ANALYTICAL PERFORMANCE EVALUATION OF A MIMO FSO COMMUNICATION SYSTEM WITH DIRECT DETECTION OPTICAL RECEIVERS UNDER TURBULENT CONDITION

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ABSTRACT

MIMO FSO correspondence is examined as of late to build up a hearty correspondence connects within the sight of atmospheric turbulence. In this paper an analytical approach is developed to assess the impact of atmospheric turbulence on BER performance of a MIMO FSO communication system with Q-ary Pulse Position Modulation (QPPM). Examination is exhibited to discover flag to clamor proportion at the yield of an immediate location collector with optical power modulator under strong turbulent condition which is modeled as gamma-gamma distribution. The outcomes demonstrate that the BER performance is emphatically debased because of the impact of atmospheric turbulence. In any case, the execution can be enhanced by expanding the quantity of transmitters, beneficiaries and request of Q in PPM. Results demonstrate that the FSO MIMO framework with M=8, N=4 Q=4 gives the 22 dB improvement at BER of 10^{-9}.

KEYWORDS

Direct detection (DD) receiver, free space optical (FSO) communication, gamma-gamma distribution, multiple input multiple output (MIMO), pulse position modulation (PPM).

1. INTRODUCTION

Free space optical (FSO) communication is accepting developing consideration in recent days because of its advantages including higher information transmission rates, more prominent data transfer capacity; bring down power utilization and better security over radio frequency (RF) interchanges [1]. Notwithstanding the real focal points, its far reaching use has been hampered by climatic disturbance prompted blurring [2]. Along these lines, diverse techniques have been acquainted with diminish the blurring impact on FSO communication framework. As a promising arrangement, the utilization of the multi-laser multi-indicator (MLMD) idea has been accounted for in ref. [3-5].

Again, by employing proper modulation technique may helps to improve the performance under turbulent conditions [6-7]. In this view, different modulation techniques are employed in FSO communication system but well reputed modulation techniques are OOK, BPSK, PPM, etc. The pulse position modulation (PPM) is one of the modulation techniques which have the interesting advantage of being average energy efficient [6].

In this paper, we provide an analytical approach to assess the execution of a MIMO FSO communication system considering the effect of atmospheric turbulence with Q-ary PP modulation scheme. The execution results are assessed regarding bit-error rate (BER), number of transmitter and receiver and power penalty suffered by the system due to the effect of turbulence at a given BER. Performances are evaluated in the presence of background radiation at the output of a direct detection receiver with optical intensity modulator under strong atmospheric turbulence which is modeled as gamma-gamma distribution. Results show that the BER performance is strongly degraded due to the effect of atmospheric turbulence and the performance can be improved by increasing the number of transmitters and receivers.

2. SYSTEM MODEL

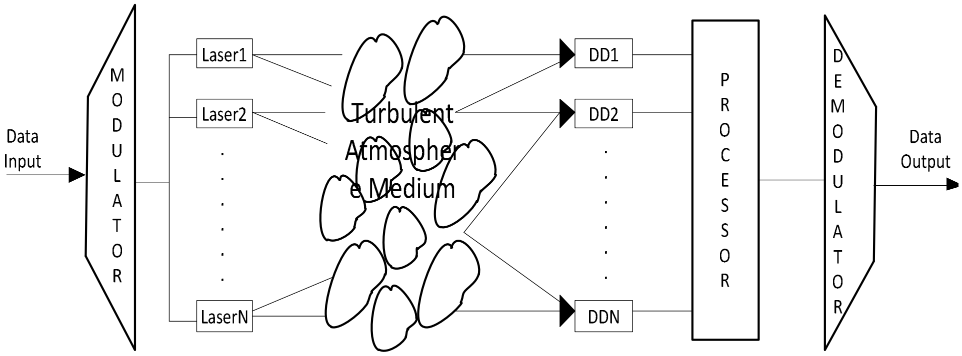

Fig. 1: Block diagram of MIMO FSO system with the effect of strong atmospheric turbulence.

A free-space optical communication system is composed of three basic parts: a transmitter, the propagation channel and a receiver. Fig 1 shows the block diagram of the free space optical MIMO system. In the system, ***M*** lasers, intensity-modulated by input symbols, all point toward a distant array of *N* photodetectors. Every laser beam width is sufficiently wide to illuminate the entire photodetector array. The ***MN*** laser-photodetector path pairs may experience fading and the amplitude of the path gain from laser ***m*** to detector ***n*** is designated as a_{nm}.

