UNIVERSITI PUTRA MALAYSIA

EFFECT OF GAMMA-GAMMA DISTRIBUTION ON PERFORMANCE OF OPTICAL DIFFERENTIAL 8-LEVEL PHASE SHIFT KEYING IN FREE SPACE OPTICAL COMMUNICATION

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By

MOHAMMAD BOROON

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

May 2016

DEDICATION

This thesis is dedicated to:
my patient and beloved parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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May 2016

Chairman : Ratna Kalos Zakiah binti Sahbudin, PhD
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The work in this thesis focuses on performance analysis of optical differential 8-level phase shift keying (OD8PSK) in free space optical (FSO) communication. The current FSO connections lack reasonable throughput and reliable communication. For long, researchers studied this vast area of optics to ensure connectivity at last mile to fiber infrastructure. Simulation analysis using an electrically coded OD8PSK and bi-level receiver containing 4 delay and add filters (DAFs) is chosen. Gamma-gamma distribution is utilized to account for scintillation regime throughout FSO transmission. Numerical investigation using two well-known semi-analytical methods namely Chi-squared representation and Karhunen-Loeve series expansion (KLSE) is conducted. These methods analyze performance of OD8PSK in different aspects to bring the most reliable outcomes. Using Chi-squared representation, the sensitivity limits of OD8PSK receiver in presence of gamma-gamma fading is investigated. This method shows for the worst bit error rate (BER), additional 21.8 photons/bit are required to maintain BER = 10^{-9}. This cause increment of 2.18 dB optical signal to noise ratio (OSNR) limit comparing to back-to-back OD8PSK and additional 8.12 dB power penalty comparing to traditional fiber models to triple spectral efficiency. Investigation of distance allowance is done by KLSE BER analysis. Using the OSNR reading of simulation results and utilizing the KLSE, The maximum permissible distance at which OD8PSK FSO can operate while maintaining BER of 10^{-9} is 1.53, 1.64, 1.72 and 1.83 km for scintillation intensities of 10^{-12}, 10^{-13}, 10^{-14} and 10^{-15} $m^{-2/3}$ respectively. Finally phase offset error analysis of DAFs is conducted by investigating the sensitivity penalty at the receiver. OD8PSK in FSO is proven to tolerate 0.75º of phase error for 1 dB sensitivity penalty for BER of 10^{-9}.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

KESAN TABURAN GAMMA-GAMMA KEATAS PRESTASI KEBEZAAN OPTIK 8-ARAS KEKUNCI ANJAKAN FASA DALAM KOMUNIKASI OPTIK RUANG BEBAS

Oleh

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Kajian dalam tesis ini memberi tumpuan kepada analisis prestasi kebezaan optik 8-aras kekunci anjakan fasa (OD8PSK) dalam komunikasi optik ruang bebas optik (FSO). Sambungan FSO peringkat kini mempunyai kekurangan dari segi data yang munasabah dan komunikasi yang boleh diharapkan. Para penyelidik telah mengkaji optik ini untuk tempoh yang lama secara luas untuk memastikan sambungan di infrastruktur serat di peringkat akhir. Analisis simulasi yang menggunakan kod secara elektrik OD8PSK dan penerima dwi-tahap yang mengandungi 4 selang dan penambahan penapis (DAFs) telah dipilih. Taburan gamma-gamma digunakan untuk mengira rejim sintilasi di sepanjang transmisi FSO. Siasatan numerik menggunakan dua kaedah semi-analisis yang terkenal iaitu gambaran *Chi-squared* dan pengembangan siri Karhunen-Loeve (KLSE) dijalankan. Kaedah-kaedah ini menganalisi prestasi OD8PSK dalam aspek-aspek yang berbeza untuk memberikan hasil yang boleh dipercayai. Dengan menggunakan gambaran *Chi-squared*, had kepekaan penerima OD8PSK dengan kehadiran gamma-gamma pudar disiasat. Kaedah ini menunjukkan kadar ralat bit (BER) yang terburuk, penambahan 21.8 foton/bit yang diperlukan untuk mengekalkan BER=10^{-9}. Ini menyebabkan kenaikan 2.18 dB had nisbah isyarat optik kepada bunyi bising (OSNR) berbanding dengan OD8PSK secara berturutan dan penambahan 8.12 dB penalti kuasa OD8PSK berbanding dengan model gentian tradisional kepada kecekapan tiga spektrum. Siasatan peruntukan jarak dilakukan dengan analisis BER KLSE. Dengan bacaan keputusan simulasi dan penggunaan KSLE, jarak maksimum yang dibenarkan di mana OD8PSK FSO boleh beroperasi dengan mengekalkan BER 10^{-9} adalah 1.53, 1.64, 1.72 dan 1.83 km untuk keamatan sintilasi 10^{-12}, 10^{-13}, 10^{-14}, dan 10^{-15} $m^{-2/3}$. Akhirnya, analisis fasa imbangan ralat DAFs dijalankan dengan menyiasat kepekaan penalti pada penerima. OD8PSK dalam FSO terbukti bertoleransi sebanyak 0.75^0 dari ralat bagi 1 dB penalti kepekaan untuk BER 10^{-9}.

