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ASYMPTOTIC BER ANALYSIS OF QAM AND PSK WITH OFDM ROFSO OVER M TURBULENCE IN THE PRESENCE OF POINTING ERRORS

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Abstract: In case where installation of optical fibre is not practically reliable, the new generation wireless communication popularized as free-space optics (FSO) systems can be used to transmit radio frequency (RF) signals.FSO technology can efficiently transfer multiple RF signals, and this new technique is commonly referred as radio on FSO (RoFSO).The major challenges in this technology are atmospheric turbulence and pointing errors. In this paper, we analysed the performance of Ro-FSO links employing the orthogonal frequency division multiplexing (OFDM) scheme under both modulation formats namely quadrature amplitude modulation (QAM) and phase shift keying (PSK) in the newly developed Malaga or M distribution turbulent channel model. The performance is evaluated with consideration of both scintillation and pointing errors in M distribution channel for higher values of the carrier to noise plus distortion ratio (CNDR). M distribution channel serves as an effective generalized model which unifies all other available statistical channel models. The novel expressions of average bit error rate (BER) has been derived and performance comparison has been done between the two modulation formats. This paper identifies the crucial parameters that deteriorate the efficiency of the OFDM signal over FSO link which can be helpful in designing an optimal system.

1 INTRODUCTION

âĂć: In present world there is unprecedented demand for deluge bandwidth and high data rate,its pivotal to achieve both mentioned above . In developing network infrastructures, to achieve large bandwidth and high data rate, radio-over-fibre (RoF) technology is considered as one of the most reliable technology.Hence free space optical (RoFSO) communication systems has motivated unprecedented research and commercial interest in the last years due to their high performance capabilities, and inclusion of the narrow laser beam used in FSO its highly secured,due to non existence of spectrum allocation as like in mobile communication its highly lucrative and feasible where laying optical fibre is practically not possible[1–8]

âĂć: An effective transmission technique used in many RoFSO systems is the orthogonal frequency division multiplexing (OFDM) scheme which uses an efficient way of a transmitting data parallel y rather than serially using many narrow band sub-carriers.The sub-carriers are orthogonal to each other, and thus, the inter symbol interference (ISI) between sub-carriers are reduced,and hence the signal separation at the receiver side using OFDM is effective and prone to less attenuation[9, 10].

âĂć: Unlike wired or optical cabled connection, ultimately performance of wireless FSO communication systems depends on the climatic conditions and the non linear characteristics of the transmission path. hence, wireless systems are exposed to atmospheric attenuation and scintillation effects. Scintillation, also known as turbulence-induced fading, causes Ir radiance fluctuations in the receiver side of the system as a result of the thermally induced changes in the refractive index of the air.The propagation of the laser beam through the atmosphere is affected by many phenomena such as absorption, scattering, refractive index fluctuation, etc. Many statistical distributions have been proposed in order to model these fluctuations, e.g., the Gamma-Gamma, K, I-K, etc. A unifying statistical models which incorporates many of the distributions referred above, is the recently launched Malaga-distribution or,the M-distribution [11–14].

âĂć: The BER performance of a serial relayed Ro-FSO OFDM system over Gamma-Gamma distribution is studied in [14].In a recent work[15] the BER performance of Ro-FSO system based on OFDM scheme with QAM is analyzed .In another recent work[16] the novel expressions for the average BER and outrage probability metrics of OFDM based Ro-FSO links over M turbulence channel is derived and analysed. We extend this work including the pointing errors and analysed the impact of pointing errors on Ro-FSO systems

âĂć: The work presented in this paper is organized as follows: in the following Section 2, we present the system's set-up and the channel's model, while in Section 3, we derive the closed form mathematical expressions for the estimation of the BER for each single RoFSO OFDM link over M turbulence channels, for QAM or PSK modulation schemes. In Section 4 we present the corresponding numerical results for the transmission of OFDM signals over turbulent RoFSO link.and results for PSK and QAM are compared and .conclusion has been done in section 5.

2 CHANNEL MODEL

: In the present paper the optical channel model I is considered as product of I_a, I_p and I_l which is given below [17]

$$I = I_l I_a I_p \tag{1}$$

âĂć: Here I_l represents atmospheric loss, I_a represents atmospheric turbulence, I_p represents pointing errors

2.1 Atmospheric loss

âĂć: where I_l represents the atmospheric loss modelled by the Beer−Lamberts law as[17] and I_P represents pointing errors which is discussed further

$$I_l = \exp(-\sigma L) \quad (2)$$

âĂć: where σ is the attenuation coefficient, L is the link length.

