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Modelling and Characterization of Subcarrier Intensity Modulation Based Free Space Optical Communication

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Abstract - **This paper is an investigation to model and characterize subcarrier intensity modulation employing *M*-ary phase shift keying and rectangular quadrature amplitude modulation for optical wireless communication over different turbulence channels. Atmospheric turbulence results in many effects causing fluctuation in the received optical power .The popular models for describing atmospheric turbulence are the lognormal distribution (for weak turbulence induced irradiance fluctuation), the *K*- distribution (for strong turbulence induced irradiance fluctuation), the negative exponential distribution (for irradiance fluctuation in saturated turbulence conditions), and the Gamma-Gamma distribution (for describing irradiance fluctuation over a wide range of turbulence regimes from weak to strong turbulence). The adaptive schemes offer efficient utilization of optical wireless communication channel capacity by adapting the modulation order according to the received signal-to-noise ratio and a pre-defined target bit-error rate requirement. The improved spectral efficiency can be achieved by the adaptive systems without increasing the transmitter power.**

Keywords: **Free-space optical communications, atmospheric turbulence, gamma-gamma distribution, intensity modulation**

I. INTRODUCTION

Free Space Optical Communication FSO involves the transfer of data/information between two points using optical radiation as the carrier signal through unguided channels. The data to be transported could be modulated on the intensity, phase or frequency of the optical carrier. An FSO link is essentially based on line-of sight (LOS), thus to ensure a successful exchange of information requires that both the transmitter and the receiver directly "see" one another without any obstruction in their path. The unguided channels could be any, or a combination, of space, sea-water, or atmosphere.

Free Space Optics (FSO) communications has received considerable attention recently as an attractive solution for high–rate last–mile terrestrial communications. The attractive features of FSO is more than the traditional RF includes Huge modulation bandwidth, Narrow beam size, Unlicensed spectrum, ease of deployment, license–free operation, high security, and high data rates. The BER analysis for both OOK and subcarrier BPSK intensity modulation [1] shows that the subcarrier PSK intensity modulation is superior to OOK intensity modulation in the presence of atmospheric turbulence. Several fading mitigation techniques have been proposed for OWC systems. In [2], Uysal *et al.* proposed error control coding in conjunction with interleaving to mitigate strong turbulence fading. However, due to slow fading nature of OWC channels, such system requires large interleavers that are impractical to implement. Zhu and Kahn proposed maximum-likelihood sequence detection (MLSD) technique for lognormal turbulence channels [3]. Due to computational complexity of the proposed technique, only suboptimal MLSD techniques can be used in practice. Spatial diversity using multiple apertures for transmission and/or reception offers significant bit-error rate (BER) performance improvement [4]. However, increasing number of apertures also increases implementation cost and complexity, and effectiveness of spatial diversity is also restricted by the spatial correlation among multiple apertures.

Adaptive transmission technique is a promising technique which takes advantage of time-varying nature of channel by varying basic transmission parameters according to the channel fading states. This technique allows higher data rate transmission under the favourable channel conditions, and it achieves smooth reduction of data rate when responding to channel degradation. Such a system provides higher spectral efficiency without increasing transmitted power or sacrificing BER requirements. Adaptive transmission technique for OWC systems was first studied in [5].

A big challenge in optical wireless communications is to mitigate signal scintillation introduced by atmospheric turbulence. Turbulence is caused by inhomogeneities of both temperature and pressure in the atmosphere [6], and is responsible for the refractive index variation of the air. Turbulence causes amplitude and phase fluctuations in the received optical beam. Such fluctuations deteriorate signal intensity at the receiver, increase bit error rate (BER), and can break the communication link. Signal scintillation caused by atmospheric turbulence severely degrades the performance of optical communication systems [7], [8]. It severely limits the applications of optical wireless communications. Convolutional codes are discussed for optical communication through atmospheric turbulence channels. Interleaving is employed to overcome memory effect in atmospheric turbulence [9] channels. In order to evaluate the impact of atmospheric turbulence and the effectiveness of corresponding countermeasures, accurate models for the fading distribution [10] are important. While the lognormal distribution is often used to model weak turbulence conditions, the Gamma–Gamma distribution [11], [12] has recently received considerable attention because of its excellent fit with measurement data for a wide range of turbulence conditions (weak to strong).

