techniques such as error correction coding, advanced modulation schemes and spatial diversity have been applied to improve weak link of FSO system. On-off-keying is commonly used modulation technique in previous researches due to it simple implementation [3]. But due to its threshold adjustment complexity alternative modulation technique Pulse position modulation (PPM) is used widely by various researchers. PPM has better power efficiency but this modulation uses symbol synchronization which results in receiver design complexity. So another modulation schemes has gained the attention called as Subcarrier Intensity Modulation (SIM), which does not requires any threshold arrangements or synchronization as required in case of OOK and PPM modulation, it also has less bandwidth efficiency[4].

So in order to combat limitations of individual modulation techniques and to further improve BER performance of FSO system there has been use of Hybrid Modulation [3-4]. Reported in previous work novel Hybrid PPM-BPSK-SIM has surpassed both PPM and BPSK-SIM modulation techniques. The BER performance against SNR of 2-PPM-BPSK-SIM has been investigated for log normal model which clearly shows better performance of hybrid modulation. [8] In another work performance of PPM-MSK-SIM is analyzed, it is shown that resulting hybrid technique combines the advantages of individual modulation schemes. This makes PPM-MSK-SIM more effective modulation technique in FSO communication systems [9]. Further in order to improve BER performance of the FSO system MPSK is introduced since it is effective modulation scheme in digital communication due to its better BER performance.

In this paper to meet the rapid requirement of high data rate in beyond 5G system we proposed a hybrid modulation technique ie LPPM-MPSK-SIM to further improve the average SER of SISO & MIMO FSO system over double generalized gamma fading distribution. System model for this modulation scheme has been given in section II. Its average SER performance has been discussed in section III.

2. SYSTEM MODEL

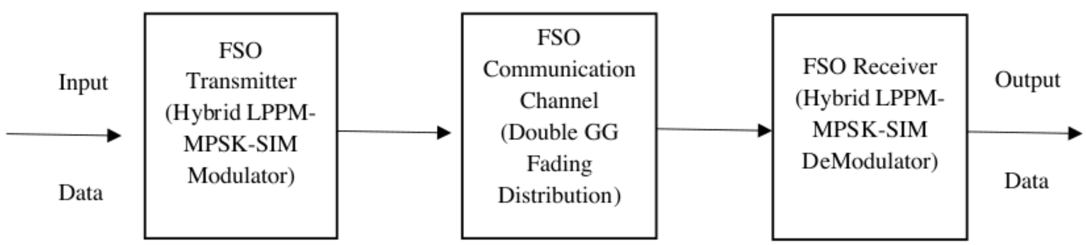

Fig 1. Block Diagram of Hybrid LPPM-MPSK-SIM communication system [1].

In the transmitter section PPM encoder converts the block of data bits $M = log2L$ into PPM code words where, M is the number of bits per PPM symbol and L is the average PPM symbol length. The PPM code words are modulated by MPSK modulator on the optical signal intensity. [10]. We then use the Double GG fading to model our FSO communication channel under moderate turbulence conditions. The optical signals are passed through an atmospheric turbulence channel and are detected at the receiver by a photoelectric detector.

2.1. Channel Model

In this paper we modeled our channel using Double GG fading distribution in which I is the received irradiance. This model is applicable for all regimes from weak to strong turbulence conditions. The PDF expression given by [1],

$$f_I(I) = \sum_{l=0}^{\infty}(a_l(m_1\gamma_1, m_2\gamma_2)I^{l\gamma_1+m_1\gamma_1-1} + a_l(m_1\gamma_1, m_2\gamma_2)I^{l\gamma_1+m_1\gamma_1-1}) \tag{1}$$

where,

$$a_l(m_1\gamma_1, m_2\gamma_2) = \frac{\gamma_1}{\Gamma(m1)\Gamma(m2)}\frac{(-1)^l}{l!}\,\Gamma\left(m_2 - (m_1 + l)\frac{\gamma_1}{\gamma_2}\right)\left(\frac{m_1}{\Omega_1}\left(\frac{m_2}{\Omega_2}\right)^{\frac{\gamma_1}{\gamma_2}}\right)^{(l+m_1)} \tag{2}$$

$$a_l(m_2\gamma_2, m_1\gamma_1) = \frac{\gamma_2}{\Gamma(m1)\Gamma(m2)}\frac{(-1)^l}{l!}\Gamma\left(m_1 - (m_2 + l)\frac{\gamma_2}{\gamma_1}\right)\left(\frac{m_2}{\Omega_2}\left(\frac{m_1}{\Omega_1}\right)^{\frac{\gamma_2}{\gamma_1}}\right)^{(l+m_2)} \tag{3}$$

2.2. Error rate analysis for L-PPM MPSK SIM

Received signals first demodulated by the MPSK demodulator then data bits are recovered by LPPM decoder. The average SER versus average electrical SNR performance analyzed for hybrid LPPM-MPSK-SIM The BER expression for hybrid LPPM-MPSK-SIM receiver is expressed as,

The BER expression for MPSK for $M \geq 4$ and $\frac{E_b}{N_o} \gg 1$, is given by [11]

$$\mathrm{P} = \frac{2}{log_2 M}Q\left(\sqrt{\gamma(I)log_2 M}\sin\left(\frac{\pi}{M}\right)\right) \tag{4}$$

where,

$$\gamma(I) = \frac{2(\xi RI)^2 P_m}{\sigma^2} \tag{5}$$

$$P_m = \frac{A^2}{2T}\int_0^T g^2\,(t)dt \tag{6}$$

where, ξ = modulation index, R = responsivity of photodetector, I = received irradiance, σ^2 = noise variance, $\sigma_{LPPM}^2 = \frac{N_o R_b L}{2M}$, P_m = average power, T = total pulse duration, $g(t)$ = pulse shaping function.

