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Coded On Off Keying System For Free Space Optical Link over Strong Turbulence and Misalignment Fading Channels

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ABSTRACT

The presence of turbulence and aiming error effects degrades the performance of optical wireless systems significantly. Error control coding techniques are frequently proposed to fulfil common bit error rate (BER) requirements for reliable communications within practical signal-to-noise ratio limits. Through symbol by symbol interleaved channels characterised by high turbulence and/or pointing error effects, we study the error performance of convolutional coded on-off keying free-space optical systems. We investigate a variety of channel types and obtain precise analytical equations for pairwise error probability. Using the transfer function approach, these formulas are used to derive upper constraints on BER performance.

Keywords- Free-Space OpticalCommunications, Atmospheric Turbulence Channel, Pair Wise Error Probability, Error Performance Analysis.

I. INTRODUCTION

Free-space optical (FSO) devices may be utilised for a range of applications, including a viable solution for the last mile problem, among others. Various impairments, on the other hand, complicate FSO connection design and reduce error performance [1]. The distance between the transmitter and receiver attenuates optical wireless signals, which are also susceptible to air turbulence. Another factor impacting performance is the proper alignment of transmitters and receivers. Building sway causes vibrations in the transmitted beam, resulting in misalignment (pointing error (PE) effects) between the transmitter and receiver [2]. Because FSO systems are typically installed on high buildings, building sway causes vibrations in the transmitted beam, resulting in misalignment (pointing error (PE) effects). Error control coding has been used to meet conventional bit error rate (BER) objectives for reliable communications within practical signal-to-noise ratio (SNR) levels. Zhu and Kahn calculated an upper bound on the pair wise error probability (PEP) of coded FSO lines using intensity modulation/direct direction (IM/DD) and offered upper bounds on BER for different coding schemes such as block, convolutional, and turbo codes in their paper. Uysal and Li evaluated the performance of convolutional coded FSO systems for turbulence channels simulated by the negative exponential (NE), K, I-K, and gamma-gamma channels, respectively, using the identical assumptions as Uysal and Li. Due to the difficulties of analytically managing these unique turbulence probability density functions (pdf) [1,] they made approximations on the generated PEP. In response to an increasing need for highspeed, tap-proof communication systems, free-space optical communication (FSO) technologies (in space and inside the atmosphere) have evolved. Satellites, deep-space probes, ground stations, unmanned aerial vehicles (UAVs), high-altitude platforms (HAPs), planes, and other mobile communication partners are all of practical importance. Furthermore, all of the linkages may be used in both military and civilian settings. FSO is the next step in net-centric connection, since bandwidth, spectrum, and security concerns encourage its use as a supplement to radio frequency (RF) communications [5]. For successful signal transmission in optical wireless systems, continuous alignment between transmitter and receiver is critical. However, high-rise buildings wobble due to thermal expansion, dynamic wind loads, and minor earthquakes, causing vibrations in the transmitter beam and, as a result, misalignment (pointing error) effects between the transmitter and receiver. The designers should enhance the beam width and power to overcome this challenge and maintain line-of-sight between the transmitter and receiver. A large beam width, on the other hand, raises the needed signal-to-noise (SNR) ratio, increasing expense and complexity, whilst a low beam width might cause outages [1]. As a result, correct optimization approaches must be used [2]. Misalignment fading has been investigated for inter-satellite laser communications as well as short-range terrestrial connectivity. Arnon used a modest detector model to construct a mathematical model to decrease transmitter power and optimise the divergence angle for a particular bit-error rate (BER). He hasn't offered closed form expressions, and he hasn't looked at the outage probability, which is a popular statistic for FSO connections. Liu [2] proposed two optimization challenges for FSO systems employing quantum cascade lasers based on Arnon's work. Farid and Hranilovic presented an FSO channel model for fading owing to air turbulence and aiming error effects in [3], which took beamwidth, pointing error variance, and detector size into account. They use a considerably simpler model for misalignment fading than the one in [1]. They looked at lognormal and gamma-gamma distributed turbulence in particular, and evaluated the system's capacity and outage likelihood. They used test and trial methods to improve the beamwidth in order to maximise the channel capacity exposed to outage, but they did not explore the BER performance. Sandalidis et al. calculated the average BER expression for an intensity-modulated/direct detection (IM/DD) FSO system with on-off keying (OOK) in [4], assuming substantial turbulence fading and pointing error effects.

II. PROPOSED SYSTEM

For the first time, we looked at the error performance of optical wireless communication systems using coded on-off keying (OOK) across symbol-by-symbol interleaved channels with high turbulence and pointing error effects. K or NE distributions are used to model turbulence. In particular, we analyse various channel combinations while considering turbulence and/or aiming error effects and develop explicit mathematical equations for the PEP. Using the transfer function approach, these formulas are then used to determine upper constraints on BER performance. Error control coding techniques are frequently proposed to fulfil common bit error rate (BER) requirements for reliable communications within feasible signal-to-noise ratio limits [1]. The following diagram depicts this.

