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BER analysis of BPSK-SIM-based SISO and MIMO FSO systems in strong turbulence with pointing errors

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ABSTRACT

Free space optics (FSO) is one of the sprouting technologies in optical communication systems domain. It can be employed as an alternative for the conventional radio frequency (RF) links to work out the current limitations in communication systems. But, the major drawback in FSO communication is the effect of random environment conditions on its performance. In this paper, we analyze the bit error rate (BER) and outage performance of single-input single-output (SISO) and multiple-input multiple-output (MIMO) FSO systems in strong atmospheric turbulence using binary phase shift keying subcarrier intensity modulation (BPSK-SIM) signaling technique. The closed-form expressions are derived and the results are realized in terms of 2D and 3D plots.

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1. Introduction

Free space optics (FSO), also known as open-air photonics or optical wireless or infrared broadband, is a full-duplex line-of-sight (LOS) technology. The technology is extremely useful where, landline connection is not feasible. FSO communication employs modulated low-powered visible or infrared (IR) lasers for transmitting data from point-to-point or multipoint through the atmospheric channel. Customarily, laser beams are employed, however non-lasing sources like light-emitting diodes (LEDs) or IR-emitting diodes (IREDs) can also be employed instead [1].

Each FSO wireless system uses an optical source, a lens or telescope that transmits light through the atmospheric channel to another lens receiving the data. FSO systems can operate over expanses of several kilometers even if there is no direct LOS, by employing tactically positioned mirrors to reflect the energy. As the fact, light is transmitted through air faster than glass, so FSO technology offers optical communication at the speed of light. Also, the photons transmitted by the laser are much quicker than electrons moving in a wire and they can pass straight through one another, whereas charge-bearing electrons cannot. As a result, large volumes of data can be transmitted through a confined space in FSO which is not possible to realize in other communication techniques [2].

Unlike conventional radio frequency (RF) links, FSO communication is cost-effective, easily upgradable, immune to radio frequency interference or saturation, serves higher bandwidth at a faster speed and requires no RF spectrum licensing or security software upgrades [3]. Hence this technology is sprouting as an appealing alternative to the present communication systems. So, FSO can be employed for applications in building-to-building connectivity, disaster recovery, network redundancy and temporary connectivity for applications such as voice and data, video services, medical imaging, fixed-line carrier bypass, CAD and engineering services [4,5].

An FSO communication system is a powerful technique to deploy wireless networks with high transmission rates like wired optical system. But, the communication using FSO depends upon the concern of the nature, most significant components being rain, dust, snow, fog or smog. Due to these random environmental conditions, the transmitted photons in the signals get faded, absorbed, scattered, diffracted and also sometimes gets lost in the channel [6]. This can block the transmission path or even shut down the network, thus impairing the signal strength and performance of the system. Multiple-input multiple-output (MIMO) system is useful for resisting temporary link blockage by birds and misalignment when merged with a wide laser beam width and hence eliminates the need for an active tracking. Various diversity techniques are also implemented to improve the link performance at relatively cheaper costs. It is employed by creating several independent paths between the transmitter and the receiver. Since, each path fades independently, there is a low chance of fading together. The performance of spatial MIMO systems was studied in [7–10]. Here, we employ the hybrid binary phase shift keying-based subcarrier intensity modulation (BPSK-SIM) technique.

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The spatial correlation between a pair of constituent transmitters in an MIMO system is investigated in [11]. In a recent work, a coherent MIMO architecture was proposed for FSO communication, and BER expressions are derived using a series expansion for gamma–gamma, K-distributed and negative exponential turbulences [12]. The performance of BPSK-SIM-based SISO system is analyzed and its parameters such as average bit error rate (BER), outage probability and channel capacity were evaluated under the strong atmospheric turbulence channel with pointing errors [13]. In this paper, we examine BER performance of the FSO system with two transmission topologies, single-input-single-output (SISO) and MIMO in strong atmospheric turbulence with pointing errors.

The paper is organized as follows: Section 2 discusses the SISO and MIMO system models. In Section 3, the gamma–gamma channel model with pointing errors for SISO and MIMO systems are discussed. In Section 4, expressions for average BER of the SISO and MIMO systems are derived and presented. Section 5 describes the numerical results with graphical analysis. Section 6 concludes the paper by summarizing the important results.