Using equation (4), (5) and (6) and substituting these values $\xi = 1, R = 1, A = 1, I = LP_m$, and $M = log_2 L$ the conditional BER expression for LPPM-MPSK-SIM can be written as [12-13]:

$$\mathrm{P}_{LPPM-MPSK-SIM} = \frac{2}{log_2 M} Q\left(\frac{1}{4}\sqrt{\gamma L log_2 L log_2 M} \sin\left(\frac{\pi}{M}\right)\right) \quad (7)$$

The unconditional average SER expression for LPPM-MPSK-SIM (for $M \geq 4$) can be expressed as,

$$\mathrm{P}_{LPPM-MPSK-SIM} = \int_0^\infty \frac{2}{log_2 M} Q\left(\frac{1}{4}\sqrt{\gamma L log_2 L log_2 M} \sin\left(\frac{\pi}{M}\right)\right) f_v(v) dv \quad (8)$$

By simplifying it & convert it into Moment generating function [12] we get finalized expression of unconditional average SER expression for LPPM-MPSK-SIM as

$$\mathrm{P}_{LPPM-MPSK-SIM} = \frac{2}{\pi log_2 M} \int_0^{\pi/2} M_v\left(\frac{\bar{\kappa}\bar{\gamma}}{sin^2\theta}\right) d\theta \quad (9)$$

where,

$$\bar{\kappa} = \frac{L log_2 L log_2 M}{32} \sin^2\left(\frac{\pi}{M}\right) \quad (10)$$

2.3. SISO system

The MGF expression of v for SISO system [1] is given by:

$$M_v(s) = \sum_{l=0}^{\infty} b_l(m_1\gamma_1, m_2\gamma_2) s^{-\frac{l\gamma_1 + m_1\gamma_1}{2}} + \sum_{l=0}^{\infty} b_l(m_2\gamma_2, m_1\gamma_1) s^{-\frac{l\gamma_2 + m_2\gamma_2}{2}} \quad (11)$$

where,

$$b_l(m_1\gamma_1, m_2\gamma_2) = \frac{a_l(m_1\gamma_1, m_2\gamma_2)}{2}\Gamma\left(\frac{l\gamma_1 + m_1\gamma_1}{2}\right) \tag{12}$$

$$b_l(m_2\gamma_2, m_1\gamma_1) = \frac{a_l(m_1\gamma_1, m_2\gamma_2)}{2}\Gamma\left(\frac{l\gamma_1 + m_1\gamma_1}{2}\right) \tag{13}$$

By solving equation (9) and (11),

$$\begin{aligned} \mathrm{P}_{LPPM-MPSK-SIM} \\ &= \sum_{l=0}^{\infty} b_l(m_1\gamma_1, m_2\gamma_2)\Lambda(m_1\gamma_1)(\kappa\bar{\gamma})^{-\frac{l\gamma_1+m_1\gamma_1}{2}} \\ &+ \sum_{l=0}^{\infty} b_l(m_2\gamma_2, m_1\gamma_1)\Lambda(m_2\gamma_2)(\kappa\bar{\gamma})^{-\frac{l\gamma_2+m_2\gamma_2}{2}} \end{aligned} \tag{14}$$

where,

$$\Lambda(m_1\gamma_1) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} (sin\,\theta)^{l\gamma_1+m_1\gamma_1}\,d\theta \tag{15}$$

$$\Lambda(m_2\gamma_2) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} (sin\,\theta)^{l\gamma_2+m_2\gamma_2}\,d\theta \tag{16}$$

on solving equations (15) and (16) in Mathematica,

$$\Lambda(m_1\gamma_1) = \frac{\Gamma\left[\frac{1}{2}(1 + (l + \mathrm{m}_1)\gamma_1)\right]}{2\sqrt{\pi}\Gamma\left[1 + \frac{1}{2}(l + \mathrm{m}_1)\gamma_1\right]} \tag{17}$$

$$\Lambda(m_2\gamma_2) = \frac{\Gamma\left[\frac{1}{2}(1 + (l + \mathrm{m}_2)\gamma_2)\right]}{2\sqrt{\pi}\Gamma\left[1 + \frac{1}{2}(l + \mathrm{m}_2)\gamma_2\right]} \tag{18}$$

Similarly, by putting equation (17) & (18) in equation (14) & after simplifying we get

$P_{LPPM-MPSK-SIM}$

$$= \frac{2}{log_2 M} \sum_{l=0}^{\infty} \left[b_l(m_1\gamma_1, m_2\gamma_2)\Lambda(m_1\gamma_1)(\bar{\kappa}\bar{\gamma})^{-\frac{l\gamma_1+m_1\gamma_1}{2}} + b_l(m_2\gamma_2, m_1\gamma_1)\Lambda(m_2\gamma_2)(\bar{\kappa}\bar{\gamma})^{-\frac{l\gamma_2+m_2\gamma_2}{2}} \right] \quad (19)$$

2.4. MIMO RC

The MGF expression of v^2 for RC MIMO system is given by [1]

$$M_{v^2}(s) = \sum_{k=0}^{n_T n_R} \binom{n_T n_R}{k} \sum_{i=0}^{\infty} \sum_{j=0}^{i} \frac{\tilde{c}_j(m_1\gamma_1, m_2\gamma_2)\tilde{c}_{i-j}(m_2\gamma_2, m_1\gamma_1)}{2\Gamma\big((n_T n_R - k)m_1\gamma_1 + km_2\gamma_2 + j\gamma_1 + (i-j)\gamma_2\big)} \Gamma\left(\frac{(n_T n_R - k)m_1\gamma_1 + km_2\gamma_2 + j\gamma_1 + (i-j)\gamma_2}{2}\right) s^{-\frac{(n_T n_R - k)m_1\gamma_1 + km_2\gamma_2 + j\gamma_1 + (i-j)\gamma_2}{2}} \quad (20)$$

The average SER expression of LPPM-MPSK-SIM for RC MIMO system is given by [1]

$$\mathrm{P}_{LPPM-MPSK-SIM} = \frac{2}{\pi log_2 M} \int_0^{\pi/2} M_{v^2}\left(\frac{\bar{\kappa}\bar{\gamma}}{{n_T}^2 n_R sin^2\theta}\right) d\theta \quad (21)$$

where,

$$\bar{\kappa} = \frac{L log_2 L log_2 M}{32} \sin^2\left(\frac{\pi}{M}\right) \quad (22)$$

By putting equation (20) in equation (21) & after solving it with Mathematica we get,

average SER expression of LPPM-MPSK-SIM for RC MIMO system can be written as,

$\mathrm{P}_{LPPM-MPSK-SIM}$

$$= \frac{2}{log_2 M} \sum_{k=0}^{n_T n_R} \binom{n_T n_R}{k} \sum_{i=0}^{\infty} \sum_{j=0}^{i} \frac{\tilde{c}_j(m_1\gamma_1, m_2\gamma_2)\tilde{c}_{i-j}(m_2\gamma_2, m_1\gamma_1)\Lambda_{ij}(n_T n_R)}{2\Gamma\big((n_T n_R - k)m_1\gamma_1 + km_2\gamma_2 + j\gamma_1 + (i-j)\gamma_2\big)} \quad (23)$$

$$\Gamma\left(\frac{(n_T n_R - k)m_1\gamma_1 + km_2\gamma_2 + j\gamma_1 + (i-j)\gamma_2}{2}\right)\left(\frac{\kappa\bar{\gamma}}{n_T^2 n_R}\right)^{-\frac{(n_T n_R - k)m_1\gamma_1 + km_2\gamma_2 + j\gamma_1 + (i-j)\gamma_2}{2}}$$

where

$$\Lambda_{ij}(n_T n_R) = \frac{\Gamma\left[\frac{1}{2}(1 - k\mathrm{m}_1\gamma_1 + \mathrm{m}_1 n_T n_R \gamma_1 + j(\gamma_1 - \gamma_2) + i\gamma_2 + km_2\gamma_2)\right]}{2\sqrt{\pi}\,\Gamma\left[\frac{1}{2}(2 - k\mathrm{m}_1\gamma_1 + \mathrm{m}_1 n_T n_R \gamma_1 + j(\gamma_1 - \gamma_2) + i\gamma_2 + km_2\gamma_2)\right]} \tag{24}$$