2.2 Atmospheric turbulence induced fading

âĂć: In this paper channel is modelled using the generalized FSO channel known as the M -distribution channel. The uniqueness in M -distribution is it covers all the channel conditions from weak to strong turbulence and it is capable of characterizing most of the existing atmospheric turbulence models for example gamma, gamma gamma, negative exponential, K distribution, log normal models. The model shown below considers the optical beam consisting of three components: (A) the line of sight[LOS] component with power Ω, (B) the scattered component coupled to the line of sight component with power $2\rho b_0$, and (C) the scattered component independent of the previous components with power $2(1-\rho)b_0$. So the total power of the scattered components is $2b_0$.

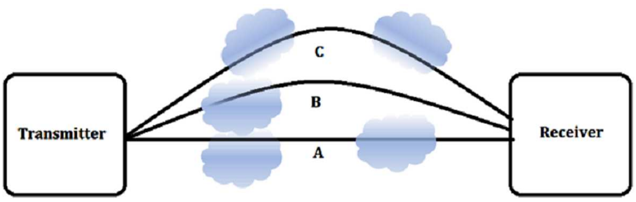

Fig. 1: FSO system beam propagation in Malaga model including small scale fluctuations[18]

The parameter q represents the amount of coupling between the scattered and line of sight component. The probability density function (PDF) of the Malaga-distribution turbulence is given by[19]

$$f_I(I) = A\sum_{k=1}^{b} a_k I^{\frac{\alpha+k}{2}-1} K_{\alpha-k}\left(2\sqrt{\frac{\alpha\beta I}{\gamma\beta+\Omega}}\right) \quad (3)$$

$$where\ A = \frac{2\alpha^{\frac{\alpha}{2}}}{\gamma^{1+\frac{\alpha}{2}}\Gamma(\alpha)}\left(\frac{\gamma\beta}{\gamma\beta+\Omega'}\right)^{\beta+\frac{\alpha}{2}} \quad (4)$$

$$a_k = \left(\begin{array}{c}\beta-1\\ k-1\end{array}\right)\frac{(\gamma\beta+\Omega')^{1-\frac{k}{2}}}{k-1!}\left(\frac{\Omega'}{\gamma}\right)^{k-1}\left(\frac{\alpha}{\beta}\right)^{\frac{k}{2}} \quad (5)$$

âĂć: with α being a positive parameter related to the effective number of large-scale cells of the scattering process, and β is a natural number where as generalized expression for β being a real number can also be derived, with an infinite summation, but it is less interesting due to the high degree of freedom of the proposed distribution. And, the pdf shows very good agreement with the data because of a simple functional form, emphasized by the fact that its β parameter being a natural number, which leads to a closed-form representation[20]. Which is a major convenience for using β as a natural number(β represents the amount of fading parameter). For simplicity, we have denoted$\gamma = 2(1-\rho)b_0$, finally the parameter $\Omega^{'} = \Omega + 2\rho b_0 + 2\sqrt{2b_0\Omega\rho}\cos(\phi_A - \phi_B)$ represents the average power from the coherent contributions. ϕ_A and ϕ_B are the deterministic phases of LOS and the coupled-to-LOS scatter components respectively.

2.3 pointing errors

âĂć: In FSO communication systems, the alignment between transmitter and receiver plays a vital role to determine the link performance and reliability. However, misalignment due to sway of buildings by wind loads, thermal expansion and weak earthquakes cause pointing errors and signal fading at the receiver. Pointing errors are denoted by I_P, which is discussed below

$$f_{I_p} = \frac{g^2}{A_0^{g^2}}(I_P)^{g^2-1}, 0 \le I_P \le A_0 \quad (6)$$

âĂć: where $A_0 = [erf(v)]^2$is the fraction of the collected optical power with $v = \sqrt{\frac{\pi}{2}}\frac{a}{w_z}$, a denotes the radius of the receiver and w_z is the beam width at the distance L. The effective beam width is given by the expression $w_{zeq} = \left[\frac{\sqrt{\pi}erf(v)w_z^2}{2ve^{-v^2}}\right]^{\frac{1}{2}}$ where $g = \frac{w_{zeq}}{2\sigma}$is the ratio between the effective beam width and the jitter standard deviation σ_s.