The input data is transmitted to the modulator first then modulated in QPP modulator. The modulated signal then transmitted to the optical intensity modulator where electro optic modulation occurs with the laser output. Then the EOIM signal transmitted to through atmospheric turbulent channel. At the receiving end the optical signal first received through the photodetector, then the received signal first amplified and passes through the electro optic demodulator to find the electrical signal output. Now the electrical signal passes through the QPPM demodulator to achieve the original data output.

3. FADING MODEL

The dependability of the correspondence connection can be resolved on the off chance that we utilize a decent probabilistic model for the turbulence. Gamma-gamma is the most suitable fading model that is design for high-performance communication link under strong turbulent condition. Al-Habash et al. [8] proposed a statistical model that factorizes the irradiance as the product of two independent random processes each with a Gamma PDF. The PDF of the intensity fluctuation is given by [9]:

$$p(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta)}{2}-1} K_{(\alpha-\beta)}(2\sqrt{\alpha\beta I}), I > 0 \tag{1}$$

I is the signal intensity, Γ(.) is the gamma function, and $\boldsymbol{K_{\alpha\beta}}$ is the modified Bessel function of the second kind and order **αβ. α** and **β** are PDF parameters describing the scintillation experienced by plane waves, and in the case of zero-inner scale are given by [9]

$$\alpha = \frac{1}{\exp\left[\frac{0.49\sigma_R^2}{(1+0.18d^2+0.56\sigma_R^{12/5})^{7/6}}\right]-1} \tag{2}$$

$$\beta = \frac{1}{\exp\left[\frac{0.51\sigma_R^2\left(1+0.69\sigma_R^{12/5}\right)^{-5/6}}{(1+0.9d^2+0.62d^2\sigma_R^{12/5})^{5/6}}\right]-1} \tag{3}$$

where $d=(kD^2/4L)^{1/2}$ and the diameter of the receiver collecting lens aperture is given by D.

This model is mathematically tractable and it is characterized by the Rytov variance σ_R^2 which is given by [10]:

$$\sigma_R^2 = 1.23C_n^2 k^{7/6} L^{11/6} \tag{4}$$

C_n^2 is the refractive index structure parameter which we assume to be constant for horizontal paths, $k = 2\pi/\lambda$ is the optical wave number and L is propagation distance.

4. THEORETICAL ANALYSIS

Let $m(t)$ represents the message at the modulator. Then $m(t)$ can be given as:

$$m(t) = \sum_k a_k p(t - kT_s) \tag{5}$$

where $T_s = N\,T_b$, T_b represents the bit period while T_s represents the symbol period.

At the transmitting end, the signals are described by the binary data bits are converted into a stream of pulses corresponding to QPPM symbol described below:

$$\begin{aligned}
e_0(t) &= A = \sqrt{2P_T}, 0 \le t \le \frac{T_b}{4} \quad '00' \\
e_1(t) &= A = \sqrt{2P_T}, \frac{T_b}{4} \le t \le \frac{T_b}{2} \quad '01' \\
e_2(t) &= A = \sqrt{2P_T}, \frac{T_b}{2} \le t \le \frac{3T_b}{4} \quad '10' \\
e_3(t) &= A = \sqrt{2P_T}, \frac{3T_b}{4} \le t \le T_b \quad '11'
\end{aligned} \tag{6}$$

The electric field output of single intensity modulator is given by:

$$e_{opt}(t) = \sqrt{2P_T}\,\left[1 + k_a.e(t)\right] e^{j\omega_c t} \tag{7}$$

where P_T represents the transmitted laser power and k_a is the intensity modulation index.

The overall electric field output of M number of intensity modulator is given by:

$$e_{opt}(t) = \sum_{m=1}^{M} \sqrt{2P_{T_m}}\,\left[1 + k_a.e(t)\right] e_m{}^{j\omega_c t} \tag{8}$$

Now the modulated signal is then transmitted through the FSO channel.

At the receiving end the signals are received by N number of receivers. So the received electrical signal can be written as:

$$r_{mn}(t) = \sum_{n=1}^{N}\sum_{m=1}^{M} \sqrt{2P_{R_m}.I_{mn}}\,\left[1 + k_a e(t)\right] e_m{}^{j\omega_c t} + n_b(t) \tag{9}$$

where $\boldsymbol{P_R = P_T} e^{-\alpha L}$ is the received optical power, α represents the atmospheric channel attenuation coefficient, L is the distance of the optical link, the background radiation is n_b and the turbulence induced fading is represented by I.