This work investigate the performance of non-adaptive and adaptive SIM systems over the Gamma-Gamma turbulence channels. Here derive closed-form series solutions for the exact BER of non-adaptive and adaptive SIM systems employing *M*-PSK and rectangular QAM (R-QAM) modulations. Novel closed-form series solution for the ASE is also derived.

The remainder of the paper is organized as follows. Section II presents the system and channel models. Section III studies Subcarrier Intensity Modulation systems employing *M*-PSK and R-QAM. Adaptive modulation strategies discussed out in Section IV. Section V describes about performance evaluation. Section VI shows the algoritham. Numerical results and discussions are presented in Section VII. Finally, Section VIII makes some concluding remarks.

II. SYSTEM AND CHANNEL MODELS

A. System Model

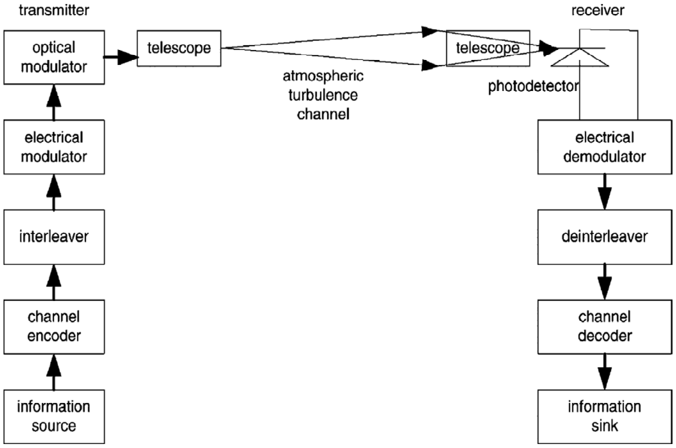


Fig.1. Block diagram of an optical communication system through atmospheric turbulence channels.

Fig. 1 shows the block diagram of an optical communication system through the atmosphere. The information generated by a source is encoded by an encoder, interleaved, and modulated into an electrical waveform by an electrical modulator. In the optical modulator, the intensity of a light source is modulated by the output signal of the electrical modulator. The light source is a laser, characterized by its wavelength, power, and beam divergence angle. There is a collimator or telescope in the transmitter to determine the direction and the size of the laser beam. The receiver consists of an optical front end, a photodetector, a demodulator, a deinterleaver, and a decoder. The optical front end contains lenses focusing the received optical field onto a photodetector. The photodetector converts the received optical field to an electronic signal, which is demodulated. The demodulator output signal is deinterleaved and decoded. The decoded bits are fed into an information sink.

B. Atmospheric Turbulence Models

Statistical model of atmospheric turbulence is well investigated in the literature. Popular models for describing atmospheric turbulence are the lognormal distribution (for weak turbulence induced irradiance fluctuation), the *K*-distribution (for strong turbulence induced irradiance fluctuation), the negative exponential distribution (for irradiance fluctuation in saturated turbulence conditions), and the Gamma-Gamma distribution (for describing irradiance fluctuation over a wide range of turbulence regimes from weak to strong turbulence).

C .The Gamma-Gamma Turbulence Model

This model is based on the modulation process where the fluctuation of light radiation traversing a turbulent atmosphere is assumed to consist of small scale (scattering) and large scale (refraction) effects. Large scale fluctuations on the other hand are generated by turbulent eddies larger than that of the first Fresnel zone or the scattering disk whichever is larger. The small scale eddies are assumed to be modulated by the large scale eddies. Consequently, the normalised received irradiance I is defined as the product of two statistically independent random processes Ix and Iy:

$$I = IxIy \qquad (1)$$

Ix and Iy arise from the large scale and small scale turbulent eddies respectively and are both proposed to obey the gamma distribution by Andrews et al.

