Optics & Laser Technology 76 (2016) 58–63

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Polarization shift keying based relay-assisted free space optical communication over strong turbulence with misalignment

K. Prabu [a,*], D. Sriram Kumar [b]

[a] School of Electronics Engineering, Vellore Institute of Technology, Vellore 632014, India
[b] Department of Electronics and Communication Engineering, National Institute of Technology, Tiruchirappalli 620015, India

ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form
14 July 2015
Accepted 21 July 2015
Available online 6 August 2015

Keywords:
Free space optics
Polarization shift keying
Strong atmospheric turbulence
Parallel relay
Outage probability

ABSTRACT

This paper investigates the outage performance of polarization shift keying (PolSK) based multihop parallel relay assisted free space optics (FSO) system over a strong atmospheric turbulence channel with misalignment fading. An exact closed form expression is derived for the end-to-end outage probability of the system. The results are compared with the direct transmission and on-off keying (OOK) based FSO systems. The results indicate that the performance of the PolSK based relay-assisted FSO system is much better than the direct transmission and OOK systems. The outage performance is enhanced by increasing the number of relay path between the transmitter and receiver.

1. Introduction

Free-space optics (FSO) is a high data rate, economic, secure, interference resistant and high-bandwidth wireless technique for transmitting broadband services via point to point channels [1]. Due to its license-free operation, infinite spectrum and its ease of deployment, it is emerging as an appealing alternative to conventional radio frequency (RF)/microwave links. The operation of FSO depends on the environmental conditions affecting the performance parameters viz. channel capacity, phase-front distortion, beam broadening, beam wander and redistribution of the intensity within the beam [2,3].

The major challenges in FSO systems are atmospheric turbulences and misalignment fading. The reasons for fading due to misalignment are varying refractive index, thermal expansion, wind load or due to quakes which causes throbbing of the transmitter beam, resulting in pointing error between the transmitter and receiver [4]. Relay assisted FSO system and multiple-input multiple-output (MIMO) techniques are effective methods to extend coverage and lessen the effects of fading [5]. Since, the amount of fading depends upon the distance covered in the turbulent environment, the signal transmission efficiency increases with the number of short hops taken.

Polarization shift keying (PolSK) is an effective alternative modulation technique used for long distance wireless optical communications. In PolSK, states of polarizations (SOPs) are used to modulate the binary information. The advantages of PolSK over the conventional modulations schemes are high immunity to the laser phase noise and do not suffer from frequency chirp [6,7]. The heterodyne binary polarization shift keying (BPOLSK)-FSO system by using MIMO technique over the gamma–gamma turbulence channel is studied in [8]. A coherent multilevel polarization shift keying (MPOLSK) based FSO system using the spatial diversity detection is proposed and its symbol error rate performance, diversity gain are studied under various turbulence regimes in [9]. In [10], the performance of the BPOLSK-FSO system over a weak atmospheric turbulence channel has been investigated.

In a recent work, the performance analysis of repetition code (RC) and orthogonal space time block code (OSTBC) in an FSO system is investigated over correlated lognormal channels [11]. Average BER and outage performance of the polarization shift keying (PolSK) modulated FSO system with time or wavelength diversity over gamma–gamma channel with pointing errors is analyzed in [12]. The average error rate performance of serial relay assisted FSO system over gamma-gamma channel is analyzed in [13]. The outage probability for on-off keying (OOK) based FSO system with decode-and-forward (DF) parallel relays over strong turbulence fading channel is investigated and the closed-form expression of the outage probability is derived in [14]. In [15], the author analyzed the performance of a dual-hop relay system composed of RF and FSO links, operating in asymmetric

---

* Corresponding author. Tel.: +919884888408.
E-mail address: nitprabu@gmail.com (K. Prabu).

http://dx.doi.org/10.1016/j.optlastec.2015.07.012
0030-3992/

communication environments. The bit error rate (BER) performance of a binary phase shift keying-subcarrier intensity modulation (BPSK-SIM) based FSO system is analyzed using DF parallel relays in [11]. Relay selection protocols are introduced in relay assisted FSO system and its outage performance is analyzed in [16]. The serial and parallel relying FSO system performance is improved and outage probability is minimized through optimal relay placement [17]. In this paper, the outage probability of the DF and PolSK based parallel relay assisted FSO system is analyzed over the strong atmospheric channel with pointing errors.

The remainder of the paper is organized as follows: Section 2 discusses the channel model used. In Section 3, a PolSK relay assisted FSO system model is discussed. In Section 4, we perform an outage analysis of the system. The results are discussed and compared in Section 5. Finally, concluding remarks are highlighted in Section 6.

2. Channel model

A PolSK based parallel relay-assisted FSO communication system is considered. The multiple copy of the information signal is transmitted to the receiver through M hops per path consists of N parallel relays. At j^{th} hop of the i^{th} path, the received signals $y_{i,j}$ can be modeled as [14]

$$y_{i,j} = \gamma h_{i,j} x_{i,j} + n_{i,j},\ i \in \{1, 2, \ldots\ldots N\},\ j \in \{1, 2.. M\} \tag{1}$$

where γ is the detector responsivity, $x_{i,j}$ is the transmitted signals of the j^{th} hop in the i^{th} path, $n_{i,j}$ is additive white Gaussian noise of the j^{th} hop in the i^{th} path, M is the number of hops, $h_{i,j}$ is the channel irradiance in the j^{th} hop in the i^{th} path and it can be modeled as [14]

$$h_{i,j} = h_{l_{i,j}} h_{s_{i,j}} h_{p_{i,j}} \tag{2}$$

where $h_{l_{i,j}}$ is the attenuation due to beam extinction and path loss, $h_{s_{i,j}}$ is the attenuation due to scintillation effects and $h_{p_{i,j}}$ is the attenuation due to the geometric spread and pointing errors. The atmospheric path loss is modeled by Beers–Lambert law is given as [18]

$$h_{l_{i,j}} = e^{-\sigma L_{i,j}} \tag{3}$$

where σ is the attenuation coefficient and $L_{i,j}$. is the propagation distance of j^{th} hop in the i^{th} path.

