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Performance evaluation of FSO system using wavelength and time diversity over malaga turbulence channel with pointing errors ☆

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ABSTRACT

There is an immense demand for high bandwidth and high data rate systems, which is fulfilled by wireless optical communication or free space optics (FSO). Hence FSO gained a pivotal role in research which has a added advantage of both cost-effective and licence free huge bandwidth. Unfortunately the optical signal in free space suffers from irradiance and phase fluctuations due to atmospheric turbulence and pointing errors which deteriorates the signal and degrades the performance of communication system over longer distance which is undesirable. In this paper, we have considered polarization shift keying (POLSK) system applied with wavelength and time diversity technique over Malaga(M)distribution to mitigate turbulence induced fading. We derived closed form mathematical expressions for estimating the systems outage probability and average bit error rate (BER). Ultimately from the results we can infer that wavelength and time diversity schemes enhances these systems performance.

1. Introduction

FSO communication is increasingly being accepted as a technology favouring huge bandwidth and high data rate. Hence researchers are focusing on FSO ignoring present radio frequency links (RF), and copious advantages like licence free huge bandwidth, high security at low installation and maintenance cost [1–6]. The idea basically is transmitting light waves consisting of data through atmosphere and collecting the light by the photo receiver at the remote distance. The transmitted optical beam travelling in free space can be absorbed, scattered or displaced depending on the atmospheric conditions prevailing, thus deteriorating the optical signal. FSO is majorly affected by the atmospheric turbulence , fog, path loss and pointing errors. Turbulence occurs because of temperature and pressure fluctuations in atmosphere which indeed leads to change in refractive index which causes rapid fluctuations in the transmitted signal known as scintillation. And due to mobility of communication terminals and weak earthquakes resulting in sway of high rise buildings which causes variations of transmitted signal. So the misalignment results in pointing error. Hence these effects like atmospheric turbulence, path loss and pointing errors are responsible for signal deterioration and ultimately system efficiency and reliability cannot be guaranteed.

The performance of an FSO system in atmospheric turbulence can be improved by including error control coding, aperture averaging and diversity techniques [7,8]. In this paper, we consider diversity technique to mitigate the atmospheric turbulence. It can be spatial, temporal and wavelength. In spatial diversity scheme, same data has been transmitted over multiple transceivers to reduce the error probability. In temporal, same data transmitted over different time slots with only one pair of transceivers. Which in case reduces the overall bit rate of the link. In wavelength diversity scheme, the optical beam is transmitted at different wavelengths at the same time slot.

Polarization Shift Keying Modulation (POLSK) which was initially proposed as an alternative encoding scheme in coherent detection (CD) optical communications [9]. It uses the state of polarization (SOPS) of an electromagnetic wave carrier as the information bearing parameter. The SOPS are unperturbed from the atmospheric turbulence when transmitted in free space and designed for long distance communication. For the FSO domain polarization is a more stable property as compared to intensity, frequency and phase. So, POLSK modulation technique has proven to be a better option for FSO systems because depolarizing property of atmosphere is very weak [10]. And it is also an effective modulation technique over conventional on-off keying (OOK) and phase shift keying (PSK) because of its high immunity to the laser phase

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Table 1
Attenuation coefficients for different weather conditions [14].

Weather condition	Attenuation σ (dB/KM)
Very clear air	0.0647
Haze	0.7360
Light fog	4.2850

noise and does not suffer from frequency chirp [9]. Experimental demonstration Performance of FSO Systems using POLSK technique is performed in [9]

Many researchers applied different diversity techniques over different atmospheric turbulence channel model to improve the performance of optical wireless communication system (OWC). In [11] the author analysed the performance of FSO system using wavelength and time diversity in OWC systems over gamma gamma turbulence channel. The same work is been carried in [12] including the effects of pointing errors. In [13] author analysed BER performance of FSO used over exponential Weibull channel using wavelength diversity. In our paper we used wavelength and time diversity in weak and strong atmospheric turbulence with pointing errors over M distribution turbulence channel. Malaga-distribution or, the M-distribution is unifying statistical model which incorporates many statistical channel models that have been proposed to describe weak-to-strong atmospheric-induced turbulence fading in the FSO system in multiple studies seen in Table 1.