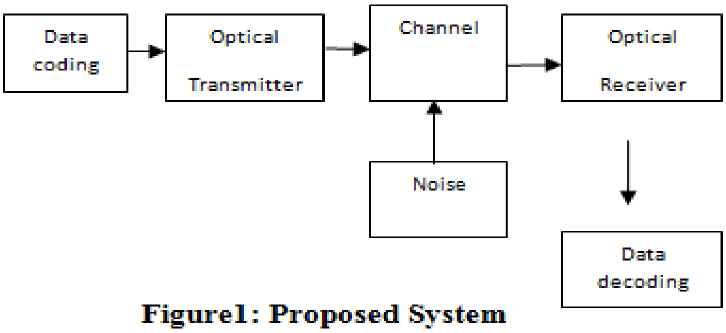


Figure1: Proposed System

Advantages of Proposed System:

1. We can achieve low BER objectives for tiny SNR levels by employing OOK coding.
2. This research may readily be applied to different turbulence models.

A) Scope

1) The suggested approach is applicable to large modulation bandwidths. An optical carrier's frequency ranges from 1012-1010 to 2000 THz data bandwidth [3].

2) The suggested technology is suitable for usage with small beam sizes. The diffraction restricted divergence of a typical laser beam is approximately 0.01-0.1 mrad [3].

3) Our proposed method is simple to set up and take down.

The FSO technology is portable and easy to set up. The FSO link may also be quickly redeployed to another site in a short amount of time [5].

III. PROPOSED METHODOLOGY

1. Data Coding:

The data coding process receives the input data. It may provide both analogue and digital data. This is where the data is encoded. The bipolar encoding approach [3] is used here.

2. Optical Transmitter:

The optical transmitter receives encoded data. It encodes data and turns it to an optical signal. Each block of data bits is initially modified by an electrical OOK modulator on the transmitter side [3].

3. Channel:

Optical data is sent over a channel. When data is sent from transmitter to receiver through a channel, noise is introduced. The coded On-Off keying technique is utilised to reduce high turbulence and channel fading [4]. It's used for secure data transmission [13].

4. Optical Receiver:

It is applied to the communication system's receiver side. It's a noise-cancelling device. It decodes optical signals and turns them into original data [3]. Demodulation occurs on the receiver's end [6].

5. Data Decoding:

We can use any type of decoding algorithm. We are using here bipolar decoding process [3].

6. System Models:

A single-input single-output (SISO) FSO system with IM/DD and OOK is considered. A light source is contained in the transmitter, and the laser beam travels in a horizontal direction. A lens on the receiving antenna focuses the received beam onto an optical receiver. Because a point receiver is employed, aperture averaging is not possible. The receiver is also assumed to use ML soft decoding [1].

7. Channel models:

a) Turbulence Channel Models:

For various degrees of turbulence severity, a variety of statistical models have been developed to characterise turbulence-induced fading. The log-normal model is one of the most often utilised models when there are modest irradiance variations and lengthy propagation lengths. Discrepancies, on the other hand, emerge when the turbulence strength increases. In that instance, the K or NE distributions can be used to simulate irradiance statistics [1, 4].

b) Misalignment Fading Model:

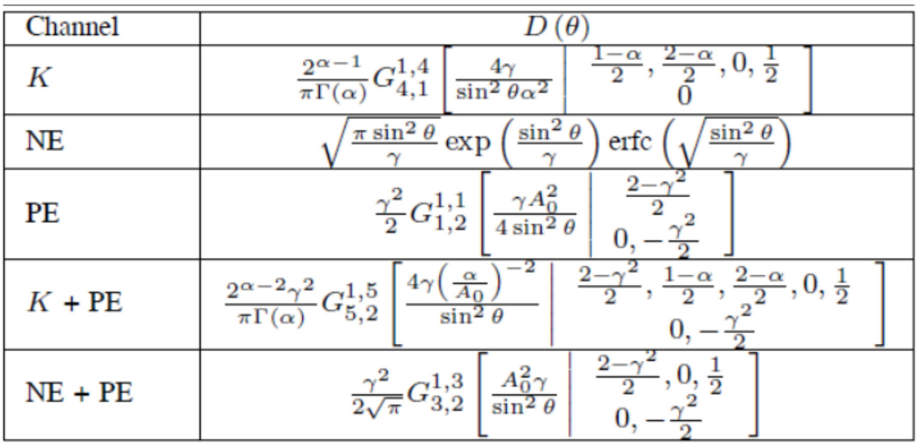
The appropriate alignment between transmitters and receivers is a difficult problem in FSO transmission particularly for long-range systems. A tractable pdf to describe misalignment fading is also introduced [5].

