Optik 124 (2013) 6516–6518

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Error rate performance analysis of optical links between high altitude platforms with misalignment fading by Hoyt distribution

Xiang Wang*, Shanghong Zhao, Lei Shi, Yongjun Li, Guhao Zhao, Zihang Zhu, Weihu Zhao

Institute of Information and Navigation, Air Force Engineering University, No. 1, Fenghao Road, Xi'an, Shannxi 710077, PR China

A R T I C L E I N F O

Article history:
Received 20 December 2012
Accepted 17 May 2013

Keywords:
High altitude platforms
Hoyt distribution
Variance ratio
Gamma–gamma distribution

A B S T R A C T

The more reality misalignments model with Hoyt distribution is used to analyze performance for optical links between high altitude platforms. Compared with the recent work in terrestrial FSO, it is proved that the variance ratio have more significant effect on error performance for optical links over long distance. Then, the expression for the pairwise error probability is analyzed and applied to obtain upper bounds on the BER performance for coded optical communications. Simulation results show that coding technique can improve error performance of optical links, but it also can enhance the influences of the variance ratio.

1. Introduction

Recently, optical communication systems for high altitude platforms (HAPs) have attracted more interest not just because of many virtues of HAPs compared with terrestrial and satellite communication systems, but because of good channel condition for laser communication in near space [1,2]. Owing to the limitation of narrow beam for optical transmission and large distance between two platforms, the spatial tracking requirement of inter-HAPs optical link becomes more stringent. Generally, a model for the FSO communication system with misalignment has been described in [3–6], where the variance in the two orthogonal directions is assumed to be identical, i.e. the radial displacement at the receive detector is determined by Rayleigh distribution. However, in the practical systems for HAP optical communication, the drift due to monsoons, temperature and pressure variations results in the platform positional instability [7,8]. Hence, for inter-HAPs optical links, the Rayleigh model is not appropriate anymore. Gappmair et al. [9] has extended the conventional model to Hoyt model, and analyzed performance of uncoded terrestrial FSO links over short distance. Xian [10] has investigated the outage probability of inter-satellite optical link without considering the effect of atmospheric turbulence. In this paper, we investigate the error rate performance for inter-HAPs optical links over long distance considering the joint effects of atmospheric turbulence by a gamma–gamma distribution and misalignment fading by Hoyt distribution. Considering the limitation of size and power loss, the probably most promising technique for mitigation of atmospheric disturbances and misalignment fading in inter-HAPs optical link is coding and interleaving [6]. We also discuss the error performance for coded inter-HAPs optical links in the end.

2. System and channel model

The received electrical signal is given by

$$y(t) = IR_0x(t) + n(t) \tag{1}$$

where I denotes the received normalized irradiance, $x(t)$ is the modulated OOK signal either 0 or 1, $n(t)$ is the AWGN with zero mean and noise power N_0, R_0 represents the effective photo-current conversion ratio of the receiver. The normalized irradiance I is considered to be a product of the attenuation due to atmospheric turbulence, the attenuation due to geometric spread and pointing errors caused by platform instability.

Following the analytical work in [9], for the gamma–gamma fading with pointing errors, the channel distribution has the form of (2).

$$f_I(I) = \frac{(\alpha\beta)\eta^2}{2\pi q_H A_0 \Gamma(\alpha)\Gamma(\beta)} \int_{-\pi}^{\pi} G_{1,3}^{3,0}\left(\frac{\alpha\beta I}{A_0} \,\middle|\, \begin{matrix} \eta^2\varepsilon(\varphi) \\ \eta^2\varepsilon(\varphi)-1,\ \alpha-1,\ \beta-1 \end{matrix} \right) d\varphi \tag{2}$$

with $erf(\cdot)$ and $G(\cdot)$ as the error function and Meijer G function, respectively. Depending on the atmospheric conditions, the scintillation parameters α and β are specified as functions of the Rytov variance σ_n^2, where $\sigma_n^2 = 1.23C_n^2k^{7/6}z^{11/6}$. Here, $k = 2\pi/\lambda$ is optical wave number, λ is the wavelength, z is the link distance, C_n^2 stands for the index of refraction structure. The parameter

* Corresponding author. Tel.: +86 029 18681829065.
E-mail address: wangxiang_626@hotmail.com (X. Wang).