2.4 Combined channel fading models

âĂć: The combined channel model for I is given as

$$f_I(I) = \int f_{I|I_a}(I|I_a)f_{I_a}(I_a)dI_a \quad (7)$$

âĂć: where $f_{I|I_a}(I|I_a)$ is the condition probability for a given turbulence state I_a, which is defined as

$$f_{I|I_a}(I|I_a) = \frac{1}{I_aI_l}f_{I_p}\left(\frac{I}{I_aI_l}\right) = \frac{g^2}{A_0^{g^2}I_aI_l}\left(\frac{I}{I_aI_l}\right)^{g^2-1}, 0 \le I \le A_0I_aI_l \quad (8)$$

âĂć: By substituting Eq.(3) and Eq.(8) in Eq.(7) we have

$$f_I(I) = \frac{g^2A}{(A_0I_l)^{g^2}}(I)^{g^2-1}\sum_{k=1}^{b} a_k \int_{I|I_lA_0}^{\infty} I^{\frac{\alpha+k}{2}-1-g^2} \times K_{\alpha-k}\left(2\sqrt{\frac{\alpha\beta I}{\gamma\beta+\Omega}}\right)dI_a \quad (9)$$

âĂć: With the help of [21] and (14) in [21], the final $f_I(I)$ can be obtained as given below [17]

$$f_I(I) = \frac{g^2AI^{-1}}{2}\sum_{K=1}^{\beta}\left(a_k\left[\frac{1}{B}\right]^{\frac{\alpha+K}{2}} G_{1,3}^{3,0}\left(\frac{I}{BA_0I_l}\middle| \begin{array}{c}1+g^2\\ g^2,\alpha,k\end{array}\right)\right) \quad (10)$$

âĂć: Where $B = \left(\frac{\Omega^1+\gamma\beta}{\alpha\beta}\right)$,$G_{p,q}^{m,n}$ [$\bullet$]is the Meijer's G-function.

3 SYSTEM MODEL

âĂć: The OFDM signal that is transmitted by the laser enters atmosphere and gets attenuated by its effects and is received at the receiver side by the photo detector (PD), as illustrated in Fig 2.OFDM is a form of multi-carrier modulation technique. It uses multiple sub-carriers within the same single channel. It employs a large number of orthogonal sub-carriers.Each is modulated by digital modulation techniques such as QAM OR PSK .The message bits are first transformed from serial to parallel form and then modulated before being converted to symbols. The total data rate is same as that of conventional single sub-carrier modulation schemes having same bandwidth. Inverse Fast Fourier Transform (IFFT) is done at

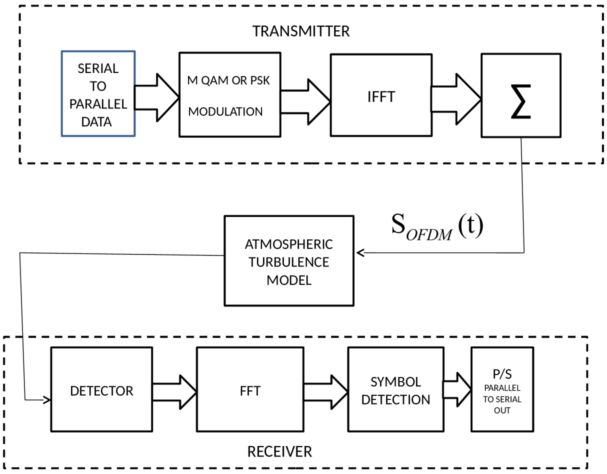

Fig. 2: Block diagram for the point to point OFDM R0FSO system

the transmitter and Fast Fourier Transform (FFT) at the receiver to retrieve the data.The RF-OFDM can be represented as [14]

$$s_{OFDM}(t) = \sum_{n=0}^{N-1} s_n(t) for 0 \le t < T_S \tag{11}$$

âĂć: where the n-th sub-carrier Sn(t), is

$$s_n(t) = X_n e^{[i(w_n + 2\pi f_c)t]} \tag{12}$$

âĂć: Here T_s is the duration of OFDM system, andX_n is the complex data represented by $X_n = a_n + jb_n$. At the transmitter the OFDM signal modulates the laser diode (LD) intensity. Due to non linear characteristic of the laser diode ,intermodulation distortion [IMD] occurs and produces higher order harmonics. The transmitted optical power can be expressed as a function of non linear expression as

$$p(t) = p_t \left[1 + \sum_{n=0}^{N-1} m_n s_n(t) + a_3 \left(\sum_{n=0}^{N-1} m_n s_n(t) \right)^3 \right] \tag{13}$$

