Optics Communications 382 (2017) 205–211

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Performance analysis of free space optical system with spatial modulation and diversity combiners over the Gamma Gamma atmospheric turbulence

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ARTICLE INFO

Article history:
Received 28 May 2016
Received in revised form
1 July 2016
Accepted 26 July 2016

Keywords:
Spatial modulation
Spatial diversity
Free space optics
Atmospheric turbulence
Average pairwise error probability (APEP)
Average bit error rate (ABER)

ABSTRACT

Atmospheric turbulence is a major impairment that degrades the performance of free space optical (FSO) communication systems. Spatial modulation (SM) with receive spatial diversity is considered as a powerful technique to mitigate the fading effect induced by atmospheric turbulence. In this paper, the performance of free space optical spatial modulation (FSO-SM) system under Gamma–Gamma atmospheric turbulence is presented. We studied the Average Bit Error Rate (ABER) for the system by employing spatial diversity combiners such Maximum Ratio Combining (MRC) and Equal Gain Combining (EGC) at the receiving end. In particular, we provide a theoretical framework for the system error by deriving Average Pairwise Error Probability (APEP) expression using a generalized infinite power series expansion approach and union bounding technique is applied to obtain the ABER for each combiner. Based on this study, it was found that spatial diversity combiner significantly improved the system error rate where MRC outperforms the EGC. The performance of this system is also compared with other well established diversity combiner systems. The proposed system performance is further improved by convolutional coding technique and our analysis confirmed that the system performance of MRC coded system is enhanced by approximately 20 dB while EGC falls within 17 dB.

1. Introduction

FSO communication system is an emerge technology that offers numerous advantages over radio frequency (RF) transmission such as higher data rates (at the order of multiple gigabits per second), cost effective, high security, wide bandwidth access and unregulated frequency spectrum [1]. Unfortunately, this type of optical links are highly vulnerably; particularly at distances of 1 km or longer as a result of atmospheric turbulence. This limits its deployment to only short distance of application area and especially in a clear weather condition [2]. This turbulence occurs as a result of random variation in the refractive index due to irregularity in temperature, wind speed and pressure changes along the link [3]. This irregularity causes rapid fluctuation of optical received signal both in phase and intensity and severely degrades the quality of the signal [4]. In other words, to investigate the impact of atmospheric turbulence on the FSO systems, it is necessary to employ accurate channel statistical distribution models and among them include lognormal, negative exponential, K-distribution and Gamma–Gamma. In most cases, lognormal distribution is usually considered to model weak turbulence over a distance within several hundred meters in clear weather [5–7]. Strong turbulence is often modeled with the negative exponential and K-distribution for FSO communication systems that span over a several kilometers [8,9]. The Gamma–Gamma distribution which agreed well with experimental data as the best distribution is often used to model a wide range of turbulence conditions (from weak to strong) [10–14]. As a result of this, for FSO systems to overcome these impairments, powerful mitigation technique needs to be deployed in order to achieve an error free system and higher spectral efficiency.

In literatures, well established types of conventional modulation schemes have been proposed and studied to mitigate the fading incur as a result of atmospheric turbulence. One of them is called On-Off Key (OOK) which is commonly employed as a result of its low cost and simplicity in implementation. However, OOK required adaptive thresholds in order to perform optimally [15]. FSO with Pulse Position Modulation (PPM) has been used in many research works due to its good power efficiency and requires no adaptive

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http://dx.doi.org/10.1016/j.optcom.2016.07.072
0030-4018/

thresholds like OOK; but this modulation scheme suffer from poor bandwidth and the need of tight symbol synchronization by the receiver [16]. Alternatively, Subcarrier Intensity Modulation (SIM) is another attractive modulation scheme for FSO applications and it has been employed with other different modulation schemes to achieve an error free communication systems [16,17,18]. However, this modulation requires a Direct Current (DC) bias to prevent the transmitting signal from becoming positive and an increase in subcarrier results in poor power efficiency [19].

Recently, spatial modulation (SM) scheme emerged as a modulation that enhanced the capacity of the multiple-input and multiple-output (MIMO) technology by employs transmit antennas in an innovative fashion. SM simply works on the principle that only one transmitting antenna is active at an instance of time while others are idles [20]. 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 [21]. Many researches results have shown that SM offers better error performance, higher spectral efficiency and low system complexity without additional increase in bandwidth and transmitting power [22,23]. The error rate performance of FSO systems that employ SM are quite limited in literatures and by our knowledge, it is still at infant stage unlike in RF systems which have been studied extensively [24]. Recently, Hwang and Cheng [25] combined SIM with Spatial Diversity (SD) in order to enhance the system error rate but the study offer no analytical framework for the system. Also, the performance of SM with the PPAM modulation was presented by [26] under lognormal and Gamma–Gamma atmospheric turbulence. It was discovered that the solution to the Gamma–Gamma turbulence was based on Meijer-G function while its close form do not offer much insights. Moreover, Peppas and Mathiopoulos [27] studied the error performance of SM for the coherent detection FSO system but the channel considered here was Homodyned-K (H-K) atmospheric turbulence and combiners were not employed.