III. SUBCARRIER INTENSITY MODULATION

In an OWC SIM link, an RF signal, $s(t)$, pre-modulated with data source, is used to modulate the irradiance of a continuous wave optical beam at the laser transmitter after being properly biased. For an atmospheric turbulence channel, the received photocurrent after direct detection using photodetector can be expressed as

$$ir(t) = RI(t)A[1 + \xi s(t)] + n(t) \qquad (2)$$

where ξ is the modulation index satisfying the condition $-1 \leq \xi s(t) \leq 1$ in order to avoid overmodulation. In (1), R is the responsivity of phtotodetector, $I(t)$ is assumed to be a stationary random process for the received irradiance fluctuation caused by atmospheric turbulence, A is the area of photodetector, and $n(t)$ is the noise term, which is assumed to be caused by background radiation (i.e., ambient light) and/or thermal noise, and it is modeled as an additive white Gaussian noise (AWGN) process with variance σ_n^2 .

The information data sequence is converted into an electrical signal

$$z(u,t) = \sum_{i=-\infty}^{\infty} d_i\, g(t - iT_s) \qquad (3)$$

Where $di \in \{1,-1\}$ is the signal level for the ith data symbol, $g(t)$ is the shaping pulse, and Ts is the symbol time. This electrical signal drives a laser. The intensity of the transmitted laser beam can be written as

$$s(t) = 1 + \sum_{i=-\infty}^{\infty} d_i\, g(t - iT_s) \qquad (4)$$

The received intensity of the optical beam can be written as

$$\mathrm{P}(t) = \frac{P}{2}\mathrm{A}(u,t) + \sum_{i=-\infty}^{\infty} \frac{P}{2}\, \mathrm{A}(u,t)\, d_i\, g(t - iT_s) \qquad (5)$$

Where P is the maximum received intensity when there is no turbulence. Hence, the received electrical signal is

$$r(t) = \mathrm{K}\{A(u,t) + \sum_{i=-\infty}^{\infty} \mathrm{A}(u,t) d_i\, \mathrm{g}(t - iT_s)\} + n(t) \qquad (6)$$

Where K is a constant determined by the received optical intensity and the photoelectric conversion efficiency, $n(t)$ is additive white Gaussian noise (AWGN).

IV. ADAPTIVE MODULATION

Adaptive modulation strategy improves the spectral efficiency of FSO systems, without increasing the transmitted average optical power. The main objective of a constant power, variable-rate adaptive transmission technique is to maximize the number of transmitted bits per symbol interval by using the largest possible modulation order while maintaining a pre-defined target BER P_0. In practice, the receiver selects a modulation order from N available choices $\{ M_1, M_2, \ldots M_N \}$, depending on the values of receiver estimated SNR² $\tilde{\gamma}$ and the target BER requirement P_0. Specifically, the range of SNR is divided into N+1 regions, and each region is associated with a modulation order, M_n, according to the following rule for R-QAM based adaptive SIM

$$M = M_n = I_n J_n = 2^n \qquad (7)$$

if $\gamma_n \leq \tilde{\gamma} < \gamma_{n+1}$, $n = 1, 2, \cdots N.$

If n is even $I_n = J_n = 2^{n/2}$,

If n is odd $I_n = 2^{(n+1)/2}$ and $J_n = 2^{(n-1)/2}$

For M-PSK based adaptive SIM system, the rule in (7) is modified to

$$M = M_n = 2^n \qquad (8)$$

if $\mu_n \leq \tilde{\gamma} < \mu_{n+1}$, $n = 1, 2, \ldots N.$

V. PERFORMANCE EVALUATION

A. Achievable Spectral Efficiency

ASE is the information rate that can be transmitted per unit bandwidth. For a constant-power, adaptive discrete rate SIM assuming ideal Nyquist data pulses for each constellation, the ASE is defined as