âĂć: where Pt represents the average transmitted optical power,a_3 and m_n are the third order non-linearity coefficient and the optical modulation index (OMI) for each OFDM frequency,

âĂć: The optical OFDM signal after getting transmitted through the free atmosphere reaches the receiver.The transmitted power gets reduced as it travels through the medium, Noise n(t) especially additive white Gaussian noise (AWGN)gets added while it gets transmitted through the free atmosphere. At the (PD) of the receiver, the optical power is given as $P_r(t) = hP(t) + P_b(t)$, where$P_b(t)$ is the undesirable background radiations and h is the channel Attenuation loss due to atmospheric turbulence and pointing error. For getting the data, PD converts the optical OFDM signal into RF-OFDM signal. The output current of the receiver is expressed as[14]

$$I(t,h) = I_0 \left[1 + \sum_{n=0}^{N-1} m_n s_n(t) + a_3 \left(\sum_{n=0}^{N-1} m_n s_n(t) \right)^3 \right] + n_{opt}(t) \tag{14}$$

âĂć: where $I_0 = \rho L_{tot} p_t I$ represents the dc value of $i(t, I)$, ρ is the responsivity of the PD, while n_{opt} stands for the optical noise which represents optical noise power known as AWGN with zero mean and variance equal to the half of the noise power, i.e. $N_o/2$[14]

$$N0 = \frac{4K_B T F}{R_L} + 2qI_0 + I_0^2(RIN) \tag{15}$$

âĂć: with K_B T and F being the Boltzmann's constant ,temperature and the noise figure of the receiver respectively, while R_L is the load resistor at the Photo-detector's side, q is the electron charge and R_{IN} stands for the relative intensity noise process which is a function of the square of the optical power.

âĂć: Moreover, the (IMD), due to the non-linear responsivity of the (LD) , which affects the carrier w_n among N equally spaced subcarriers of the OFDM system model and directly propotional on the third order non linearity coefficient, a_3,and the OMI for each subcarrier, m_n, is given as [16]

$$\sigma_{IMD}^2 = \frac{9a_3^2 m_n^6}{8} \left(\frac{D_2(N,n)}{2} + D_3(N,n) \right) \rho L_{tot} P_t I \tag{16}$$

âĂć: where the values of D_2 and D_3 are estimated as functions of the specific sub-carrier number, n, and the total number of the N subcarriers of the OFDM signal as [16]

$$\begin{aligned} &D_2(n,N) = 0.5[N - 2 - 0.5(1 - (-1)^N)(-1)^N] \\ &D_3(n,N) = 0.5n(N - n - 1) + 0.25[(N-3)^2 - 5] - \\ &0.125[(1 - (-1)^N)(-1)^{N+n}] \end{aligned} \tag{17}$$

âĂć: Considering the optical noise and the IMD, the total average carrier to noise plus distortion $(CNDR_n(I))$ at the receiver, for every subcarrier, n, is given as[16]

$$CNDR_n(I) = \frac{(m_n \rho L_{tot} p_t I)^2}{2\left(\frac{N_0}{T_S} + \sigma_{IMD}^2\right)} \tag{18}$$

âĂć: The $CNDR_n$ per OFDM sub-carrier, obtained can be approximated, with the following expression[14],

$$[CNDR_n]_{AV} \approx \frac{(m_n \rho L_{tot} p_t)^2}{2\left(\left[\frac{N_0}{T_S}\right]_{AV} + [\sigma_{IMD}^2]_{AV}\right)} \tag{19}$$

âĂć: where the subscripts n and A_V denote the n_{th} OFDM subcarrier and the average over scintillation value of each specific quantity, respectively.