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I certify that a Thesis Examination Committee has met on 05 May 2016 to conduct the final examination of Mohammad Boroon on his thesis entitled "Effect of Gamma-Gamma Distribution on Performance of Optical Differential 8-Level Phase Shift Keying in Free Space Optical Communication" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

APD	Avalanche Photodiode
APSK	Amplitude Phase Shift Keying
BER	Bit Error Rate
DAF	Delay-and-Add Interferometer Filter
DPSK	Differential Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
EDFL	Erbium-Doped Fiber Laser
FSO	Free Space Optical
GSL	Geometrical Spreading Loss
IM/DD	Intensity Modulation Direct Detection
IR	Infra-Red
ISI	Inter-Symbol Interference
KLSE	Karhunen-Loeve Series Expansion
LED	Light Emitting Diode
LD	Laser Diode
LOS	Line of Sight
MZM	Mach-Zehnder Modulator
NRZ	Non-Return-Zero
OD8PSK	Optical Differential 8-level Phase Shift Keying
OOK	On-Off Keying
OSNR	Optical Signal to Noise Ratio
PDF	Probability Density Function
PM	Phase Modulator
PPM	Pulse Position Modulation
PRBS	Pseudo-Random Bit Sequence
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QL	Quantum Limit
QPSK	Quadrature Phase Shift Keying

RF	Radio Frequency
RZ	Return-Zero
SPM	Self-Phase Modulation
VCSEL	Vertical Cavity Surface Emitting Laser
VLC	Visible Light Communication
WDM	Wavelength Division Multiplexing
WOC	Wireless Optical Communication
XPM	Cross-Phase Modulation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Optical communication which at first initiated with fiber optics sparkled a revolution in global communication and network systems. Ever since its introduction in 1980s, the major objectives of optical communications were to increase the throughput of systems to meet demands of higher number of users but thereafter, accessibility became an issue when users became more scattered. By evolution of wireless networks in radio frequency (RF) band, there were already a stream of demands that overwhelmed that technology in all bandwidths. In other words, local wireless networks became too popular and the bandwidths were too scarce; that led up to higher price of bandwidth acquisition and licensing. In past few years wireless optical communication (WOC) emerged as a promising resolution to overcome the deficiencies of RF spectrum [1]. Free space optical (FSO) is a wireless optics technology that uses air (instead of fiber) for its transmission medium. It is a point-to-point technology highly dependent on line of sight (LOS) availability [2]. License free performance, insensitivity from radiation and high transmission data rate make this technology ahead of its RF counterpart [3]. FSO also has several advantages comparing to fiber optics; fast deployment and mobility are the most advantageous aspects of its function [4]. The research for more reliability and more data rate transmission along with higher link range has repeatedly been conducted by scientists. Furthermore, study of degrading factors such as internal optical loss, atmospheric induced loss, geometrical loss and etc, proved to have results directly proportional to systems performance. In the past few years advanced modulation of FSO systems are one of the attractive approaches to address these challenges. Researchers have focused their efforts on producing multi-level modulations such as quadrate amplitude modulation (QAM) FSO [5], and advanced optical coding. Phase shift keyed (PSK) modulation which transfers data by recognition of phase shifts has been studied to produce multi-level transmission in FSO [5-8]. Optical differential 8-level phase shift keyed (OD8PSK) is an eight level phase modulation which operates by precise definition of phases with 45 degrees in-phase angle [9]. OD8PSK, transmits 3 data bits per symbol under a modification of Grey code which helps reduce the bit error rate (BER) as when there is an error in a symbol it only affects one bit error instead of all 3 bits. Moreover, it provides higher data rate transmission capacity as compared to traditional on-off keyed (OOK) module by increasing optical efficiency. There has been several researches to investigate performance of an OD8PSK signal [10-13]. The most common performance evaluation is by BER analysis [11, 13], receiver sensitivity [13] and electrical characteristics of receiving signal [12, 14]. Study of effects of atmosphere on performance on FSO signal is another point of attention in this thesis. The air affects signal in many ways such as absorption, scattering and attenuation and it varies with different climate conditions. To study the effect of scintillation, several methods have been presented to account for range of scintillation [3, 5, 15-19]. The gamma-gamma distribution of atmospheric loss brings the most accurate findings among others. This is supported by the fact that gamma-gamma model can cover a wide range of changes in air refractive index variations from weak to strong. In detail, this research combines an OD8PSK communication system with characteristics of a FSO channel and under simulation and theoretical analysis, proves its performance capabilities.