0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2013.05.045

A_0, η and $\varepsilon(\varphi)$ can be calculated respectively using the relations $A_0 = \mathrm{erf}^2(\upsilon)$, $\eta = \omega_z[\pi^{1/2}\mathrm{erf}(\upsilon)/2\upsilon\exp(-\upsilon^2)]^{1/2}/2\sigma_x$ and $\varepsilon(\varphi) = [1-(1-q_H^2)\cos^2\varphi]/q_H^2$, which $q_H = \sigma_y/\sigma_x$ is the variance ratio of horizontal and vertical pointing error; $\upsilon = (\pi/2)^{1/2}R_a/\omega_z$ where R_a is receiver aperture radius; $\omega_z = \omega_0[1+\varepsilon(\lambda z/\pi\omega_0{}^2)^2]^{1/2}$ is the beam waist at distance z, $\omega_0 = 2\lambda/\pi\Phi$ is beam waist at $z=0$ and $\varepsilon = (1+2\omega_0^2/\rho_0^2(Z))^{1/2}$, $\rho_0(z) = (0.55C_n^2k^2z)^{-3/5}$.

Then, the average BER of IM/DD with OOK can be evaluated with the help of the integration theorem for G-function [11] yielding to (3).

$$p_e = \frac{2^{\alpha+\beta}\eta^2}{32\pi^{5/2}q_H\Gamma(\alpha)\Gamma(\beta)}\int_{-\pi}^{\pi} G_{6,3}^{2,5}\left(\frac{8A_0^2}{\alpha^2\beta^2}(\gamma R_0 h)^2 \times \left| \begin{matrix} \frac{2-\eta^2\xi(\theta)}{2}, \frac{1-\alpha}{2}, \frac{2-\alpha}{2}, \frac{1-\beta}{2}, \frac{2-\beta}{2}, 1 \\ 0, \frac{1}{2}, \frac{-\eta^2\xi(\theta)}{2} \end{matrix}\right.\right) d\theta \qquad (3)$$

with $\Gamma(\cdot)$ as the standard gamma function. The SNR of the receiver $\gamma = GP_T/\sigma_N$, which G is antenna gain.

3. Upper bounds on the bit error rate

Considering a convolutional code with rate 1/3 and constraint length of 3 as an example and using the transfer function of convolutional code, the union bound on the average BER can be found as [12]

$$P_b(E) \le \frac{1}{\pi}\int_0^{\pi/2} \frac{D^6(\theta)}{(1-2D^2(\theta))^2}d\theta \qquad (4)$$

where $D(\theta)$ is defined based on the underlying the pairwise error probability expression (PEP).

Under the assumption of perfect knowledge of the channel state information and maximum-likelihood (ML) soft decoding, the PEP is given by [13]

$$P(X,\hat{X}) = \frac{1}{\pi}\int_0^{\pi/2}\left[\int_0^{\infty}\exp\left(-\frac{\gamma}{4}\frac{I^2}{\sin^2\theta}\right)f(I)dI\right]^{|\Omega|}d\theta \qquad (5)$$

By substituting (2) into (5), as well as expressing the exp(·) integrands as Meijer's G-functions [11], the unconditional PEP is given by

$$P(X,\hat{X}) = \frac{1}{\pi}\int_0^{\pi/2}\left[\frac{2^{\alpha+\beta}\eta^2}{16\pi^2 q_H\Gamma(\alpha)\Gamma(\beta)}\int_{-\pi}^{\pi}G_{5,2}^{1,5}\left(\frac{4A_0^2\gamma}{\sin^2(\theta)\alpha^2\beta^2}\left|\begin{matrix}\frac{2-\eta^2\xi(\varphi)}{2}, \frac{1-\alpha}{2}, \frac{2-\alpha}{2}, \frac{1-\beta}{2}, \frac{2-\beta}{2} \\ 0, \frac{-\eta_s^2\xi(\varphi)}{2}\end{matrix}\right.\right)d\varphi\right]^{|\Omega|}d\theta \qquad (6)$$