3. RESULT & DISCUSSIONS

In this section, with the use of MATLAB, we analyze the average SER performance of Hybrid LPPM-MPSK-SIM over Double GG distribution for moderate turbulence conditions. The parameters used for moderate turbulence condition are $m_1 = 2.65$, $m_2 = 0.85$, $\gamma_1 = 0.9135$, $\gamma_2 = 1.4358$, $\Omega_1 = 0.9836$, $\Omega_2 = 1.1745$ and $\sigma_{Rytov}^2 = 2$. In RC MIMO system simulation no of lasers n_T and no of photodetectors n_R considered as $n_T = 2$ and $n_R = 2$ respectively. It is required to truncate (11) into finite series for numerical calculation. So, the maximum limit of l in (11) is required to be finite value. We consider the maximum limit of l as 10, 20, 50, 100 and the result are found to be almost equal. Here we present the result for the values of l varying from 0 to 10.

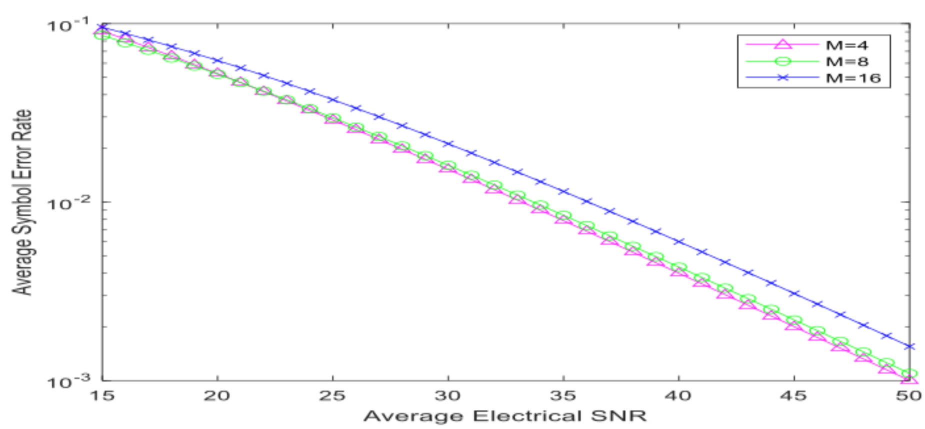

Fig. 2 shows the average SER of hybrid LPPM-MPSK-SIM for SISO system over Double GG fading with L=4, and M= 4, 8, & 16 for the average electrical SNR.

Fig. 2 illustrates average SER of Hybrid LPPM-MPSK-SIM for SISO system with L=4 for the average electrical SNR between 15dB and 50dB. We find that at an average electrical SNR of 50dB average SER is 0.000999, 0.001096 and 0.001552 for M=4, 8 and 16 respectively.

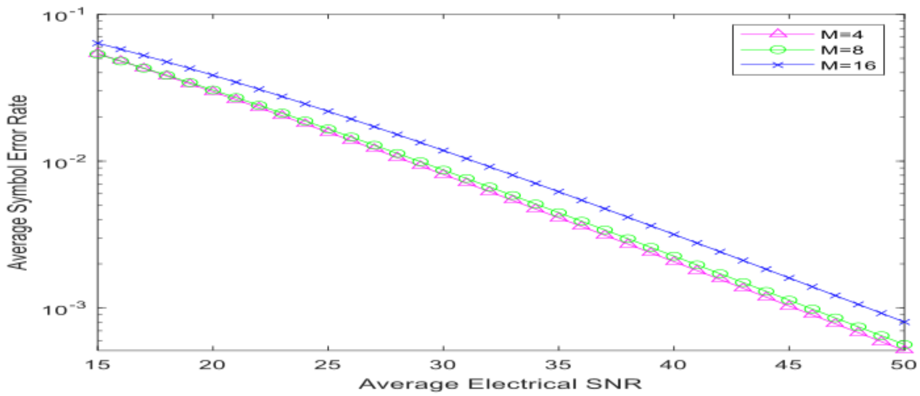

Fig. 3 shows the average SER of hybrid LPPM-MPSK-SIM for SISO system over Double GG fading with L=8, and M= 4, 8, & 16 for the average electrical SNR.

Fig. 3 illustrates average SER of Hybrid LPPM-MPSK-SIM for SISO system with L=8 for the average electrical SNR between 15dB and 50dB. We find that at an average electrical SNR of 50dB average SER is 0.0005136, 0.00564 and 0.0008027 for M=4, 8 and 16 respectively.

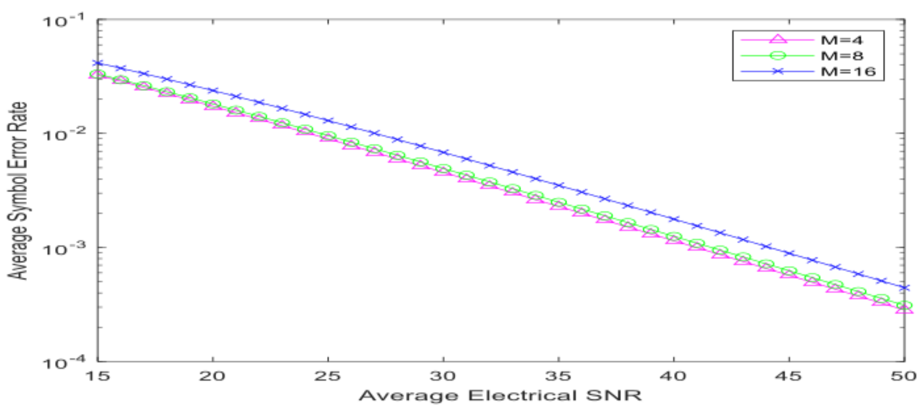

Fig. 4 shows the average SER of hybrid LPPM-MPSK-SIM for SISO system over Double GG fading with L=16, and M= 4, 8, & 16 for the average electrical SNR.