Based on our study, it was discovered that; at any instant in time, SM causes the FSO systems to act as a single-input and single-output (SISO) configuration and its performance therefore needs to be improved by employing SD at the receiver end. In this paper, we studied the performance of uncoded and coded optical spatial modulation FSO systems combined with (SD) over Gamma–Gamma turbulence channel. SD has been well known as an efficient mitigation technique which is mostly useful in preventing temporary beam blockage and misalignment [28,29]. Research studies have shown that there are three reception diversity combiners used for communication system and this includes Maximum Ratio Combiner (MRC), Equal Gain Combiner (EGC) and a simple Selection Combiner (SC) [30,31] but MRC and EGC are considered in this work due to their optimum performances. In analyzing this proposed system, we first derived the APEP for each diversity scheme as a power series expression by using Moment generating function (MGF) and the ABER for the systems is obtained through union bound technique. The ABER of the proposed system is compared with conventional FSO systems that employ the same SD as mitigation tool such as SIM-EGC-Differential Phase Shift Key (DPSK), and SIM-MRC-Binary Phase Shift Key (BPSK) presented in [32]. The system performance is further improved by introducing coding technique.

The remainder of this paper is organized as follows: after this introduction section, Section 2 presented the system and channel model. In Section 3, we presented the performance analysis of uncoded and coded SM-FSO-SD. Numerical and simulation results for the system performance with their interpretation are presented in Section 4. Finally, the conclusion and remarks are outlines in Section 5.

The mathematical notations used throughout in this paper are defined as follows: $x!$ is the factorial of a positive integer x, $E[x]$ is the statistical expectation of a random variable x, $f_x(.)$ denotes the probability density function of a random variable x, $\Phi_x(.)$ is the moment generating function of a random variable x, $\Gamma(.)$ is the Gamma function, $Q(.)$ is Gauss Q-function, $B(.,.)$is Beta function, $*$ denotes the convolution operator, $\binom{x}{y}$ denotes binomial coefficient, $[.]^T$is the matrix transpose, $\|.\|_F^2$ is the squared Frobenius norms, $|x|$ denotes the magnitude of complex number x, $K_x(.)$ is the modified Bessel function of second kind and order x, $\hat{}$ is the estimated value at the receiver side.

2. System and channel models

2.1. System model

The general model of SM-FSO-SD system is illustrated in Fig. 1, which consists of MIMO optical wireless link with two transmit lasers N_t and N_r receiver photo detector (PD). A random independent sequences of incoming information bit streams 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 $x_{l,p} = [0..x_p..0]^T$ in which the symbol x_p from the p^{th} BPSK constellation is transmitted by the l^{th} active transmit-laser. The corresponding optical MIMO channel output after the transmission of x_p from the active laser can be modeled as [26]:

$$y = \sqrt{\mu} H x_{l,p} + \eta \tag{1}$$

where $\mu = \frac{R^2 P_r^2}{\sigma_\eta^2}$ is the average electrical signal to noise ratio (SNR) at each receiver unit with R being the PD responsivity and P_r is the

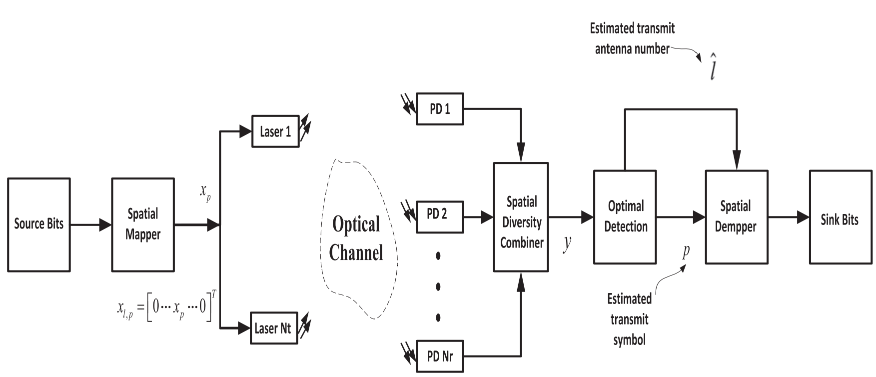

Fig. 1. FSO Spatial modulation with spatial diversity system.