The output current of the photo detector can be expressed as:

$$\begin{aligned}
i_d(t) &= R_d \left| r_{mn}(t) \right|^2 \\
&= R_d \left| \sum_{n=1}^{N}\sum_{m=1}^{M} \sqrt{2P_{R_m}.I_{mn}}\,\left[1 + k_a e(t)\right] e_m{}^{j\omega_c t} + n_b(t) \right|^2
\end{aligned} \tag{10}$$

The output power is given by:

$$S_{MN}(I)=R_d\left|\frac{\left[\sum_{n=1}^{N}\sum_{m=1}^{M}\sqrt{2P_{R_m}.I}\left[1+k_a e(t)\right]e_m{}^{j\omega_c t}e^{\frac{M}{N}}\right]}{2}\right|^2 \tag{11}$$

The noise power produced by the band pass filter can be expressed as:

$$\begin{aligned}\sigma_n{}^2 &= \sigma_{sh\_sig}{}^2+\sigma_{th}{}^2\\ &= 2eB[I_s]+\frac{4kT}{R_L}B\end{aligned} \tag{12}$$

Now the SNR with the fading effect introduced by the turbulence can be expressed as:

$$S_{mn}(I)=R_d\left|\frac{\left[\sum_{n=1}^{N}\sum_{m=1}^{M}\sqrt{2P_{R_{mn}}.I_{mn}}\left[1+k_a\sum_{k}a_k p(t-kT_b)\right]e_{mn}{}^{j\omega_c t}\right]}{2}\right|^2 \tag{13}$$

Without turbulence and in the presence of AWGN only, the BER is given by:

$$BER_{MN}(I)=\frac{1}{2}erfc\left(\frac{\sqrt{SNR_{MN}(I)}}{Q\big/Q-1}\right) \tag{14}$$

The pdf of I_{mn} can be obtained by *M*.(*N-1*) fold convolution of the pdf of the input SNR as:

$$p(I_{mn})=p(I_{11})\otimes p(I_{21})\otimes p(I_{12})\otimes p(I_{31})\otimes p(I_{13})\otimes..........\otimes p(I_{M(N-1)}) \tag{15}$$

Finally, the average BER is given by:

$$BER=\int BER_{MN}(I).p(I)dI \tag{16}$$

5. RESULTS AND DISCUSSION

Following the analytical approach presented in section IV, we evaluate the bit error rate performance result of a MIMO FSO link with Q-ary PPM and direct detection scheme.

Table 1: System Parameters used for computation

Symbol	Parameter Name	Value
B_r	Bit Rate	10 Gbps
M	No. of transmitter	1~8
N	No. of receiver	1~8
L	Link Distance	2500 m
C	Channel Type	Gamma-gamma
λ	Laser wavelength	1550nm
R_d	PIN photo detector Responsivity	0.85
k_a	Optical modulation index	1
L	Link distance	500 m-3.6 km
P_r	Received power	-30 to -10 dBm
C_n^2 ,	Refractive index structure Parameter	$10^{-14}m^{-2/3}$

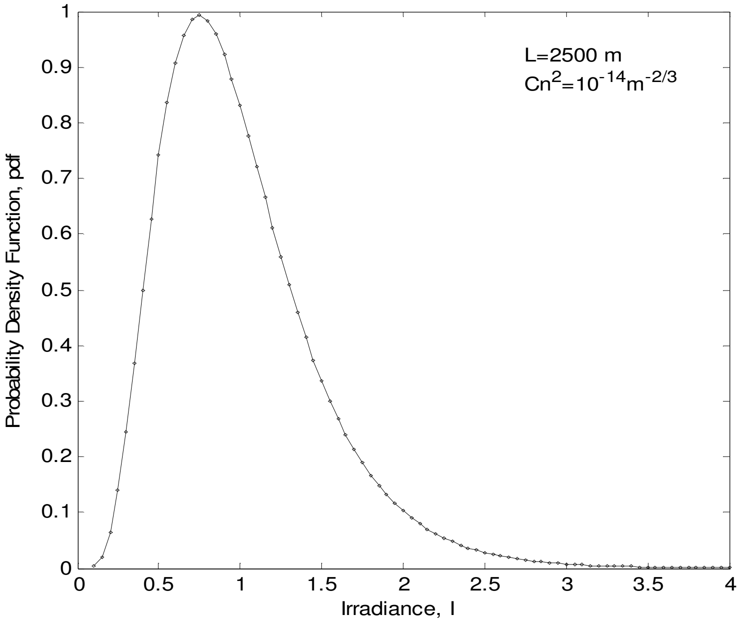

Fig. 2: Plots of probability density function versus irradiance for gamma-gamma distribution.