Fig. 4 illustrates average SER of Hybrid LPPM-MPSK-SIM for SISO system with L=16 for the average electrical SNR between 15dB and 50dB. We find that at an average electrical SNR of 50dB average SER is 0.000284, 0.000311 and 0.0004427 for M=4, 8 and 16 respectively.

From Fig 2, 3 & 4 it is clearly observed that as value of M increases in hybrid LPPM-MPSK-SIM average Symbol error rate increases for a standard value of LPPM. By observing we also found that as value of L increases in hybrid LPPM-MPSK-SIM average Symbol error rate decreases for standard value of M. So by proper selection of M & L we get an improved average SER.

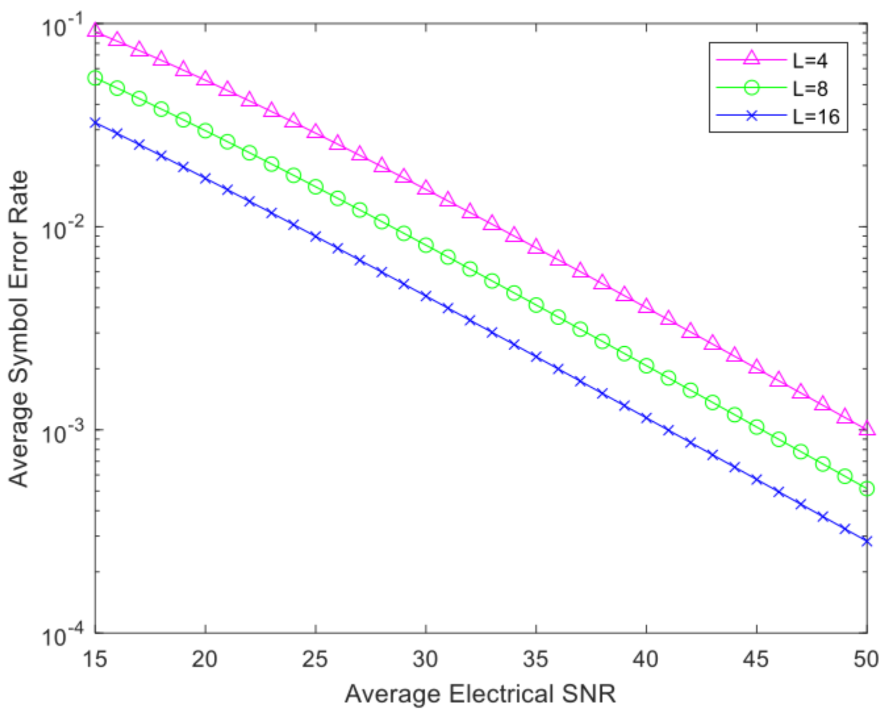

Fig. 5 shows the average SER of hybrid LPPM-MPSK-SIM for SISO system over Double GG fading with M=4, and L= 4, 8, & 16 for the average electrical SNR.

Fig. 5 illustrates average SER of Hybrid LPPM-MPSK-SIM for SISO system with M=4 for the average electrical SNR between 15dB and 50dB. We find that at an average electrical SNR of 50dB average SER is 0.000999, 0.0005536 and 0.000282 for L=4, 8 and 16 respectively.

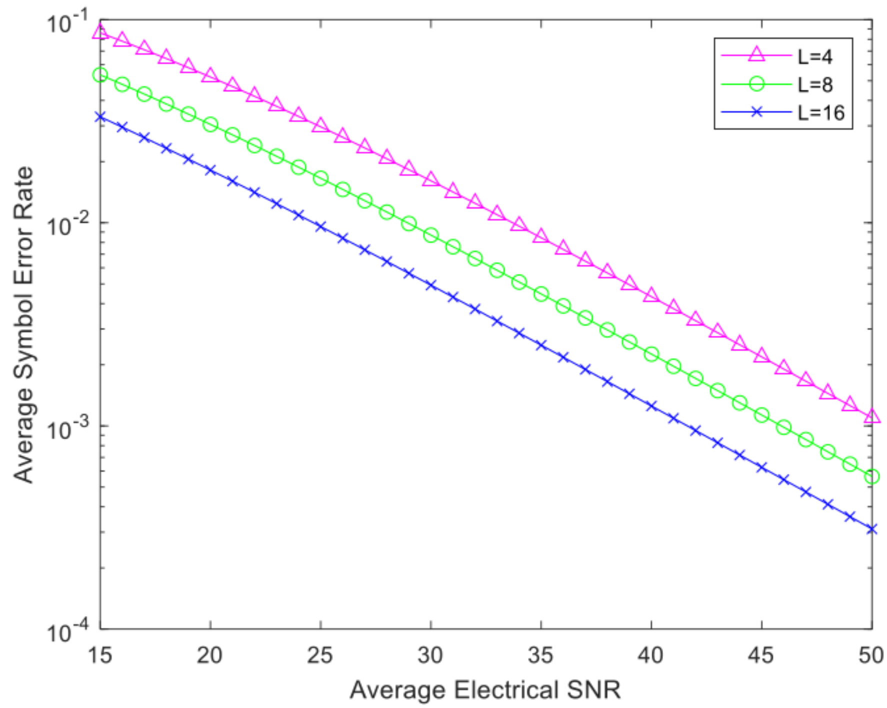

Fig. 6 shows the average SER of hybrid LPPM-MPSK-SIM for SISO system over Double GG fading with M=8, and L= 4, 8, & 16 for the average electrical SNR.

Fig. 6 illustrates average SER of Hybrid LPPM-MPSK-SIM for SISO system with M=8 for the average electrical SNR between 15dB and 50dB. We find that at an average electrical SNR of 50dB average SER is 0.001096, 0.000564 and 0.000311 for L=4, 8 and 16 respectively.