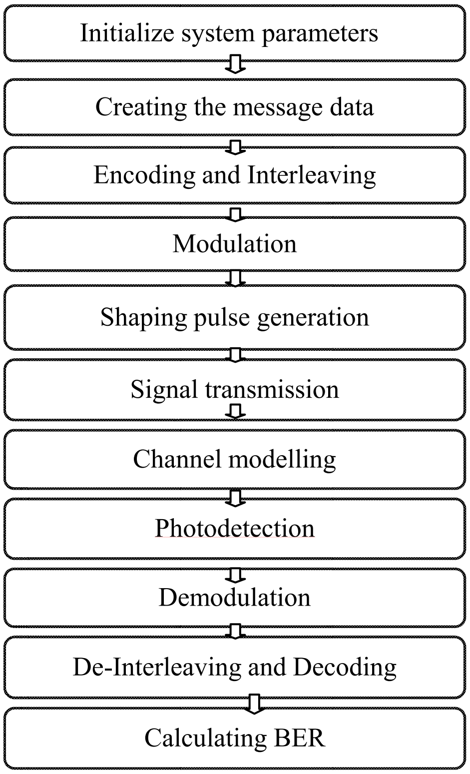
$$S = \frac{R}{W} = \sum_{n=1}^{N} \log_2 M_n \qquad (9)$$

Where R and W represent the transmitted data rate and bandwidth measured in bits/s and in Hz, respectively.

B. Bit Error Rate

The BER of a constant-power, adaptive discrete rate system can be calculated as the ratio of the average number of erroneous bits to the total average number of transmitted bits.

VI. ALGORITHM



At the transmitter end, the RF subcarrier signal is modulated by the data sequence using PSK or QAM. The optical intensity must satisfy the non-negativity constraint, a proper DC bias must be added to the RF electrical signal in order to prevent clipping and distortion in the optical domain. The laser operates in its linear region to avoids over modulation induced clipping.

At the receiver's end, the optical power which is incident on the photodetector is converted into an electrical signal through direct detection. After removing the DC bias and demodulating through an electrical PSK demodulator, the sampled electrical signal obtained at the output of the receiver. Atmospheric turbulence is a major performance degrading factor in FSO systems, which leads to intensity variations of the received optical signals. For its statistical description, various statistical models have been proposed depending on the turbulence strength. In weak turbulence conditions the most widely accepted fading model is the lognormal (LN) one. In this case, the logarithm of the intensity variations is normally distributed. In moderate to strong turbulence conditions, the recently proposed Gamma Gamma (GG) model can be used for the statistical description of turbulence-induced fading. According to this model, intensity fluctuations are considered to be derived from the product of small-scale and large-scale fluctuations, both statistically defined by the Gamma distribution.

Optical wireless systems are severely limited by power and error correcting coding is desired. The atmospheric turbulence is relatively slow compared with the data rates in optical wireless systems. This means the scintillation is almost the same over successive bits, the channel has memory. The decoding algorithms for convolutional codes cannot exploit the channel memory and are not optimum for atmospheric turbulence channels. Having low complexity, convolutional codes and the Viterbi decoding algorithm are efficient to correct random errors. When the instantaneous scintillation is severe, it can cause burst errors and severely degrade decoder performance. Interleaving can be employed interleaving is employed, the bound calculation is simplified and the decoding algorithm is simplified and optimum. Interleaving can help improve system performance in optical communications through relatively slow scintillation channels. Interleaving can help reduce decoder complexity to change the bit sequence in coded information blocks. Although there might be successive bit errors in the received bit stream, a deinterleaver changes the bit sequence of the received information block back, and makes the occurrences of errors random. Block interleaving is assumed to improve the performance of the Viterbi decoder in the presence of atmospheric turbulence. When

significantly and simplify the performance analysis for decoding. Convolutional codes can be employed in optical communications through atmospheric turbulence channels to improve performance and to reduce the transmission power.