2. System models

2.1. Single-input single-output system model

The FSO system considered here has one transmitting and one receiving apertures. The signals to be transmitted are modulated by using BPSK-SIM signaling technique and transmitted via telescope into discrete time ergodic channel with additive white Gaussian noise (AWGN). The transmitted signal gets scattered due to natural turbulence in the atmospheric channel. These corruptions of signals are triggered by various environmental elements. In this work, we consider strong atmospheric turbulence channel. The signal (y) received at the receiver [14] can be expressed as

$$y = h\gamma P_{\mathrm{FSO}} x + n \tag{1}$$

where h is the channel state, γ is the detector responsivity, x is the transmitted signal, n is the noise caused by various sources and P_{FSO} is the average optical transmitted power. The channel state h models the optical intensity fluctuations resulting from atmospheric loss, turbulence and fading as [15]

$$h = h_{\mathrm{l}} h_{\mathrm{s}} h_{\mathrm{p}} \tag{2}$$

where h_{l} is the attenuation due to beam extinction and path loss, h_{s} due to scintillation effects and h_{p} due to the geometric spread and pointing errors.

Also, the signal-to-noise ratio (SNR) of the received signal considered in [16] is expressed as

$$\mathrm{SNR}(h) = \frac{(\gamma h)^2}{2\sigma^2} \tag{3}$$

where σ_n^2 is the variance of the channel noise.

2.2. Multiple-input multiple-output system model

The FSO system considered here has M transmitting and N receiving apertures. The transmitted signals are BPSK-SIM modulated and transmitted via telescope into discrete time ergodic channel with AWGN in strong atmospheric turbulence. The signal (y_n) received at the receiver can be expressed as [17]

$$y_n = x\gamma \sum_{m=1}^{M} h_{mn} + v_n, \quad n = 1, 2, \ldots, N \tag{4}$$

where x is the transmitted signal, γ is the detector responsivity, h_{mn} is the irradiance from the m^{th} transmitter and n^{th} receiver, v_n is the AWGN with zero mean and variance $\sigma_v = N_0/2$. The irradiance h_{mn} models the optical intensity fluctuations resulting from atmospheric loss, turbulence and fading [15] is given by

$$h_{mn} = h_{l_{mn}} h_{s_{mn}} h_{p_{mn}} \tag{5}$$

where $h_{l_{mn}}$ is the attenuation due to beam extinction and path loss from the m^{th} transmitter and n^{th} receiver, $h_{s_{mn}}$ due to scintillation effects and $h_{p_{mn}}$ due to the geometric spread and pointing errors.

3. Channel models

3.1. Single-input single-output channel model

The strong atmospheric turbulence channel is demonstrated employing the combined effects of atmospheric turbulence and pointing errors. The probability density function (PDF) of the considered channel model for SISO system [13] is expressed using the Meijer G function as

$$f_h(h) = \frac{\alpha\beta\xi^2}{A_0 h_l \Gamma(\alpha)\Gamma(\beta)} G_{1,3}^{3,0}\left[\frac{\alpha\beta h}{A_0 h_l}\middle|_{-1+\xi^2,\alpha-1,\beta-1}^{\xi^2}\right] \tag{6}$$

where α and β represent the effective number of large- and small-scale turbulent eddies, $\Gamma(\cdot)$ is the gamma function.

3.2. Multiple-input multiple-output channel model

The PDF of the considered channel model for MIMO systems is expressed using the Meijer G function as

$$f_{h_{mn}}(h_{mn}) = \frac{\alpha_{mn}\beta_{mn}\xi_{mn}^2}{A_{0_{mn}} h_{l_{mn}} \Gamma(\alpha_{mn})\Gamma(\beta_{mn})} \times G_{1,3}^{3,0}\left[\frac{\alpha_{mn}\beta_{mn}h_{mn}}{A_{0_{mn}} h_{l_{mn}}}\middle|_{-1+\xi_{mn}^2,\alpha_{mn}-1,\beta_{mn}-1}^{\xi_{mn}^2}\right] \tag{7}$$

where α_{mn} and β_{mn} represent the effective number of large- and small-scale turbulent eddies and $\Gamma(\cdot)$ is the gamma function.

4. Average BER

4.1. Single-input single-output system

For a BPSK-SIM-signaled communication system, the conditional BER probability depends on the fluctuation intensity [18,19] and can be expressed as

$$P_{\mathrm{ec,SISO}}(h) = 0.5 \times \mathrm{erfc}\left(\frac{h\gamma}{2\sigma}\right) \tag{8}$$

where γ is the photo detector responsivity and σ^2 is the variance of the channel noise.

For a gamma–gamma channel with pointing errors, the average BER $P_{\mathrm{e,SISO}}$ can be realized by averaging Eq. (8) over the PDF of h can be estimated as

$$P_{\mathrm{e,SISO}} = \int_0^{\infty} P_{\mathrm{ec,SISO}}(h) f_h(h)\,\mathrm{d}h \tag{9}$$

By using Eqs. (6) and (8) in Eq. (9), the average BER can be obtained as

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