4 BER analysis of OFDM RoFSO link

âĂć: In this section we present average BER for OFDM RoFSO optical link for QAM and PSK format in turbulence channel modeled by M distribution. M and K being the order of modulation for QAM and PSK respectively. The BER expression of M QAM optical link is given by [14] . Here it is assumed that Gray coded mapping is used at the receiver .Gray coded mapping advantages include better BER performance because adjacent constellation points will only differ in one bit, so in case of an error only one bit will be wrong. For the natural mapping multiple bits may be wrong and hence high BER

$$P_{b,m-QAM} = \frac{N^{-1}}{\log_2(M)}$$
$$\times \sum_{N=0}^{N-1} \left\{ 1 - \left[1 - (1 - \sqrt{M^{-1}}) erfc\left(\sqrt{\frac{3CNDR_n(I)}{2(M-1)}} \right) \right]^2 \right\} \tag{20}$$

$$\begin{aligned} p_{b,m-QAM,AV} &= \frac{\left(1-\sqrt{M^{-1}}\right) N^{-1}}{\log_2(M)} \sum_{n=0}^{N-1} \int_0^{\infty} 2\text{erfc}\left(\sqrt{\frac{3CNDR_n(I)}{2(M-1)}}\right) f_I(I) \\ &- \frac{\left(1-\sqrt{M^{-1}}\right) N^{-1}}{\log_2(M)} \sum_{n=0}^{N-1} \int_0^{\infty} \left(1-\sqrt{M^{-1}}\right) \text{erfc}^2\left(\sqrt{\frac{3CNDR_n(I)}{2(M-1)}}\right) f_I(I) \end{aligned} \tag{21}$$

$$p_{b,M-QAM} \approx \frac{2(1-\sqrt{M^{-1}})N^{-1}}{\log_2 M} \sum_{n=0}^{N-1} \int_0^{\infty} \left[erfc\left(\sqrt{\frac{3CNDR}{2(M-1)}}\right) - \frac{(1-\sqrt{M^{-1}})}{72}\left(\exp\left[-\frac{3CNDR_n(I)}{M-1}\right]\right.\right.$$

$$+ 9\exp\left(-\frac{4CNDR_n(I)}{M-1}\right) + 6\exp\left(-\frac{7CNDR_n(I)}{2(M-1)}\right)] \times f_I(I)(22)$$

âĂć: Where N is the number of sub-carriers, erfc(.) stands for the complementary error function and M is given as $M = 2^{\xi}$. Simplifying the equation we get the simplified version for average BER expression over turbulence channel as Eq.(21)

âĂć: where $f_I(I)$represents PDF of combined M distribution channel model .To obtain the average BER, we substitute the PDF of combined M distribution channel and $erfc^2(x)$ which is approximated as $erfc^2(x) \approx [\exp(-x^2) + 3\exp(-4x^2/3)]^2/36$ [22] in Eq. (21) and the complementary $erfc(\bullet)$ can be expressed as Meijer G function using [[19], Eq. (8.4.14.2)] $erfc(x) = \frac{1}{\sqrt{\pi}} G_{1,2}^{2,0}\left[x^2 \middle| \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix}\right]$ and also exponential term can also be expressed as Meijer G function [21]. The closed form average BER expression for OFDM RO-FSo links with M-QAM over combined M distribution channel Model is expressed as Eq.(23)using [21].

âĂć: BER expression for K-PSK modulation can be expressed as[14]

$$P_{b,k-psk} \approx \frac{N^{-1}}{\log_2(K)} \sum_{n=0}^{N-1} \left\{erfc\left[\sqrt{CNDR_n(I)}\sin(\frac{\pi}{k})\right]\right\} \tag{24}$$

âĂć: Thus, for the average BER estimation of the N-sub-carriers K-PSK OFDM FSO link over M distribution channel is expressed as[14]

$$P_{b,k-psk} \approx \frac{N^{-1}}{\log_2(K)} \sum_{n=0}^{N-1} \int_0^{\infty} \left\{erfc\left[\sqrt{CNDR_n(I)}\sin(\frac{\pi}{k})\right] f_I(I)dI\right\} \tag{25}$$

âĂć: The average BER of OFDM ROFSO link with K PSK is calaculated using the M distribution channel model Eq.(10) and the Meijer G representation of error function and exponential functions.The final closed form expresssion of average BER is derived in Eq,(26) using [[21],Eq.(21)].