The plots of the probability density function are shown in Fig. 2 for gamma-gamma distribution for a link distance of 2500 m and refractive index structure parameter, C_n^2 is $10^{-14}m^{-2/3}$. In particular, notice the gamma-gamma model has a much higher density in the high amplitude region, leading to a more severe impact on system performance.

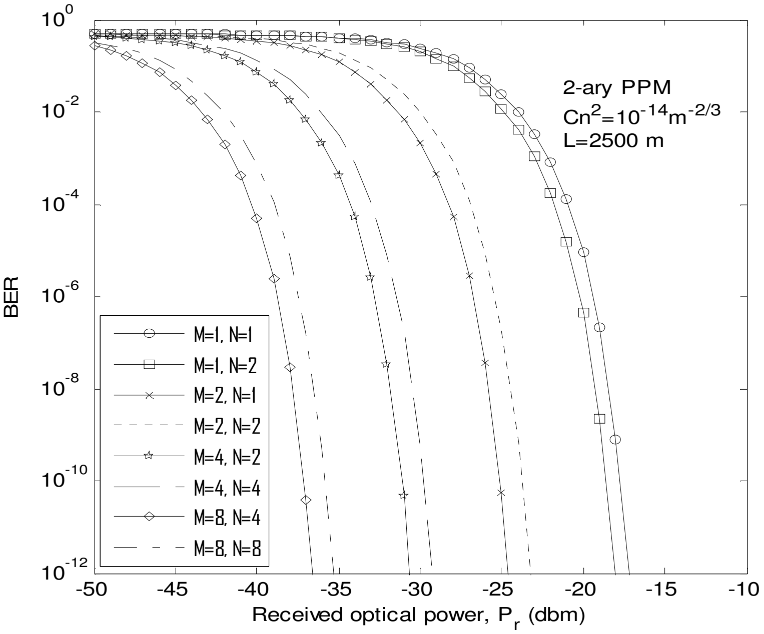

Fig. 3: Plots of BER versus received power for FSO communication system with 2-PP modulation mapping with variable transmitter and receiver.

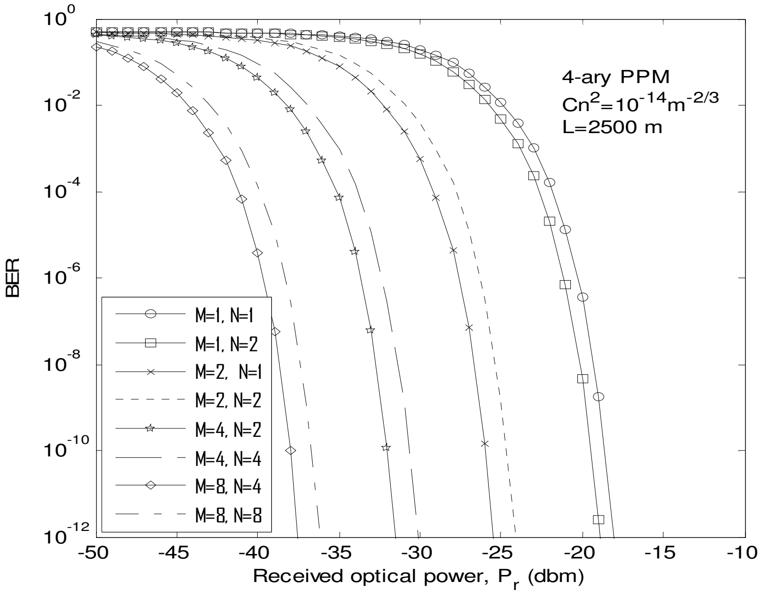

Fig. 4: Plots of BER versus received power for FSO communication system with 4-PP modulation mapping with variable transmitter and receiver.