IV. ERROR PERFORMANCE

For coded systems, the PEP has been the basic method for the union bounds calculation and is used as the main criterion for code design [1]. This metric represents the probability of choosing the coded sequence **X**^ = (x1^,….,xN^) when **X** = (x, ..., xN) is transmitted [5]. Assuming the assumptions in [3], i.e., maximum likelihood soft decoding with perfect CSI and OOK transmission, the conditional PEP subject to fading coefficients **I** = (I1, I2, ..., IM) is given as

$$P\left(\mathbf{X}, \hat{\mathbf{X}}\,|\mathbf{I}\right) = Q\left(\sqrt{\frac{E_s}{2N_0}\sum_{k\epsilon\Omega} I_k^2}\right)$$

where $Q(\cdot)$ is the Gaussian Q function, Es is the total transmitted energy, and **X** and **X**^ differ from each other. We have obtained error performance using K and NE channel. The expression of D(ϴ) for K and NE channel is given as



Channel	$D(\theta)$
K	$\frac{2^{\alpha-1}}{\pi\Gamma(\alpha)} G_{4,1}^{1,4}\left[\frac{4\gamma}{\sin^2\theta\alpha^2} \,\middle\vert\, \begin{matrix} \frac{1-\alpha}{2}, \frac{2-\alpha}{2}, 0, \frac{1}{2} \\ 0 \end{matrix}\right]$
NE	$\sqrt{\frac{\pi\sin^2\theta}{\gamma}} \exp\left(\frac{\sin^2\theta}{\gamma}\right) \operatorname{erfc}\left(\sqrt{\frac{\sin^2\theta}{\gamma}}\right)$
PE	$\frac{\gamma^2}{2} G_{1,2}^{1,1}\left[\frac{\gamma A_0^2}{4\sin^2\theta} \,\middle\vert\, \begin{matrix} \frac{2-\gamma^2}{2} \\ 0, -\frac{\gamma^2}{2} \end{matrix}\right]$
K + PE	$\frac{2^{\alpha-2}\gamma^2}{\pi\Gamma(\alpha)} G_{5,2}^{1,5}\left[\frac{4\gamma\left(\frac{\alpha}{A_0}\right)^{-2}}{\sin^2\theta} \,\middle\vert\, \begin{matrix} \frac{2-\gamma^2}{2}, \frac{1-\alpha}{2}, \frac{2-\alpha}{2}, 0, \frac{1}{2} \\ 0, -\frac{\gamma^2}{2} \end{matrix}\right]$
NE + PE	$\frac{\gamma^2}{2\sqrt{\pi}} G_{3,2}^{1,3}\left[\frac{A_0^2\gamma}{\sin^2\theta} \,\middle\vert\, \begin{matrix} \frac{2-\gamma^2}{2}, 0, \frac{1}{2} \\ 0, -\frac{\gamma^2}{2} \end{matrix}\right]$

V. NUMERICAL RESULTS AND DISCUSSION

This section contains many numerical studies that test the performance of the interleaved symbol by symbol channel under turbulence and/or misaligned fading situations. We simply consider the turbulence impact at first. The resultant PEP expressions for the K and NE channels, provided by (1), in terms of the electrical average SNR, are shown in Fig. 2. In that diagram, we utilise many values of parameter and assume an error event of duration 2, i.e., = 2. The results reveal that when turbulence weakens (increases), the system performance does not improve much. Because the K distribution is less sensitive at high values of, this occurs. Furthermore, when PEP = 20, the PEP is extremely similar to that of the NE channel. This is to be expected, given that the K distribution for tends to be NE. Non Return to Zero (NRZ) and Return to Zero (RZ) modulation methods are used to achieve coded on off keying (RZ). Figure 3 depicts this.