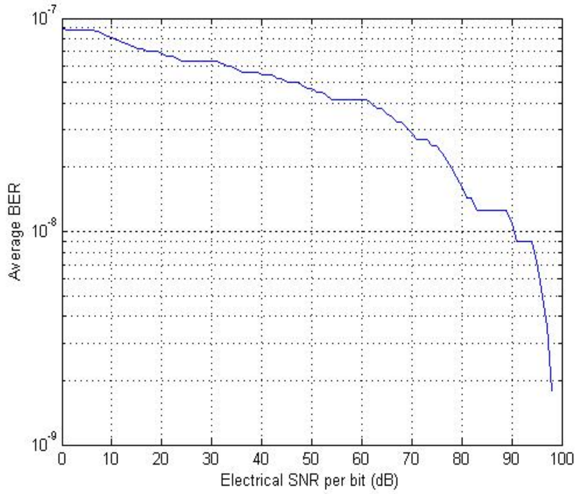


Fig.2. BER of 32-PSK based adaptive SIM over the Gamma-Gamma turbulence channels.

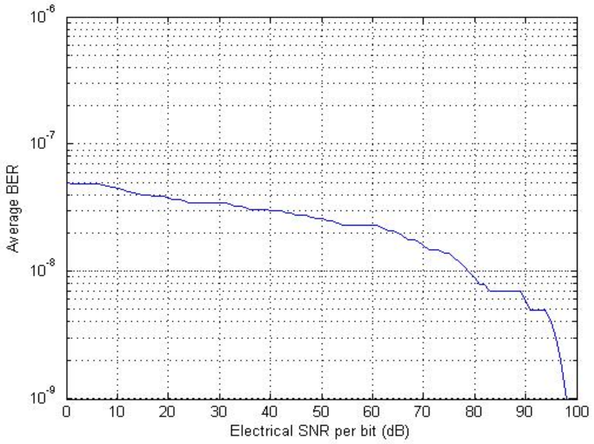


Fig.3. BER of 16-QAM based adaptive SIM over the Gamma-Gamma turbulence channels.

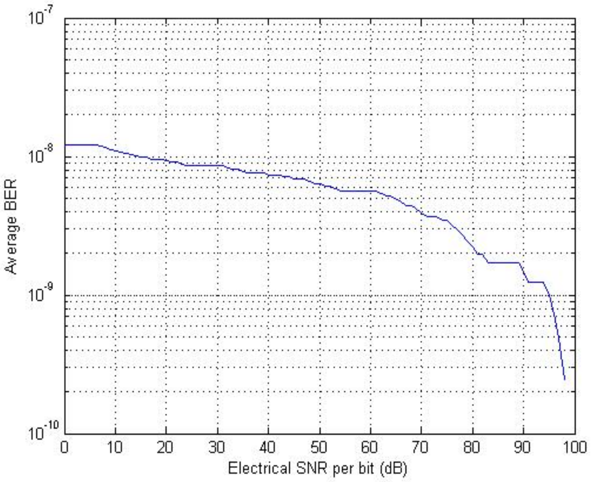


Fig.4. BER of 64-QAM based adaptive SIM over the Gamma-Gamma turbulence channels.

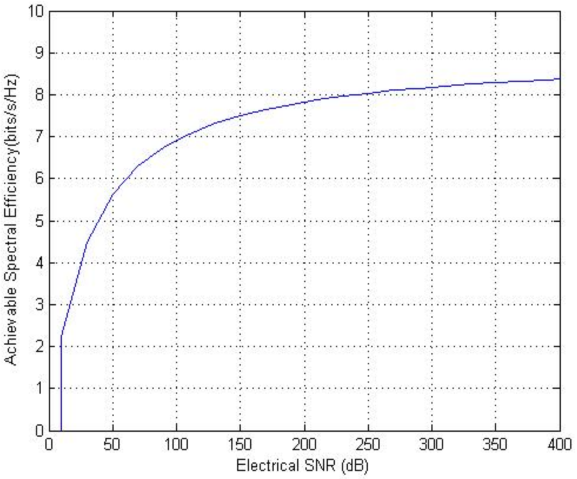


Fig.5. ASE of *M*-PSK based adaptive SIM over the Gamma-Gamma turbulence channels.

