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Optical spatial modulation over Gamma–Gamma turbulence and pointing error induced fading channels

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ABSTRACT

The installations of free space optical (FSO) systems on many structures may account to link availability degradation and poor system performance due to vibration in the transmitted optical beam between the transmitter and the receiver coupled with atmospheric turbulence fading within the channel. In this paper, we study the performance of free space optical spatial modulation system (FSO-SM) under the influence of Gamma–Gamma turbulence channel and misalignment effect. We derived the average bit error rate (ABER) for the system using a power series approach by eliminating the difficulty incur with Meijer-G function adopted in many related researches. The effect of pointing error on the system performance is therefore analyzed under the normalized transmitter beam waist and jitter variance conditions and the numerical results reveal how receive diversity significantly improved the system error rate. It was found that the proposed system outperformed the conventional FSO systems. Furthermore, convolutional coding is employed to enhance the system performance and the study discovered that a very low optical power is required by the system to achieve a minimum error rate.

1. Introduction

Free space optical (FSO) systems is gaining an enormous attention by the research community as an alternative technology for wireless radio frequency (RF) communication; due to its cost effectiveness, unlicensed bandwidth, high security and simplicity in design and set-up [1]. Despite the great potential of FSO systems, however, the system link is attributed to many challenges caused by atmospheric turbulence induced fading. As the optical wave propagate through the channel, both the amplitude and the phase of the beam suffer from random variation caused by change in atmospheric refractive index as a result of inhomogeneity in temperature and pressure along the link [2] which hence, deteriorate the system performance. In addition to atmospheric turbulence, pointing error effect may also degrade the performance of FSO system which is often experience as a result of building sway or beam wander caused by dynamic wind loads, thermal expansion and weak earthquake. The consequences of these vibrations in the transmitted beam lead to misalignment between the transmitter and receiver and limit the system performance [3,4]. Beside the building sway, as the link distance between the transmitter and receiver increases the more the misalignment effect become pronounces.

Various studies have been carried out on the combined effect of pointing error with atmospheric turbulence under different weather conditions [5–11]. Firstly, in the works of [5] and [7], the detector size and beam waist were assumed to be

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negligible. Farid and Hranilovic presented a model which provides solution to the beam waist, pointing error and detector size issues considering lognormal and Gamma–Gamma turbulence conditions. In order to provide a closed form expression for this composite channel which was not presented by [6] for the system performance metric, different mathematical methods have been developed in literatures which lead to further studies on pointing error. In the works presented by Sandalidis in [8] and [9], Meijer-G function was used to obtain the closed form expression for the system metrics. These results offer no any additional insight into the FSO system due to its complexity and difficulty incur in obtaining the close form expression by Meijer-G function. Also, the result obtained by [10] was based on a Taylor series expansion of Meijer-G function which has the same challenges with that of presented in [8,9]. Notwithstanding, Song et al. applied series expansion approach to study the combine effect of pointing error for subcarrier binary phase shift key modulated FSO system. This approach is highly efficient and accurate than the one presented by [12] which cannot be applied to all operation conditions. However, further study for this work confirmed that, subcarrier intensity modulation is a multiple-subcarrier modulation technique commonly used for FSO system. Based on the studies, it is observed that such modulation types offer good bandwidth efficiency as compared to pulse position modulation and hence required no adaptive threshold unlike in the case of On-Off modulation [13]. In spite of this, the modulation scheme suffers from poor optical power efficiency which limits the numbers of subcarriers.

Recently, spatial modulation (SM) has been attracted as a promising Multiple Input Multiple Output (MIMO) and digital modulation concept for free space optical (FSO) communication systems. This is because, compare with other MIMO counterparts, it makes use of only one active transmitting antenna at an instance of time while others are idles without deteriorating the system performance [14]. As a result of this, it avoids inter-channel interference (ICI), inter-antenna synchronization and reduces multiple RF chain at the transmitter without deteriorating the system performance [15]. Many studies have shown that SM aims at reducing the system complexity and it offers better error performance and higher spectral efficiency without additional increase in bandwidth and transmitting power [16,17]. The research in the area of SM is still at infancy stage unlike in radio frequency systems where it has been studied extensively [18]. For instant, Hwang et al. used SM with receive diversity to enhance the error performance of the SIM FSO system [19]. In [20], the authors studied the performance of a coherent receiver over H-K turbulence channel. Also, Ozbilgin and Koca considered the combination of SM with pulse position and amplitude modulation for FSO system under the Lognormal and Gamma–Gamma turbulence channels [21]. Thus, in all the works stated above, none of them considered the effect of pointing error with the atmospheric turbulence for SM-FSO systems. In this paper, we present the error rate performance of optical spatial modulated FSO system with pointing error under the Gamma–Gamma atmospheric turbulence channel. We applied the series expansion in [11] to determine the APEP and the ABER is then obtained by union bounding technique. Moreover, the system error performance is enhanced by introduction of convolutional coding technique at a minimum optical power.

The remainder of this paper is organized as follows: after this introduction section, Section II presented the system and channel model. In section III, present the performance analysis of uncoded and coded SM-FSO. Numerical and simulation results for the system performance with their interpretation are presented in section IV. Finally, the conclusion and remarks are outlines in Section V.

2. System model

The general model of SM-FSO-SD system consider in this work consists of $N_t \times N_r$ MIMO optical wireless link with N_t and N_r are the number of transmit laser and receive photo-detector (PD) respectively. This system is illustrated to consist of a SM mapper, BPSK modulator, transmit lasers, atmospheric channel, receive photo-detectors and SM demapper for BPSK and transmitter index respectively. At each time instant, random sequence of information bit stream to be transmitted over the optical channel are grouped into block of $\log_2(N_t M)$ bits. The first group of $\log_2(N_t)$ bits are used to select the active transmit-laser index l for optical transmission while the remaining $\log_2(M)$bits are mapped into constellation vectors of $x_{l,q} = \left[0 \ldots x_q \ldots 0\right]^T$ in which the symbol x_q from the q^{th} BPSK constellation is transmitted by the l^{th} active transmit-laser. The corresponding optical MIMO channel output after the transmission of x_q from the active laser can be modeled as:

$$\begin{aligned} y &= \sqrt{\rho} H X_{l,q} + n \\ &\triangleq \sqrt{\rho} h_l x_q + n \end{aligned} \quad (1)$$

where $\rho = \frac{RP_t}{\sigma_n^2}$ is the average electrical signal to noise ratio (SNR) at reach receiver unit and n independent identically distributed (I.I.D.) according to $\sim CN\left(0, \sigma_n^2\right)$. At the receiving end, a jointly optimal detection (OD) is employed to estimate the laser transmit index $\hat{l}$ and $\hat{q}$ BPSK constellation symbol which are used to decode the transmitted bit stream and thus can be expressed as [22]:

$$\begin{aligned} [\hat{l}, \hat{q}] &= \arg\max_{\hat{l},\hat{q}} p_Y(y|x_{l,q}, H) \\ &\triangleq \arg\min_{\hat{l},\hat{q}} \sqrt{\rho} \| h_l x_q \|_F^2 - 2Re\{y^H h_l x_q\} \end{aligned} \quad (2)$$