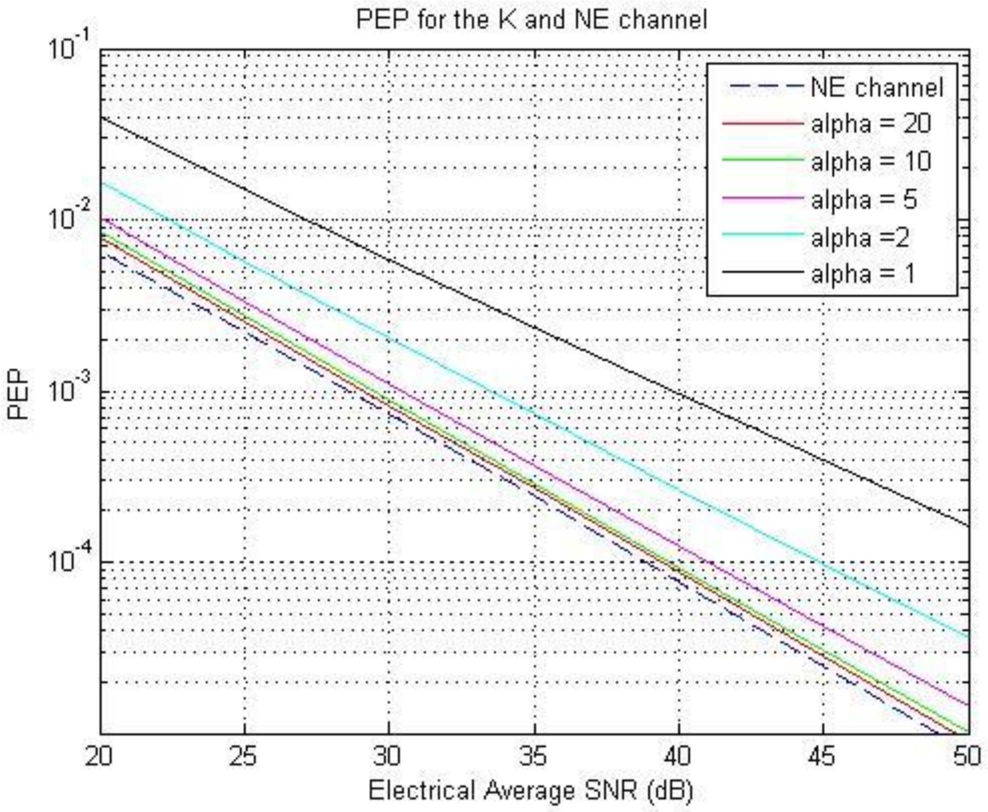


Figure2: PEP for the K and NE channel

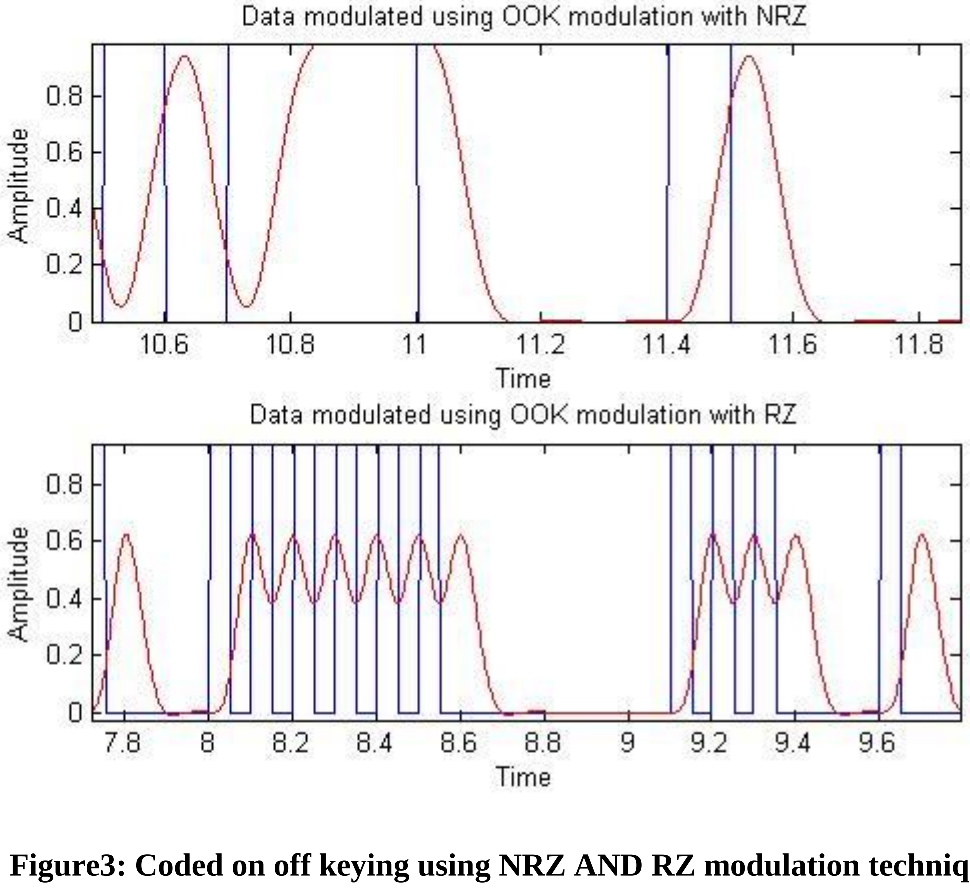


Figure3: Coded on off keying using NRZ AND RZ modulation technique

VI. CONCLUSION

Using convolutional error control coding techniques, we evaluated the error rate performance of an IM/DD with OOK optical wireless system. We assumed symbol-by-symbol interleaved channels with significant turbulence and/or fading misalignment. Using the transfer function approach, we were able to extract accurate PEP expressions and achieve upper constraints on BER performance.

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