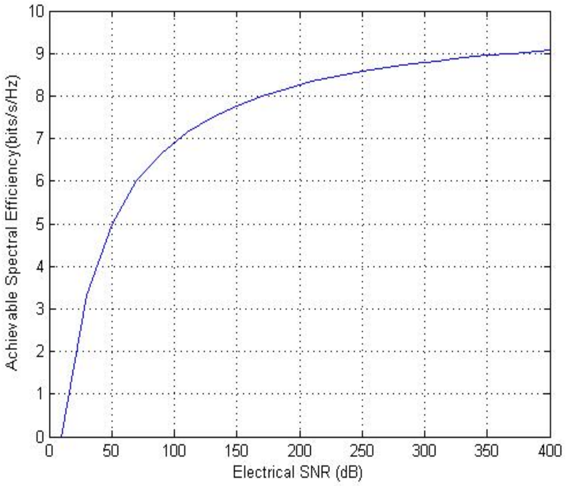


Fig.6. ASE of R-QAM based adaptive SIM over the Gamma-Gamma turbulence channels.

VII. NUMERICAL RESULTS

Fig.2, Fig.3 & Fig 4 presents the BER performance of 32-PSK, 16-QAM, 64-QAM and based adaptive SIM regions over a strong Gamma-Gamma turbulence channel. It is also depicted that the adaptive SIM system always offers a BER less than the target BER, satisfying the basic design goal of the adaptive SIM system. It also see that the R-QAM based adaptive SIM outperforms the *M*-PSK based adaptive SIM in terms of BER performance. This is an expected outcome, because for $M \geq 8$, an R-QAM always offers better BER performance than an *M*-PSK modulation over a fading channel.

From both Fig. 5 and Fig. 6, it is obvious that the adaptive SIM offers large spectral efficiency gain compared to the non -adaptive SIM in the strong turbulence conditions. However, spectral efficiency gain gets reduced as the turbulence strength decreases. This is because at moderate turbulence conditions non-adaptive SIM requires less average SNR to achieve the target BER. Also observed that the adaptive SIM systems can achieve higher ASE in a moderate turbulence condition in the low SNR regimes. This result is expected since for a less faded channel the receiver tends to select a higher order modulation while maintaining the minimum BER requirements. The R-QAM based adaptive SIM provides improved ASE than the *M*-PSK based adaptive SIM for low to moderate SNR values. The SNR thresholds of R-QAM based adaptive SIM are smaller than that of *M*-PSK based adaptive SIM for $M \geq 8$. As a result, receiver of R-QAM based adaptive SIM tends to achieve a larger modulation compared to that of *M*-PSK based modulation. Hence, in low to moderate values of SNR R-QAM based adaptive SIM achieves larger ASE. However, when the SNR is asymptotically large, receivers of both adaptive SIM select the largest available modulation order.

VIII. CONCLUSION

The subcarrier intensity modulation can help to effectively mitigate the signal scintillation caused by atmospheric turbulence in optical communications. Subcarrier intensity modulation and convolutional codes can be employed in optical communications through atmospheric turbulence channels to improve performance and reduce transmission power. Interleaving can help to reduce decoder complexity significantly and simplify performance analysis for decoding. The adaptive SIM offers large spectral efficiency gain compared to the non-adaptive SIM in the strong turbulence conditions. However, spectral efficiency gain gets reduced as the turbulence strength decreases. The R-QAM based adaptive SIM provides improved ASE than the *M*-PSK based adaptive SIM. The results obtained after a series of analysis for both non-adaptive and adaptive SIM systems employing R-QAM and *M*-PSK over the Gamma-Gamma turbulence channels show that the R-QAM based adaptive SIM offers improved ASE and BER performance compared to the *M*-PSK based adaptive SIM.