In this article, we considered the strong atmospheric turbulence. It can be modeled by gamma–gamma distribution with scintillation parameters α and β, which are indicated as functions of the Rytov variance and a geometry factor. The probability density function (PDF) of the strong atmospheric turbulence can be modeled as a gamma–gamma distribution is given by [18]

$$f_{h_{s_{i,j}}}\left(h_{s_{i,j}}\right) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} h_{s_{i,j}}^{(\alpha+\beta)/2-1} K_{(\alpha-\beta)}\left(2\sqrt{\alpha\beta h_{s_{i,j}}}\right) \tag{4}$$

where α and β are the effective number of large and small scale turbulent eddies, $\Gamma(\cdot)$ is the gamma function and $K_{(\alpha-\beta)}$ is the modified Bessel function of the second kind of order $(\alpha-\beta)$.

The misalignment between the transmitter and receiver degrades the performance and reliability of the FSO communication system. By considering a circular detection aperture of radius r and a Gaussian beam, the PDF of h_p is given by [19]

$$f_{h_p}\left(h_p\right) = \frac{\xi^2}{A_0^{\xi^2}} h_p^{\xi^2-1},\ 0 \le h_p \le A_0 \tag{5}$$

where $A_0 = [erf(v)]^2$ is the fraction of the collected poweat $r = 0$. The Gauss error function $erf(\cdot)$ is defined as $erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$. The radial distance is denoted as r and ξ is the ratio between the equivalent beam radius at the receiver and the pointing error displacement (jitter) standard deviation at the receiver.

The combined channel distribution for strong atmospheric turbulence regime is given by [20]

$$f_{h_{i,j}}\left(h_{i,j}\right) = \frac{2\xi^2(\alpha\beta)^{(\alpha+\beta)/2}}{\left(A_0 h_{l_{i,j}}\right)^{\xi^2}\Gamma(\alpha)\Gamma(\beta)} h_{i,j}^{\xi^2-1} \times \int_{h_{i,j}/A_0 h_{l_{i,j}}}^{\infty} h_{s_{i,j}}^{(\alpha+\beta)/2-1-\xi^2} K_{(\alpha-\beta)}\left(2\sqrt{\alpha\beta h_{s_{i,j}}}\right) dh_{s_{i,j}} \tag{6}$$

where α and β are the effective number of large and small scale turbulent eddies, $\Gamma(\cdot)$ is the gamma function, $K_{(\alpha-\beta)}$ is the modified Bessel function of the second kind of order $(\alpha-\beta)$. The effective number of large and small scale turbulent eddies α and β for a spherical wave are given by [18].

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

$$\beta = \left[exp\left(\frac{0.51\delta_n^2\left(1 + 0.69\delta_n^{12/15}\right)^{-5/6}}{\left(1 + 0.9d^2 + 0.62d^2\delta_n^{12/15}\right)^{5/6}}\right) - 1\right]^{-1} \tag{8}$$

where $d = \sqrt{kD^2/4L}$, $k = 2\pi/\lambda$, is the optical wave number, with λ being the operational, L is the length of the optical link and D is the receiver's aperture diameter. The parameter δ_n^2 is the Rytov variance and is given as, $\delta_n^2 = 0.5C_n^2 k^{7/6} L^{11/6}$ and the C_n^2 represents the refractive index structure parameter.

The modified Bessel function $K_{(\alpha-\beta)}$ is expressed in terms of Meijer G function using [21, Eq. (14)] and simplified using [22, Eq. (07.34.21.0085.01)], a closed-form expression for the channel model is obtained as [23]

$$f_{h_{i,j}}\left(h_{i,j}\right) = \frac{\alpha\beta\xi^2}{A_0 h_l \Gamma(\alpha)\Gamma(\beta)} G_{1,3}^{3,0}\left[\frac{\alpha\beta h_{i,j}}{A_0 h_l}\middle|\begin{matrix}\xi^2\\ \xi^2-1,\ \alpha-1, \beta-1\end{matrix}\right] \tag{9}$$

The cumulative distribution function (CDF) of $f_{h_{i,j}}(\cdot)$ can be defined as

$$F_{h_{i,j}}\left(h_{i,j}\right) = \int_0^{h_{i,j}} f_{h_{i,j}}\left(h_{i,j}\right) dh_{i,j} \tag{10}$$

The CDF can be obtained by substituting Eq. (9) in (10), we get [24]

$$F_{h_{i,j}}\left(h_{i,j}\right) = \frac{\xi^2}{\Gamma(\alpha)\Gamma(\beta)} G_{2,4}^{3,1}\left[\frac{\alpha\beta}{A_0 h_{l_{i,j}}} h_{i,j}\middle|\begin{matrix}1, 1+\xi^2\\ \xi^2, \alpha,\ \beta,\ 0\end{matrix}\right] \tag{11}$$

3. System model

3.1. Parallel relay configuration

A parallel relay-assisted FSO communication system with PolSK modulation technique is considered. The source information is modulated using PolSK signaling technique and its multiple copies are transmitted from the transmitter to the receiver using parallel relays with two hops. Assume that, a relay assisted FSO system consists of N parallel relay paths between the transmitter and the