1.2 Motivation

There has been several methods of implementation of an outdoor FSO system utilizing different modulations [5-8, 16, 20-25]. Nevertheless, these models all lack a state of efficiency in optical spectrum and hence provide limited performance. Multi-level modulation formats have proven their superiority in spectral efficiency and data rate transmission. If accurately coded and modulated they can increase throughput to a great extent. It has been reported that OD8PSK modulation format utilizing a multi-level modulation with specific in-phase PSK produces optimum results in fiber [12, 14, 26, 27], however, there has not been a study of this module in free space medium. Moreover, to implement this new technology, an accurate and reliable optical signal atmospheric loss investigation is required. Therefore, to meet these scientific demands, in this thesis an OD8PSK communication system operating at 21 Gbps has been simulated and analytically investigated over an accurate gamma-gamma distribution of scintillation effects.

1.3 Problem Statement

The following problems need to be addressed

i. Lack of research on implementation of higher order phase modulations in FSO
ii. Feasibility of OD8PSK modulation in FSO communication
iii. Performance investigation of OD8PSK in FSO communication

1.4 Objectives

Based on the problem statement stated earlier, there are several objectives needed to be realized and fulfilled which are mentioned below:

i. To define a relationship between OD8PSK modulation and FSO medium.
ii. To analyze the effects of atmospheric scintillation (gamma-gamma distribution) on performance of outdoor OD8PSK – FSO system using simulation analysis
iii. To investigate the effects of scintillation on BER of receiving FSO signal using numerical analysis
iv. To define performance limitations (distance, sensitivity and phase offset error tolerance) of using OD8PSK in gamma-gamma distribution

1.5 Scope and Limitation

Figure 1.1 shows the scope of works covered in this master research. This work focuses on FSO, which can be divided based on ground or terrestrial implementation. The objective of this thesis is to propose an outdoor ground to ground FSO system based on modulation technique and atmospheric turbulence analysis. However, the main motivation is to implement a multi-level PSK modulation on performance analysis of a medium and long range FSO system. In this work, an OD8PSK is proposed due to many advantages such as higher spectral efficiency and simple balanced-direct detection receiver designed for it. A single channel FSO communication is realized by employing a 1550 nm laser source.