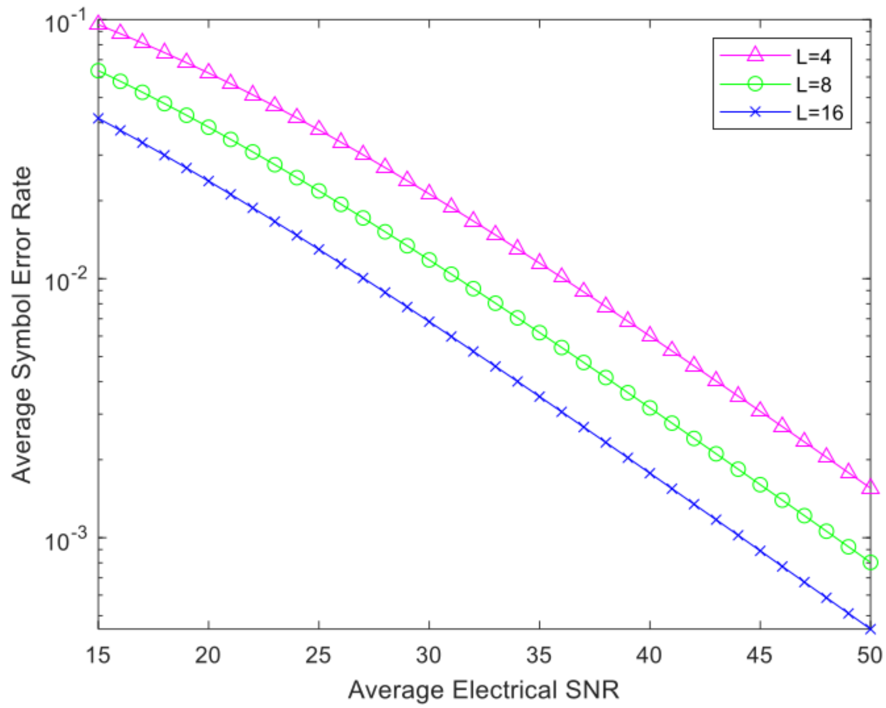

Fig. 7 shows the average SER of hybrid LPPM-MPSK-SIM for SISO system over Double GG fading with M=16, and L= 4, 8, & 16 for the average electrical SNR.

Fig. 7 illustrates average SER of Hybrid LPPM-MPSK-SIM for SISO system with M=16 for the average electrical SNR between 15dB and 50dB. We find that at an average electrical SNR of 50dB average SER is 0.001532, 0.0008027 and 0.0004437 for L=4, 8 and 16 respectively.

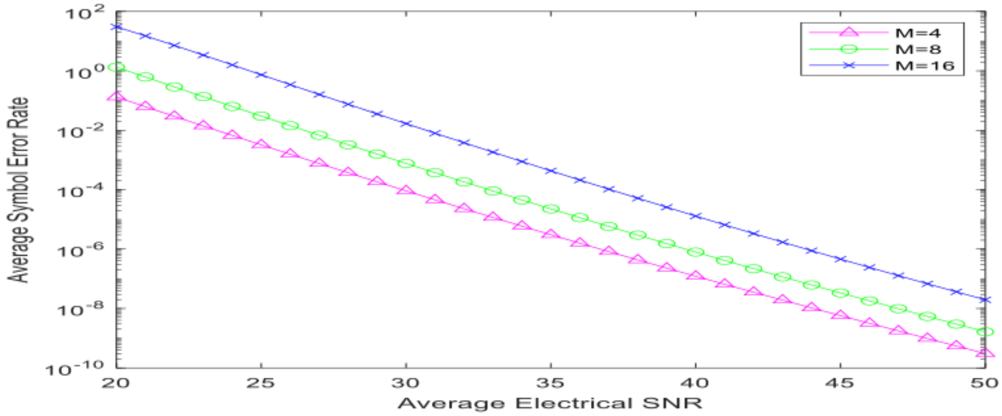

Fig. 8 shows the average SER of hybrid LPPM-MPSK-SIM for RC MIMO system over Double GG fading with L=4, and M= 4, 8, & 16 for the average electrical SNR.

Fig. 8 illustrates average SER of Hybrid LPPM-MPSK-SIM for MIMO RC system with L=4 for the average electrical SNR between 20dB and 50dB. We find that at an average electrical SNR of 25dB average SER is 0.003274, 0.03004 and 0.7381 for M=4, 8 and 16 respectively.

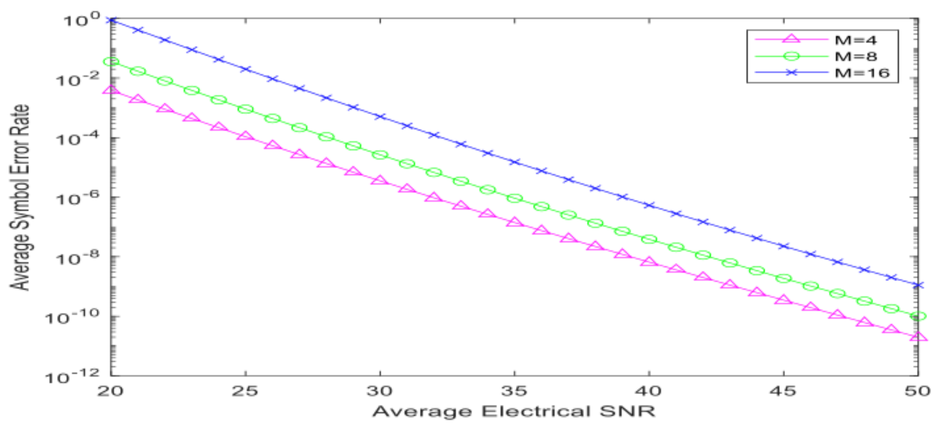

Fig. 9 shows the average SER of hybrid LPPM-MPSK-SIM for RC MIMO system over Double GG fading with L=8, and M= 4, 8, & 16 for the average electrical SNR.

Fig. 9 illustrates average SER of Hybrid LPPM-MPSK-SIM for MIMO RC system with L=8 for the average electrical SNR between 20dB and 50dB. We find that at an average electrical SNR of 25dB average SER is 0.0001069, 0.0009014 and 0.01986 for M=4, 8 and 16 respectively.

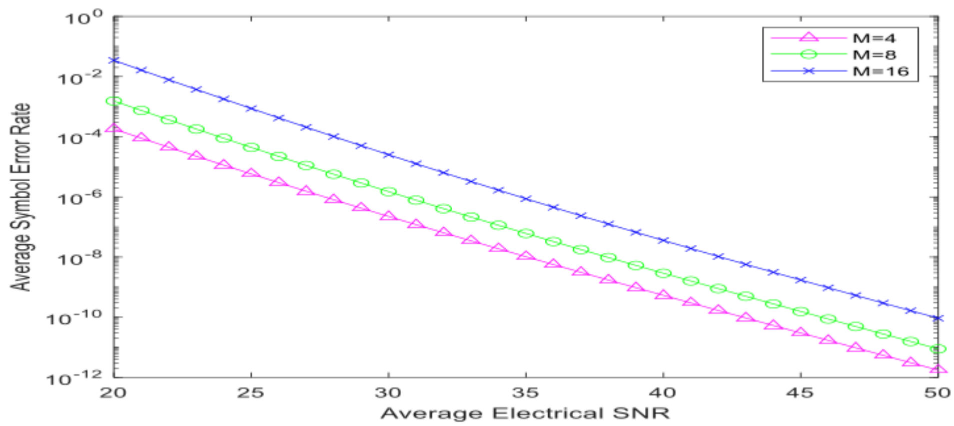

Fig. 10 shows the average SER of hybrid LPPM-MPSK-SIM for RC MIMO system over Double GG fading with L=16, and M= 4, 8, & 16 for the average electrical SNR.