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REFERENCES

[1] W. O. Popoola and Z. Ghassemlooy, “BPSK subcarrier intensity modulated free-space optical communications in atmospheric turbulence,” IEEE/OSA J. Lightwave Technol., vol. 27, pp. 967–973, Apr. 2009.

[2] M. Uysal, S. M. Navidpur, and J. Li, “Error rate performance of coded free-space optical links over strong turbulence channels,” IEEE Commun. Lett., vol. 8, pp. 635-637, Oct. 2004.

[3] X. Zhu and J. M. Kahn, “Free-space optical communication through atmospheric turbulence channels,” IEEE Trans. Commun., vol. 50, no. 8, pp. 1293–1300, Aug. 2002.

[4] N. D. Chatzidiamantis, A. S. Lioumpas, G. K. Karagiannidis, and S. Arnon, “Adaptive subcarrier PSK intensity modulation in free space optical systems,” IEEE Trans. Commun., vol. 59, pp. 1368–1377, May 2011.

[5] Vu, Dang, Thang, and Pham , “Bit error rate analysis of rectangular QAM/FSO systems using an APD receiver over atmospheric turbulence channels,” IEEE/OSA J. Opt. Commun., vol. 57, pp. 437 - 446, May 2013.

[6] I. B. Djordjevic, “Adaptive modulation and coding for free-space optical channels,” IEEE/OSA J. Optical Commun. Netw., vol. 2, pp. 221–229, May 2010.

[7] Samimi, H, “Optical communication using subcarrier intensity modulation through generalized turbulence channels,” IEEE/OSA J. Opt. Commun., vol. 4, pp. 378 - 381, May 2012.

[8] M. Z. Hassan, X. Song, and J. Cheng, “Subcarrier intensity modulated wireless optical communications with rectangular QAM,” IEEE/OSA J. Opt. Commun. Netw, vol. 6, pp. 522–532, June 2012.

[9] Xuegui Song and Julian Cheng “Optical Communication Using Subcarrier Intensity Modulation in Strong Atmospheric Turbulence,” IEEE. Lightwave Technol., vol. 30, pp. 3484 - 3493, November 2012.

[10] C. K. Datsikas, K. P. Peppas, N. Sagias, and G. Tombras, “Serial free space optical relaying communications over Gamma-Gamma atmospheric turbulence channels,” IEEE/OSA J. Opt. Commun. Netw., vol. 2, pp. 576–586, Aug. 2010.

[11] M. L. B. Riediger, R. Schober, and L. Lampe, “Fast multiple-symbol detection for free-space optical communications,” IEEE Trans. Commun., vol. 57, pp. 1119–1128, Apr. 2009.

[12] E. Bayaki, R. Schober, and R. K. Mallik, “Performance analysis of MIMO free-space optical systems in Gamma-Gamma fading,” IEEE Trans. Commun., vol. 57, pp. 3415–3424, Nov. 2009.

[13] K. P. Peppas and C. K. Datsikas, “Average symbol error probability of general-order rectangular quadrature amplitude modulation of optical wireless communication systems over atmospheric turbulence channels,”IEEE/OSA J. Opt. Commun. Netw., vol. 2, pp. 102–110, Feb. 2010.

[14] W. Popoola, Z. Ghassemlooy, J. Allen, E. Leitgeb, and S. Gao, Freespace optical communication employing subcarrier modulation and spatial diversity in atmospheric turbulence channel,” IET Optoelectron., vol. 2, pp. 16–23, Feb. 2008.

[15] T. A. Tsiftsis, H. G. Sandalidis, G. K. Karagiannidis, and M. Uysal, “Optical wireless links with spatial diversity over strong atmospheric turbulence channels," IEEE Trans. Wireless Commun., vol. 8, no. 2, pp. 951-957, Feb. 2009.