The remainder of the paper is arranged as follows. In Section 2 the channel model with pointing errors is discussed. In Section 3, we introduce the FSO system model with wavelength and time diversity. In Sections 4 and 5, we derived the expressions for average BER and outage probability of the considered system . Section 6 describes the numerical results with graphical analysis for efficient and reliable system. Ultimately conclusion in Section 7.

2. FSO channel model

In the present paper the optical channel model I_m is considered as product of I_a, I_p and I_l which is given below [14]

$$I_m = I_l I_a I_p. \tag{1}$$

Here I_l represents atmospheric loss, I_a represents atmospheric turbulence, I_p represents pointing errors.

2.1. Atmospheric loss

Where I_l represents the atmospheric loss modelled by the Beer–Lambert's law as [14] and I_P represents pointing errors which is discussed further

$$I_l = \exp(-\sigma L) \tag{2}$$

where σ is the attenuation coefficient, L is the link length. The σ under different weather conditions at a wavelength of 1550 nm is chosen from [14] and the values adopted can be found in Table 1 and link length is 1 km.

2.2. Atmospheric turbulence induced fading

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 Table 2 for example gamma, gamma gamma, negative exponential, K distribution, log normal models [15–17]. And also the effect of misalignment errors between transmitter and the receiver due to non line of sight also known as pointing errors whose reduction is pivotal for efficient FSO system. 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 $2b_0$. See Fig. 1.

Table 2
List of existing distribution models for atmospheric optical communications and generation by using the proposed M distribution model [15].

Distribution model	conditions
Gamma	$\rho = 0,\ \gamma = 0$
Gamma-gamma	$\rho = 1, \gamma = 0,\ \Omega' = 1$
Lognormal	$\rho = 0, \gamma = 0,\ var[\lvert U_L\rvert] = 0$
K distribution	$\rho = 0,\ \Omega = 0$ or $\beta = 1$
Exponential distribution	$\rho = 0,\ \Omega = 0$

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 [14]

$$f_{I_m}(I_m) = A_m \sum_{k=1}^{b} a_{k_m} I_m^{\frac{\alpha_m+k}{2}-1} K_{\alpha_m-k}\left(2\sqrt{\frac{\alpha_m \beta_m I_m}{\gamma\beta_m+\Omega}}\right) \tag{3}$$

$$\text{where } A_m = \frac{2\alpha_m^{\frac{\alpha_m}{2}}}{\gamma^{1+\frac{\alpha_m}{2}}\Gamma(\alpha_m)}\left(\frac{\gamma\beta_m}{\gamma\beta_m+\Omega'}\right)^{\beta_m+\frac{\alpha_m}{2}} \tag{4}$$

$$a_{k_m} = \binom{\beta_m-1}{k-1}\frac{(\gamma\beta_m+\Omega')^{1-\frac{k}{2}}}{k-1!}\left(\frac{\Omega'}{\gamma}\right)^{k-1}\left(\frac{\alpha_m}{\beta_m}\right)^{\frac{k}{2}} \tag{5}$$

with α_m being a positive parameter related to the effective number of large-scale cells of the scattering process, and β_m is a natural number where as generalized expression for β_m 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_m parameter being a natural number, which leads to a closed-form representation [18]. Which is a major convenience for using β_m as a natural number(β_m 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

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

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

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 $g_m = \frac{w_{zeq}}{2\sigma}$ is the ratio between the effective beam width and the jitter standard deviation σ_s.

2.4. Combined channel fading models

The combined channel model for I_m is given as [14]

$$f_{I_m}(I_m) = \int f_{I_m|I_a}(I_m|I_a) f_{I_a}(I_a) dI_a \tag{7}$$