Fig. 10 illustrates average SER of Hybrid LPPM-MPSK-SIM for MIMO RC system with L=16 for the average electrical SNR between 20dB and 50dB. We find that at an average electrical SNR of 25dB average SER is 0.0000057, 0.0000044 and 0.000866 for M=4, 8 and 16 respectively.

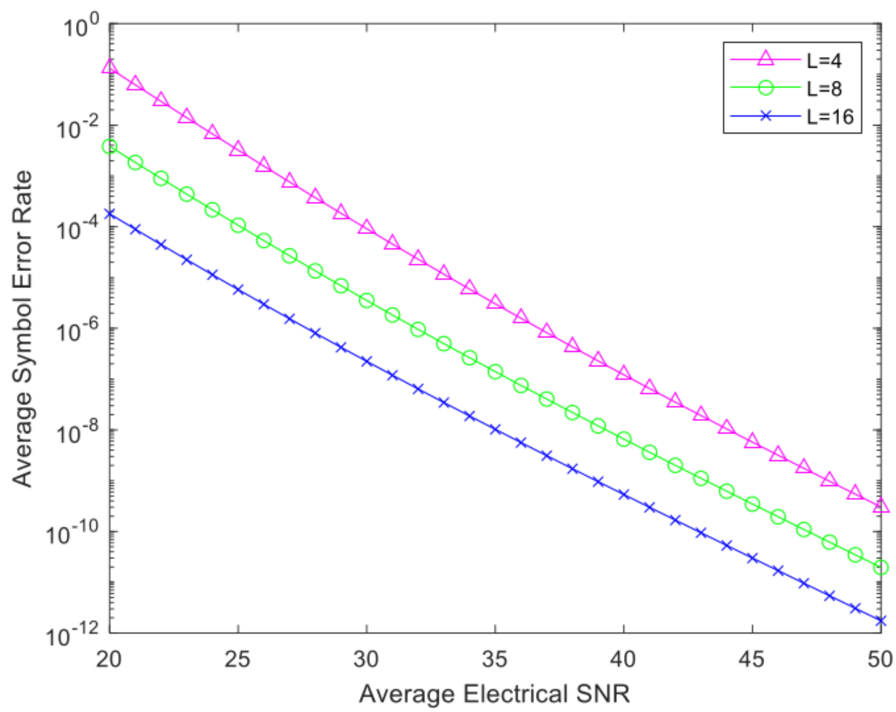

Fig. 11 shows the average SER of hybrid LPPM-MPSK-SIM for RC MIMO system over Double GG fading with M=4, and L= 4, 8, & 16 for the average electrical SNR.

Fig. 11 illustrates average SER of Hybrid LPPM-MPSK-SIM for MIMO RC system with M=4 for the average electrical SNR between 20dB and 50dB. We find that at an average electrical SNR of 25dB average SER is 0.003224, 0.001006 and 0.00000572 for M=4, 8 and 16 respectively.

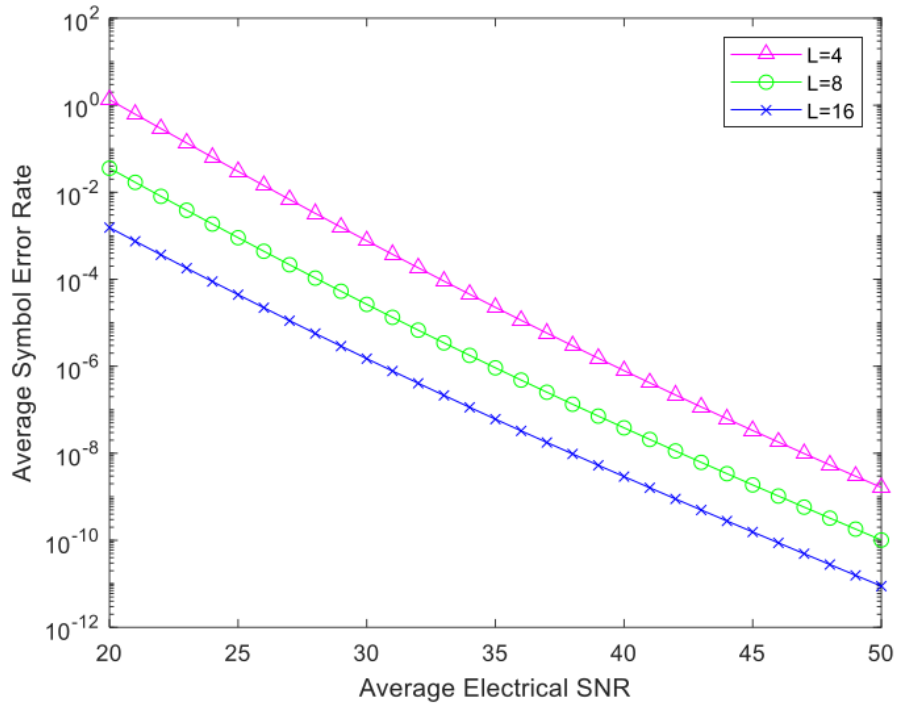

Fig. 12 shows the average SER of hybrid LPPM-MPSK-SIM for RC MIMO system over Double GG fading with M=8, and L= 4, 8, & 16 for the average electrical SNR.

Fig. 12 illustrates average SER of Hybrid LPPM-MPSK-SIM for MIMO RC system with M=8 for the average electrical SNR between 20dB and 50dB. We find that at an average electrical SNR of 25dB average SER is 0.03004, 0.0009014 and 0.0000441 for L=4, 8 and 16 respectively.