5 Numerical results

In this section we present the derived equations for BER for both QAM and PSK .We have considered M for QAM and K for PSK.QAM and PSK OFDM RoFSO communication system over M modelled turbulence channels. It is clear that using individually the Eq. (23) and (26), the BER metric for each specific case of OFDM modulation scheme, i.e. QAM and PSK, M turbulence model can be easily estimated.

âĂć: In order to obtain the results , we have chosen N of the OFDM sub-carriers to be 1000 three values for the modulation format parameters M, K, i.e.4, 16 and 64.similarly we have assumed the following parameters α=9,β=5,ρ=0.9 for weak and α=2,β=2 ,ρ=0.95 for strong turbulence conditions. Again we have set the other parameters as follows . Duration of OFDM symbol is assumed to be 1 ms and the corresponding operating wavelength is 1550 nm . The average transmitted optical power P_{av} and the total atmospheric losses L_{tot} is assumed to be 20 dBm and -20 dB respectively. Moreover the detector responsivity is equal to 0.9 A/W and the load resistor is 50 Ω . The relative intensity noise R_{IN} = -130dB/Hz while the absolute temperature and the parameter a_3 are 300K and 9×10^{-4} respectively.we consider an aperture radius r=10 cm. The β is chosen carefully to be natural or whole number . This is done to simplify the calculations .

âĂć: In Fig 3 we have compared BER performance of different orders of modulation in two different atmospheric turbulence conditions for QAM type of modulation . It is evident that as the order of modulation (M) for QAM increases the BER performance deteriorates. Moreover the BER performance is better in weak turbulent conditions where the parameters are α=9,β=5 ,ρ=0.9. than in strong turbulence conditions where α=2,β=2 ,ρ=0.95. The results thus obtained are unique.

âĂć: Fig. 4 narrates that the BER performance of K-PSK OFDM system, for the different orders i.e K=4, 16 and 64. The results are plotted for weak and strong atmospheric turbulent regimes. From the Fig. 4, we can observe that as the order of modulation (K) increases, the BER performance degrades. As we have expected, the better BER performance is achieved for weak atmospheric turbulence.

âĂć: Fig 5 we have compared BER performance for both QAM and PSK type of modulation . Clearly we can observe that QAM has better performance then compared to PSK , for the same order of modulation. This is attributed by the fact that for the same order of modulation , the Euclidean distance in M-QAM type of modulation between the corresponding signal points is more than that of K-PSK

âĂć: Fig6 we have analysed the change in BER pattern for varying normalized jitter and normalized beam width for OFDM-QAM Ro-FSO links . As we observe the BER performance of the system is highly degraded when the normalized jitter.

âĂć: The BER performance is analysed in terms of normalized jitter(σ_s/r) and normalized beam width (w_z/r) is illustrated in Fig. 7. The BER is 5×10^{-2} when the normalized jitter is low and BER performance rises to 2×10^{-1} as normalized jitter becomes high . When the value of σ_s/r is small enough the pointing error effects reduces and the fluctuations of the optical signal originates only from

$$p_{b,m-QAM,AV} = \frac{2^{a-1}g^2AB^{\alpha/2}(1-\sqrt{M^{-1}})}{4\pi\sqrt{\pi}}\frac{1}{N\log_2 M}\sum_{n=0}^{N-1}\sum_{K=1}^{\beta}a_kB^{k/2}2^kG_{7,4}^{2,6}\left(24X\,\middle|\,\begin{matrix}\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2},1\\0,\frac{1}{2},\frac{-g^2}{2},\frac{1-g^2}{2}\end{matrix}\right) \tag{23}$$
$$-\left(\frac{O}{72}\right)\sum_{n=0}^{N-1}\sum_{K=1}^{\beta}a_kB^{k/2}2^kG_{6,3}^{1,6}\left(48X\,\middle|\,\begin{matrix}Y\\Z\end{matrix}\right)-\left(\frac{0}{8}\right)\sum_{n=0}^{N-1}\sum_{K=1}^{\beta}a_kB^{k/2}2^kG_{6,3}^{1,6}\left(64X\,\middle|\,\begin{matrix}Y\\Z\end{matrix}\right)$$
$$-\left(\frac{O}{12}\right)\sum_{n=0}^{N-1}\sum_{K=1}^{\beta}a_kB^{k/2}2^kG_{6,3}^{1,6}\left(56X\,\middle|\,\begin{matrix}Y\\Z\end{matrix}\right)$$

