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REGULAR PAPER

Performance of a subcarrier intensity modulated differential phase-shift keying over generalized turbulence channel

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ABSTRACT

Optical wireless communication technologies are finding a greater interest and wider attention within the research community of late. In this paper, we investigate the performance of a free space optical communication system over a generic propagation model called *M*-distributed channel in the presence of atmospheric turbulence. We analyzed a Subcarrier intensity-modulated free-space optical (SIM-FSO) communication system using DPSK and closed form expressions are derived using Meijer *G* function for bit error rate, channel capacity and outage probability for *M*-distribution.

1. Introduction

Recently, optical wireless communication (OWC) has gained elevated research focus as an alternative to the conventional wireless communication technologies because of the potential improvement in delivering high speed data communication over short distance. The key attraction of OWC system is their high bandwidth, easy deployment, cost effectiveness and free from license regulations [1]. OWC technology is found to be suitable for both indoor as well as outdoor applications. The OWC used for outdoor is commonly termed free space optics (FSO). Random intensity fluctuation induced by atmospheric turbulence often degrades the performance of FSO communication system. On off keying (OOK) based intensity modulation/direct detection (IM/DD) is widely employed in FSO system because of its simplicity [2]. However, in order to achieve optimal performance, OOK needs adaptive detection threshold [3] to vary in accordance with the underlying irradiance fluctuation and noise. Also OOK provides poor transmission rate. Hence pulse position modulation (PPM) [4] has been projected as an alternative of OOK modulation as it does not require any adaptive thresholds. There onwards, several statistical models have been proposed to model the behavior of atmospheric turbulence with different modulation schemes [5–11]. Log-normal [12], *K* [13] and the gamma–gamma (GG) distribution [13,14] are the few successful approaches. The log-normal distribution is valid only in weak turbulence and *K* for strong turbulence condition. The gamma–gamma distribution is suitable to model moderate to strong turbulence channels.

A new propagation channel model termed *M* (Malaga) distribution [15] has been adopted recently which unifies most of the previously proposed statistical models and is valid for a wide range of turbulent conditions. Performance analysis of FSO communication systems with OOK modulation over *M*-distributed turbulence channel [16,17] is already analyzed. In [18] error rate performance of binary phase shift keying based subcarrier intensity modulation (BPSK-SIM) is studied using Meijer *G* function. The performance of a FSO communication system with differential phase-shift keying (DPSK) for different atmospheric turbulence channels has already been analyzed [19,20]. A DPSK-SIM FSO link is considered over negative exponential atmospheric turbulence environment and analyzed the performance in [21]. In [22], the bit error rate (BER) and outage probability of DPSK based FSO communication system

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over a M-distributed turbulent channel has been reported. The author used series expansion to express the probability density function (PDF).

2. Paper contributions and organization

In this paper, we generalize the results obtained in [21] for all turbulence regimes and derive a novel and general closed-form analytical expression for the bit error rate, channel capacity and outage probability of the system. Since a generic distribution is used to model the turbulence-induced fading, the derived expressions can be used for analyzing the performance of a DPSK-SIM based FSO system over most of the statistical models proposed so far, including gamma–gamma, K, and negative exponential distributions. To the best of our knowledge, this is the first work that investigate the performance of a DPSK-SIM based FSO system. The remainder of the paper is organized as follows. In Section 2, the M-distributed turbulence channel model is discussed. In Section 3, the performance of a DPSK based SIM-FSO communication system over turbulence channel is presented. Section 4 presents corresponding numerical results. Finally, paper is concluded in Section 5.

3. Channel model

The M-turbulence model is based on a physical model that includes three terms as shown in Fig. 1 [16] (reproduced with the permission from authors): the first term is a line of sight (LOS) component represented by U_L; the second term U_S^C is a component that is scattered by the eddies on the propagation axis and coupled to the LOS contribution and the third term U_S^G is the component due to scattering by off-axis eddies. The average power of the LOS term and the average power of the total scatter components are represented by $\Omega = E[|U_L|^2]$ and $2b_0 = E[|U_S^C|^2 + |U_S^G|^2]$, respectively. In addition, the average power of individual scatter term is given by $E[|U_S^C|^2] = \rho 2b_0$ and $E[|U_S^G|^2] = (1-\rho)2b_0$, for the coupled-to-LOS scattering term and the classic scattering component received by off-axis eddies, respectively, where the parameter ρ represents the amount of scattering power coupled to the LOS component and ranges from 0 to 1.