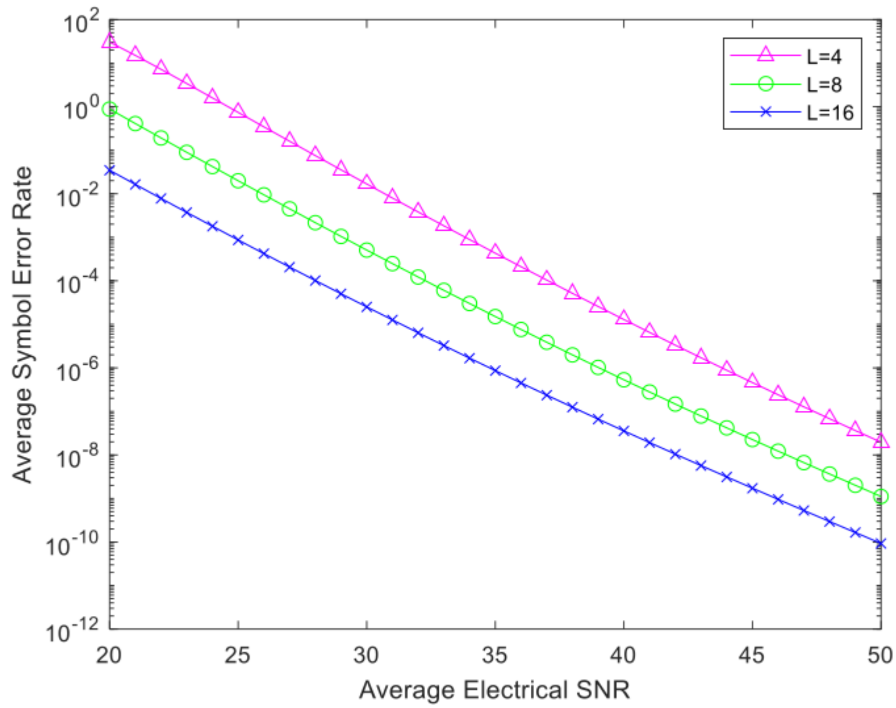

Fig. 13 shows the average SER of hybrid LPPM-MPSK-SIM for RC MIMO system over Double GG fading with M=16, and L= 4, 8, & 16 for the average electrical SNR.

Fig. 13 illustrates average SER of Hybrid LPPM-MPSK-SIM for MIMO RC system with M=16 for the average electrical SNR between 20dB and 50dB. We find that at an average electrical SNR of 25dB average SER is 0.7381, 0.01986 and 0.0008661 for L=4, 8 and 16 respectively.

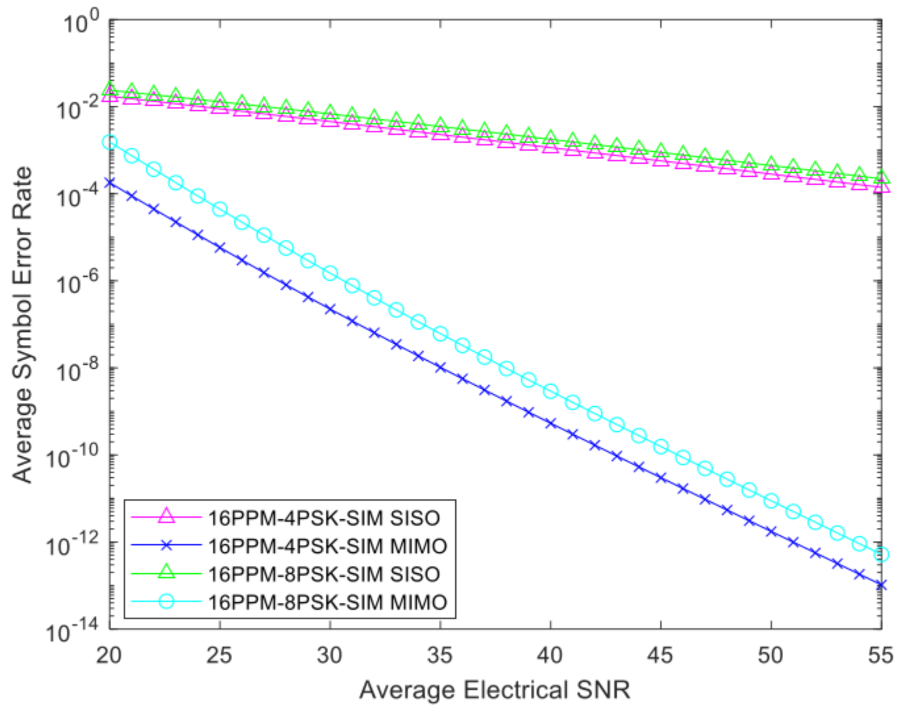

Fig 14. shows the average SER verses average electrical SNR with 16PPM-4PSK-SIM and 16PPM-8PSK-SIM for SISO and MIMO RC system.

In Fig. 14 we present the average SER verses average electrical SNR of 16PPM-4PSK-SIM and 16PPM-8PSK-SIM for both SISO and RC MIMO FSO systems. We clearly observe that MIMO system improves the average SER performance as compared to SISO system. We can also observe that 8PSK shows improved SER as compared to 4PSK both in case of SISO as well as MIMO systems.

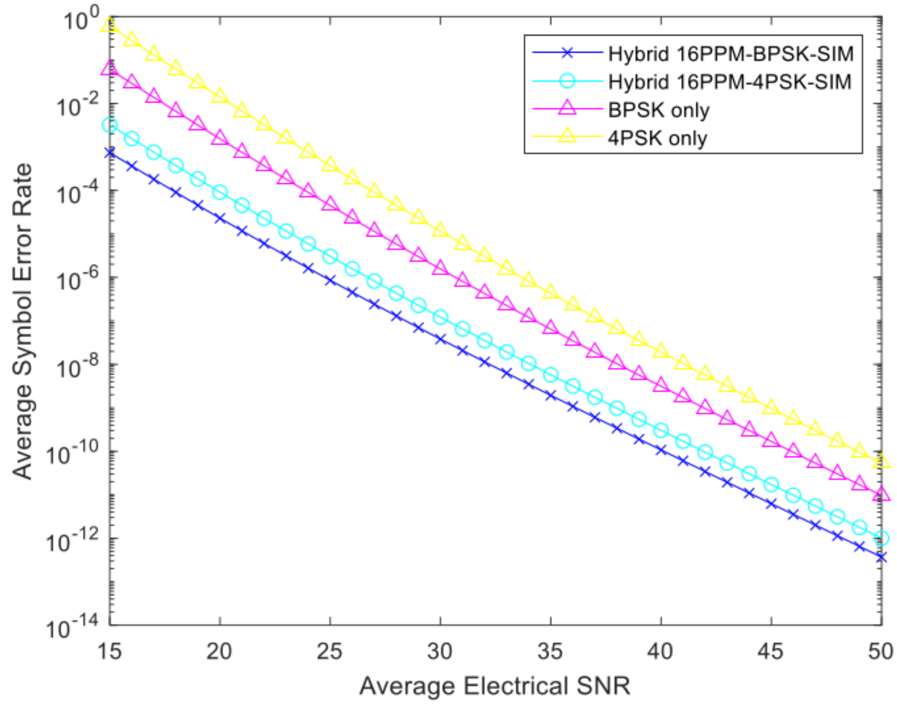

Fig 15. shows the average SER verses average electrical SNR with 16PPM-BPSK-SIM, 16PPM-4PSK-SIM, BPSK and 4PSK for RC MIMO system.