Where
X = $[CNDR_n(I)]_{AV}\,{A_0}^2B^2\frac{1}{(M-1)}$

Where
Y = $\left[\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2}\right]$

Where
Z = $\left[0,\frac{-g^2}{2},\frac{1-g^2}{2}\right]$

Where
O = $\left[\frac{2^{a-1}g^2AB^{\alpha/2}(1-\sqrt{M^{-1}})^2}{4\pi}\frac{1}{Nlog_2M}\right]$

$$P_{b,k-psk} = \frac{g^2A2^{\alpha-2}B^{\frac{\alpha}{2}}}{4N\log_2K\left(\pi^{\frac{3}{2}}\right)}\sum_{n=0}^{N-1}\sum_{K=1}^{\beta}a_kB^{k/2}2^k\times G_{7,4}^{2,6}\left(16\sin^2(\frac{\pi}{k}){A_0}^2B^2\left[CNDR_{n,l}\right]_{AV}\Big|_{0,\frac{1}{2},\frac{-g^2}{2},\frac{1-g^2}{2}}^{\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2},1}\right) \tag{26}$$

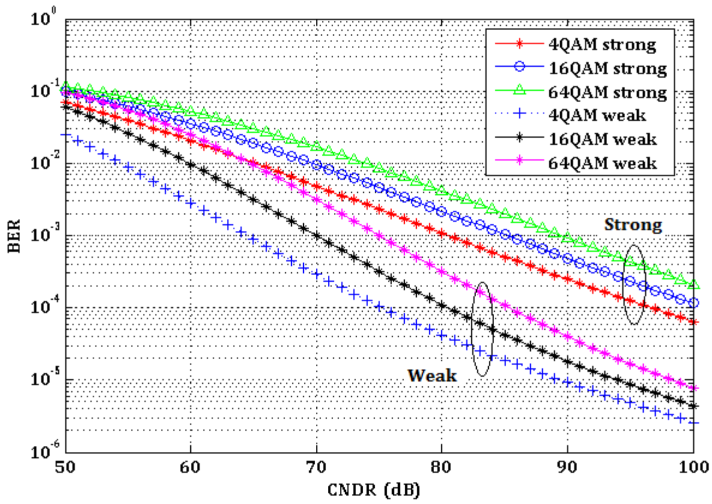

Fig. 3: Comparison of BER in terms of CNDR for QAM over weak and strong turbulence channel.

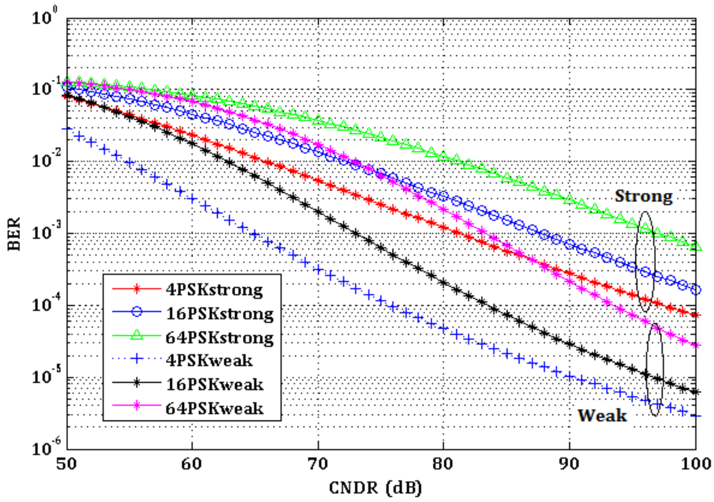

Fig. 4: Comparison of BER in terms of CNDR for PSK over weak and strong turbulence channel