In our case, using the integrand of PEP expression given by (15), the exact $D(\theta)$ formulas is given

$$D(\theta) = \frac{2^{\alpha+\beta}\eta^2}{16\pi^2 q_H\Gamma(\alpha)\Gamma(\beta)}\int_{-\pi}^{\pi}G_{5,2}^{1,5}\left(\frac{4A_0^2\gamma}{\sin^2(\theta)\alpha^2\beta^2} \times \left|\begin{matrix}\frac{2-\eta^2\xi(\varphi)}{2}, \frac{1-\alpha}{2}, \frac{2-\alpha}{2}, \frac{1-\beta}{2}, \frac{2-\beta}{2} \\ 0, \frac{-\eta_s^2\xi(\varphi)}{2}\end{matrix}\right.\right)d\varphi \qquad (7)$$

4. Numerical results and discussion

We restrict our considerations to a scenario with two platforms at an altitude of 20 km each and separated by 300 km. In this scenario, the following parameters are assumed: $C_N^2 = 7.5\times10^{-18}$ for the index-of-refraction structure constant of inter-HAP optical links, and $R_0 = 0.98$ for the detector responsivity; furthermore, residual pointing error of horizontal direction and antenna gain are supposed to be $\sigma_{x\text{-}rms} = 25$ m and $G = 10^{12}$, respectively; finally, as typical values for optical wavelength and receiver aperture, $\lambda = 1550$ nm and $R_a = 10$ cm will be chosen.

Fig. 1 shows the evolution of the average BER of inter-HAP optical links over long distance as a function of the average SNR with different value of the variance ratio (q_H). Compared with the result of [9], the impact of the variance ratio on the average BER is

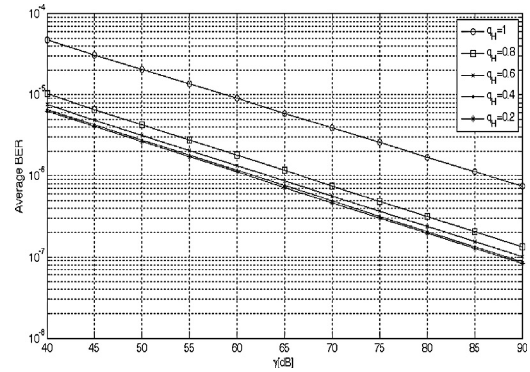

Fig. 1. Evolution of the average bit error probability as a function of the average SNR.

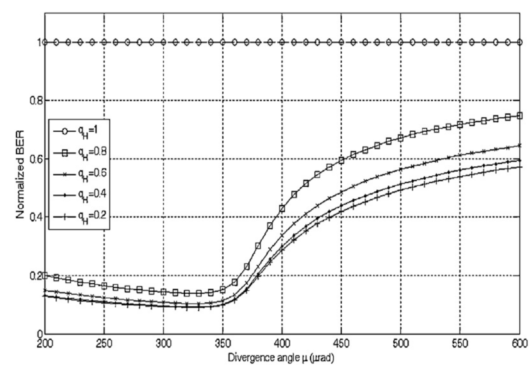

Fig. 2. Evolution of the normalized BER as a function of the divergence angle.

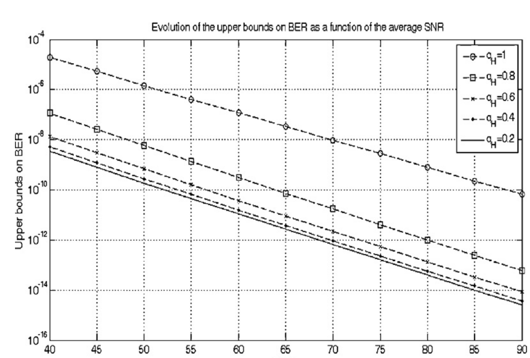

Fig. 3. Evolution of the upper bounds on BER as a function of the average SNR.