In Fig. 15 we present the average SER verses average electrical SNR of 16PPM-BPSK-SIM, 16PPM-4PSK-SIM, BPSK and 4PSK for RC MIMO system. We clearly observe that hybrid modulation improves the average SER performance of MIMO system as compared to conventional modulation schemes.

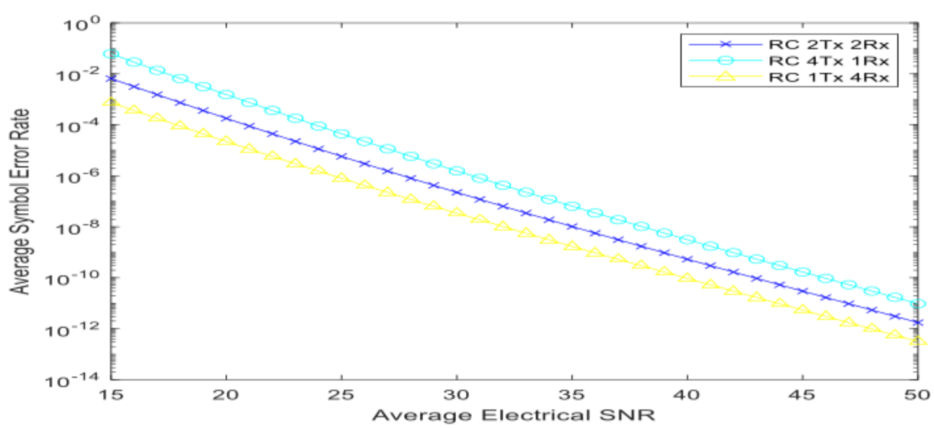

Fig 16. shows the average SER verses average electrical SNR with hybrid 16PPM-4PSK-SIM for RC MIMO system

In Fig. 16 we present the average SER verses average electrical SNR of hybrid 16PPM-4PSK-SIM for RC MIMO system with different numbers of lasers and photo detectors. We clearly observe that increase in number of photo detectors as compared to number of lasers improved the average SER performance in RC MIMO FSO communication system.

4. Conclusion

In this paper, the average SER performance of FSO communication system has been analyzed by using hybrid SIM with LPPM and MPSK modulation technique over double GG distribution. The SER analysis has been done for both SISO and MIMO for average electrical SNR under the moderate turbulence condition. We observed from MATLAB simulation that the SER was decreasing on increasing the value of average length of PPM symbol, L. Thus, it is concluded that the hybrid SIM with LPPM and MPSK modulation technique perform better for both SISO and MIMO over the double GG distribution under moderate turbulence condition.

References

1. Xiang Yi n, Mingwu Yao,Xiaoyang Wang. MIMO FSO communication using subcarrier intensity modulation over double generalized gamma fading. *X.Yi et al/Optics Communications 2017 386 (64–72)*
2. Mohammadreza A , Kashani , Murat Uysal , and Mohsen Kavehrad. On the Performance of MIMO FSO Communications over Double Generalized Gamma Fading Channels. *IEEE ICC 2015 - Optical Networks and Systems Symposium*
3. Hongzhan Liu , Renbo Liao ,Zhongchao Wei, Zhiyun Hou. BER Analysis of a Hybrid Modulation Scheme Based on PPM and MSK Subcarrier Intensity Modulation *.IEEE Photonics Journal Vol. 7,No. 4, August 2015.*
4. Ting Jiang , Lin Zhao , Hongzhan Liu , Dongmei Deng. Performance Improvement for Mixed RF–FSO Communication System by Adopting Hybrid Subcarrier Intensity Modulation. *MDPI Appl. Sci. 2019, 9, 3724.*
5. Anbarasi, K., Hemanth, C., & Sangeetha, R. G. (2017). A review on channel models in free space optical communication systems. Optics & Laser Technology, 97, 161-171.
6. Nistazakis, H. E., Assimakopoulos, V.D. and Tombras, G.S., 2011. Performance estimation of free space optical links over negative exponential atmospheric turbulence channels. OPTIC-International Journal for Light and Electron Optics, 122(24), pp.2191-2194.
7. Rajat Kumar Giri, Bijayananda Patnaik. Bit Error Rate Performance Analysis of Hybrid Subcarrier Intensity Modulation-Based FSO with Spatial Diversity in Various Weather Conditions. *J. Opt. Commun. 2017*
8. M. Faridzadeh, A. Gholami. BPSK-SIM- PPM Modulation for Free Space Optical Communications *.International Symposium on Telecommunications 2014*
9. M. Faridzadeh *, A. Gholami*, Z. Ghassemlooy**, and S. Rajbhandari Hybrid 2-PPM-BPSK-SIM with the Spatial Diversity for Free Space Optical Communications *.IET International Symposium IEEE 2012*
10. Tiwari, P., Kumar, N., Singh, P., Srivastava, C., Lakshmanan, M., Jain, P. and Katiyar, S., 2019, March. Modeling and Analysis of Hybrid SIM with L-PPM and MSK over Double Generalized Gamma Distribution in Free Space Optical Communication System. In *2019*

International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN) (pp. 1-4). IEEE.

11. Lu, J., Letaief, K.B., Chuang, J.I. and Liou, M.L., 1999. M-PSK and M-QAM BER computation using signal-space concepts. *IEEE Transactions on communications*, *47*(2), pp.181-184.
12. Ghassemlooy, Z. and Popoola, W.O., 2010. Terrestrial free-space optical communications. *Mobile and Wireless Communications Network layer and circuit level design*, pp.355-392.
13. Liu, H., Liao, R., Wei, Z., Hou, Z. and Qiao, Y., 2015. BER analysis of a hybrid modulation scheme based on PPM and MSK subcarrier intensity modulation. *IEEE Photonics Journal*, *7*(4), pp.1-10.
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14 Jagadeesh, VK, Vineeth Palliyembil, P.

Muthuchidambaranathan, and Francis M. Bui. "Free space optical communication using subcarrier intensity modulation through generalized turbulence channel with pointing error", Microwave and Optical Technology Letters, 2015.
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