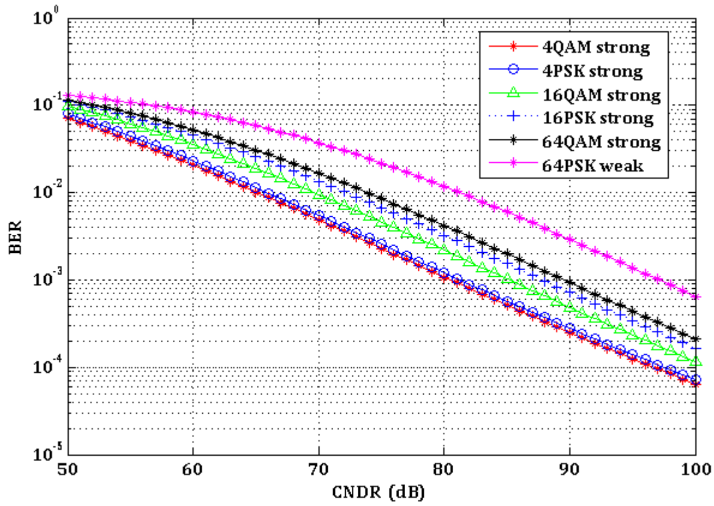

Fig. 5: Comparison of BER against CNDR for QAM and PSK over strong atmospheric turbulence

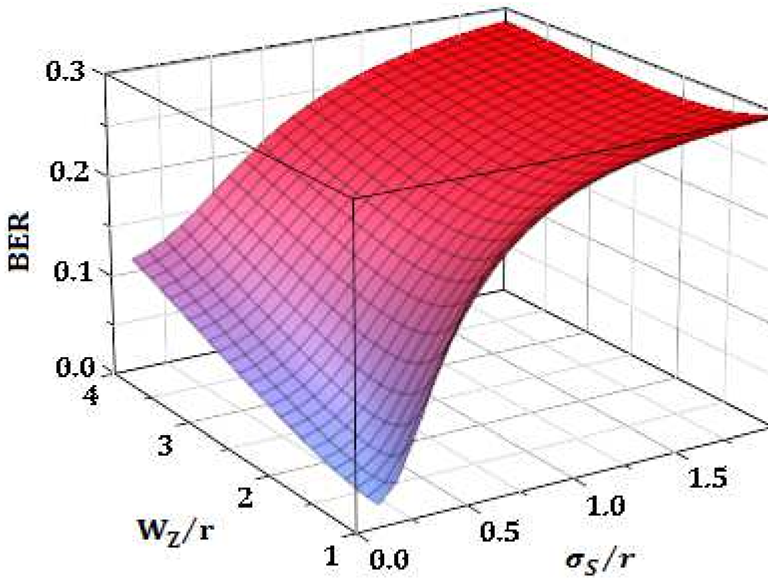

Fig. 6: BER as a function of Beam Radius and Jitter Standard Deviation with pointing error for QAM OFDM system.

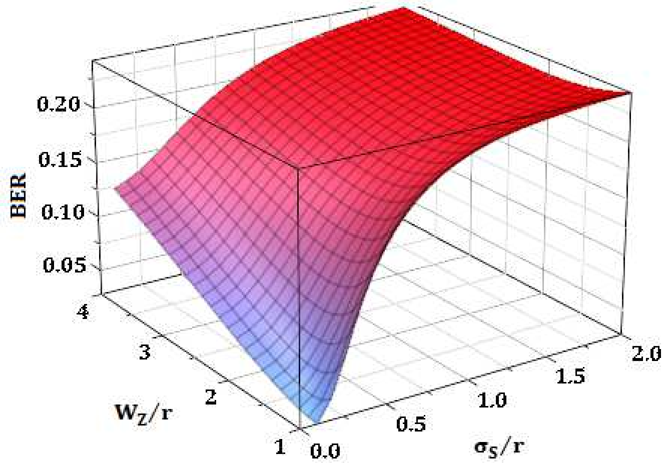

Fig. 7: BER as a function of Beam Radius and Jitter Standard Deviation with pointing error for PSK OFDM system.

the Malaga distribution turbulence . Moreover it is observed the performance is better with tapered normalized beam-width W_Z/a. This 3D plot can be utilized to find the optimum beam-width that achieves minimum BER for given normalized jitter.

6 conclusion

In this paper, we have derived the novel closed form expressions for OFDM based Ro-FSO system M-turbulence channel with pointing errors. The results are plotted and compared for M-QAM and K-PSK OFDM systems. The impact of pointing errors and the effects of atmospheric turbulence for weak and strong regimes are analysed. Also, the performance of the OFDM based RoFSO system is analysed for various orders of QAM and PSK with respect to data rate and error rate respectively. The effect of normalized beam width and normalized jitter on the performance of RoFSO system is studied using 3 D plots.

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7 References

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