Fig. 3, 4 and 5 includes the plots of BER versus optical received power for FSO communication system with 2, 4 and 8-ary PPM for variable combination of transmitters and receivers. From the close analysis of the figures it is clear that the FSO MIMO system with *M*=8, *N*=4 *Q*=2 provides the 17 dB improvement at BER of 10^{-9} whereas the FSO MIMO system with *M*=8, *N*=4 *Q*=4 provides the 19 dB improvement at BER of 10^{-9}. Again the MIMO processing (*M*=2, *N*=4,*Q*=8) provides the 18 dB improvement at BER of $10^{-9.}$ Overall various combinations are performed to obtain maximum gain but the excellent improvement found with *M*=8, *N*=4 *Q*=4.

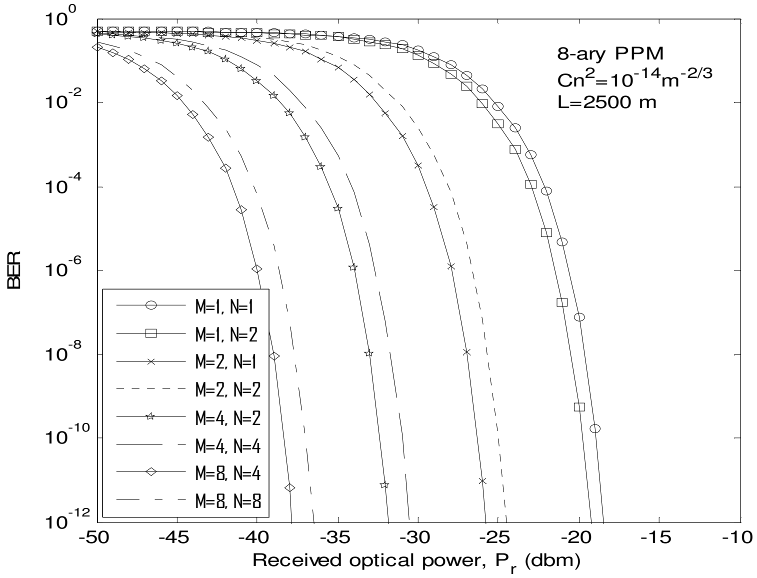

Fig. 5: Plots of BER versus received power for FSO communication system with 8-ary PP modulation mapping with variable transmitter and receiver.

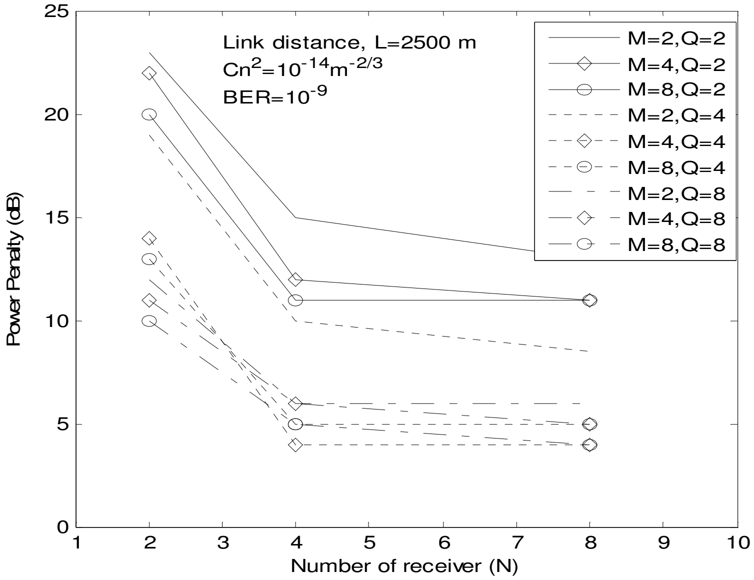

Fig. 6: Plots of power penalty for MIMO FSO communication system under strong turbulence strength with variable number of transmitter and receiver.

Plots of power penalty versus variable combination of transmitters and receivers with the order of Q in MIMO FSO communication system under strong atmospheric turbulence are shown in Fig. 6.It is found that the system with M=2, N=4 Q=2 provides 21 dB improvement at BER of 10^{-9} whereas the system with M=2, N=4 Q=4 provides the 22 dB improvement for same.

6. CONCLUSIONS

A novel analytical approach is displayed to assess the execution of MIMO FSO communication link under solid climatic disturbance which is demonstrated as gamma-gamma distribution. Investigations are reached out to decide the key ideas and difficulties in structuring and understanding the execution furthest reaches of a free space optical communication framework under multiple input multiple out framework. It is seen that for comparative framework design, the BER execution and power penalty because of climatic choppiness are enhanced with increment in number of transmitters, receivers and order of Q in PPM. In general the framework configuration is helpful to set up an elite correspondence connect.

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