Impact of Pointing Jitter on the Performance of Free-Space Optical Communications over Doubly Stochastic Turbulence Channel

Sudhanshu Arya and Yeon Ho Chung

Department of Information and Communications Engineering,
Pukyong National University, Busan 48513, Republic of Korea

ABSTRACT

We present the impact of a random pointing error, that is, the jitter, on the bit error rate (BER) performance of free-space-optical communication link over doubly stochastic turbulence fading channel. In particular, we consider I-K distributed turbulence fading. Average BER performance is investigated with the received signal assumed to experience combined effects of the scintillation, misalignment fading, path loss, and noise. Simulation results are provided to demonstrate the validity of the study.

1. INTRODUCTION

Free-space optical (FSO) links come with several advantages over radio frequency (RF) communications. It includes large bandwidth, freedom from electromagnetic interference, low power, low cost, and secure transmission [1]. However, there are two major challenging issues with optical links. First, the communication performance is very much prone to channel impairments caused by the scattering, absorption, and turbulence. Second, optical links require accurate pointing, acquisition, and tracking (PAT).

The impairments caused by atmospheric scattering and absorption mainly result in the fall of a received signal-to-noise ratio (SNR) which may lead to an outage. On the other hand, atmospheric turbulence or scintillation can cause severe bit or symbol error rates at the receiver as the turbulence results in the random fluctuation in the received signal [2].

Equally important but mostly ignored, optical links are also highly dependent on accurate PAT. The pointing errors can occur due to the misalignment between the transmitter and the receiver or due some mechanical vibrations present in the optical system. Pointing error is mainly composed of two components: Boresight and Jitter. A boresight is a fixed error whereas a jitter represents a random error due to the random misalignment between the transceiver pair [3].

In this paper, we perform the average bit error rate analysis for the FSO link with pointing jitter. We consider doubly stochastic distributed turbulence fading. In particular, we consider I-K distributed turbulence fading. Unlike the K distribution, the I-K distribution is applicable to all conditions of turbulence strength and shows a good agreement with the experimental results [4].

The rest of the paper is organized as follows. Section 2 covers the system model. Simulation result with discussion is presented in Section 3. Finally, conclusions are drawn in Section 4.

2. SYSTEM MODEL

An FSO communication link over atmospheric turbulence fading is illustrated in Fig. 1. The transmitter modulated the input bits onto the instantaneous intensity of an optical beam through laser driver. In this work, we consider intensity modulated direct detection using on-off keying (OOK) modulation.

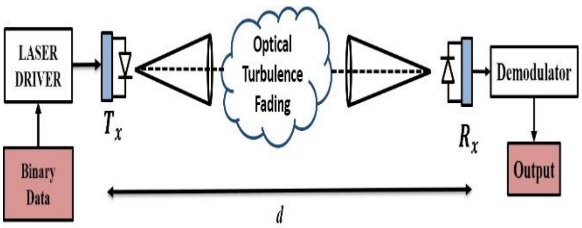

Fig.1 System model: FSO link over doubly stochastic turbulence fading.

The received electrical signal can be well modeled as

$$y(t) = HSx(t) + w, \quad (1)$$

where x is the transmitted intensity corresponding to the input bit and H denotes the optical channel state. S is the photodetector responsivity measured in A/W. w represents the additive white Gaussian noise with variance σ_w^2.

The optical channel state H is composed of three factors and can be given as

$$H = h_{PL} h_J I, \quad (2)$$

where h_{PL} represents a deterministic optical path loss given by Beers-Lambert Law. h_J is a random variable and represents a pointing jitter. Assuming independent and identical Gaussian distributions for the horizontal and vertical displacement in the received optical beam, the probability distribution function (PDF) of h_J can be modelled as

$$f_{h_J}(h_J) = \frac{\gamma^2}{V_0^{\gamma^2}} h_J^{\gamma^2 - 1}, 0 \le h_J \le V_0, \quad (3)$$

where $\gamma = \frac{w_{eq}}{2\sigma_j}$.

It is defined as the ratio of the equivalent received beam width to the standard deviation of the pointing error displacement at the receiver. I is also a random variable and denotes the turbulence fading. In this work, we model the turbulence fading with I-K distribution.

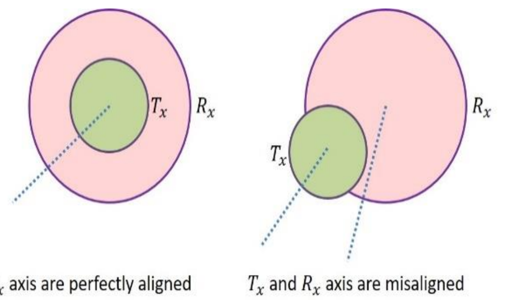

Fig.2 Illustration of the transmitter and the receiver misalignment in optical link.

Fig. 2 illustrate the optical transceiver pair with transmit beam axis and receiver field-of-view (FOV) axis are misaligned.

3. RESULT ANALYSIS

In this section, we study the error performance of an FSO communication link impaired by the I-K distributed turbulence fading and the random

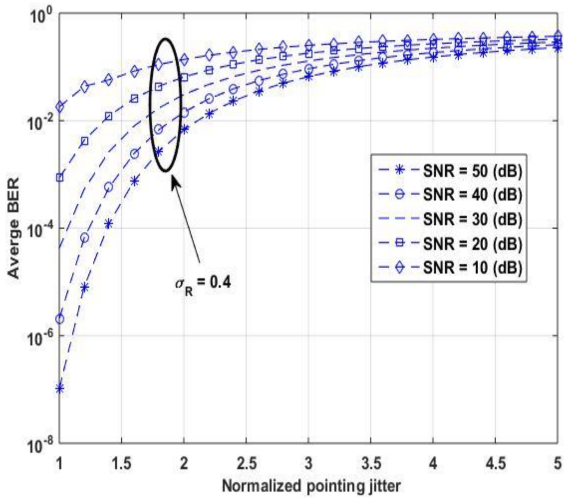

Fig.3 Average BER against the normalized pointing jitter over I-K distributed turbulence fading.

pointing error. We assume the plane wave propagation. The atmospheric path loss coefficient is set to 0.44 dB/km. The Rytov variance, describing the strength of the turbulence, is set to 0.16. The turbulence parameters α and β are set to 14.1108 and 12.5379, respectively. The normalized Gaussian beam width is set to 2.

In Fig. 3, the average BER performance is illustrated against the normalized pointing jitter over different SNR values. The normalized jitter varies between 1 and 5. As can be seen, as the alignment between the transmitter and receiver increases, the average BER increases significantly. It is also interesting to note that when the normalized jitter increases beyond 2.5, the slope of the average BER curve approaches to zero irrespective of the SNR values. This can be attributed to the fact that at a misalignment error greater than 2.5, the received optical power at the photodiode falls drastically. It is to be noted that the average BER curves obtained in Fig. 3 are valid for any combination of propagation path, optical wavelength, and turbulence strength.

4. CONCLUSIONS

In this paper, we have presented the impact of random pointing error, i.e., the pointing jitter due to the misalignment of the transmitter beam and receiver FOV axis. We have considered the doubly stochastic turbulence fading. The average BER performance analysis was presented.

5. ACKNOWLEDGMENT

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