As derived in [16] the M-pdf of the irradiance I is given by

$$f_I(I) = A\sum_{k=1}^{\beta} a_k I^{\frac{\alpha+k}{2}-1} K_{\alpha-k}\left(2\sqrt{\frac{\alpha\beta I}{\xi_g\beta+\Omega'}}\right) \tag{1}$$

where

$$A = \frac{2\alpha^{\frac{\alpha}{2}}}{\xi_g^{1+\frac{\alpha}{2}}\Gamma(\alpha)}\left(\frac{\xi_g\beta}{\xi_g\beta+\Omega'}\right)^{\beta+\frac{\alpha}{2}} \tag{2}$$

$$a_k = \frac{(\xi_g\beta+\Omega')^{1-\frac{k}{2}}}{(k-1)!}\left(\frac{\Omega'}{\xi_g}\right)^{k-1}\left(\frac{\alpha}{\beta}\right)^{\frac{k}{2}} \tag{3}$$

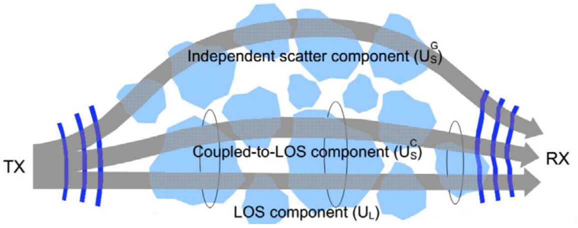

Fig. 1. M-distributed turbulence channels [16].

Here α is a positive parameter related to the effective number of large-scale cells of the scattering process and the parameter β represents the amount of fading and are given by

$$\alpha \approx \left[\exp\left(\frac{0.49\sigma_R^2}{(1+0.18d^2+0.56\sigma_R^{12/15})^{7/6}}\right)-1\right]^{-1} \tag{4}$$

$$\beta \approx \left[\exp\left(\frac{0.51\sigma_R^2(1+0.69\sigma_R^{12/15})^{-5/6}}{(1+0.9d^2+0.62d^2\sigma_R^{12/15})^{5/6}}\right)-1\right]^{-1} \tag{5}$$

where $d=\sqrt{\frac{kD^2}{4L}}$, $k = 2\pi/\lambda$ is the optical wave number, λ is the wavelength, L is the length of optical link and D is the receiver aperture diameter. The Rytov variance σ_R^2 is given as $\sigma_R^2 = 0.5C_n^2 k^{7/6} L^{11/6}$, where C_n^2 is the refractive index structure parameter. Atmospheric turbulence is well characterized by Rytov variance. In [23], the authors have used some experimental data of C_n^2 provided by University of Waseda, Japan to find the typical value of σ_R^2. At night (1 a.m.), C_n^2 parameter registered its minimum value as $7\times10^{-15}\mathrm{m}^{2/3}$. At sunrise (6.45 a.m.), the value is $1.2\times10^{-14}m^{2/3}$ and at midday it is $2.8\times10^{-14}\mathrm{m}^{2/3}$. The corresponding σ_R^2 are 0.32, 0.52 and 1.2, respectively for a length $L = 1$ km, $\lambda = 785$ nm and $D = 100$ mm.

The average power from the coherent contributions is given as $\Omega' = \Omega + \rho 2b_0 + 2\sqrt{\rho 2b_0\Omega}\cos(\phi_A - \phi_B)$. For simplicity, we have denoted $\xi_g = E[|U_S^G|^2] = 2b_0(1-\rho)$. In Eq. (1), $K_\nu(.)$ represents the modified Bessel function of the second kind and order ν. The existing atmospheric distribution models for optical communications can be generated from the M-distribution model and is presented in [16].

The generalized form of Eq. (1) with β being a real number is given in [24] as

$$f_I(I) = A^{(G)}\sum_{k=1}^{\infty} a_k^{(G)} I^{\frac{\alpha+k}{2}-1} K_{\alpha-k}\left(2\sqrt{\frac{\alpha I}{\xi_g}}\right) \tag{6}$$

where

$$A^{(G)} = \frac{2\alpha^{\frac{\alpha}{2}}}{\xi_g^{1+\frac{\alpha}{2}}\Gamma(\alpha)}\left(\frac{\xi_g\beta}{\xi_g\beta+\Omega'}\right)^{\beta+\frac{\alpha}{2}} \tag{7}$$

$$a_k^{(G)} = \frac{(\beta)_{k-1}(\alpha\xi_g)^{\frac{k}{2}}(\Omega')^{k-1}}{[(k-1)!]^2\xi_g^{k-1}(\Omega'+\xi_g\beta)^{k-1}} \tag{8}$$

$(\beta)_k$ represents the Pochhammer symbol.

4. Performance analysis of DPSK based SIM-FSO

In DPSK, the information is encoded as phase differences between successive signal transmissions. In binary DPSK, corresponding to the information bits 0 and 1, the relative phase shifts are 0° and 180° respectively. This indicates that the information bit 1 is transmitted by shifting the carrier phase by 180° relative to the phase in the previous signaling interval, while the information bit 0 by a zero phase shift relative to the previous carrier phase. At the receiver side, demodulation is performed based on the phase difference between the received signals in two consecutive intervals. DPSK is an attractive alternative to ordinary PSK modulation. It avoids the need for complex carrier recovery schemes to provide an accurate phase estimate. Compared to PPM, SIM is bandwidth efficient and does not require an adaptive decision threshold similar to OOK [3]. The performance of the DPSK based SIM in analyzed with the help of BER, channel capacity and outage probability.