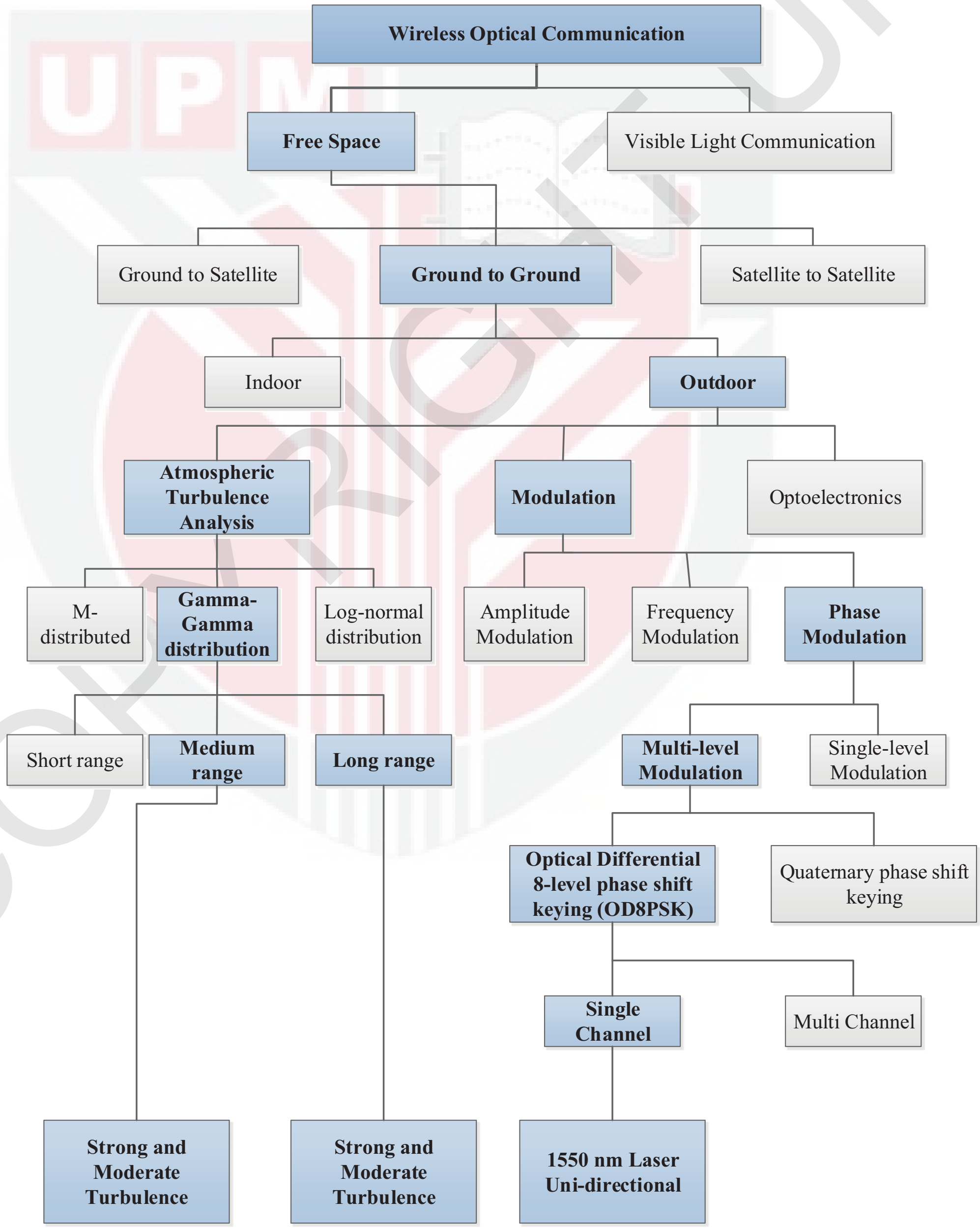

Figure 1.1: Scope of research

1.6 Thesis Contribution

This thesis contributes to current knowledge of FSO with expansion extent to investigate for the first time, the performance of OD8PSK communication system on a turbulent atmosphere in FSO medium. Such method has never been introduced before, therefore novelty is a part of contributions. Moreover, Using simulation and analytical results, performance analysis of this method is studied and presented which is a new finding. The final conclusion would help expand this field of study and broaden a future research opportunities in FSO.

1.7 Thesis Layout

In general, this thesis consist of five chapters.

Chapter 1, which is this current chapter, gives a general introduction of the topics and defines the context of the work.

Chapter 2 introduces an overview background on the concept of optical communication in wireless and free space. It then explains the theoretical backgrounds of free space optics and describes the methods previously proposed. Moreover, principle operation of OD8PSK generation and review of literature is briefly discussed and at the end of the chapter, analysis methods of atmospheric turbulence is concisely described.

Chapter 3 discusses the utilization of previously proposed model for OD8PSK system originating 3 signals at transmitter as electrical encoding part. The transmitter and receiver configurations used in simulation are shown. Furthermore, preliminary results of the configuration is presented. This proves feasibility of the method in new transmission condition. Characteristics of the simple direct detection optical receiver is then studied. In addition, the degrading function of gamma-gamma distribution as the governing regime of atmospheric scintillation is studied. Using simulation and numerical results, preliminary results are shown and the method is proved optimum.

Chapter 4 is devoted to the performance results of the OD8PSK FSO system at 21 Gbps at varying transmission distances. Results focus on reliable and robust performance of system under severe weather conditions. The influences of degrading factors such as differences in refractive indices of air packets, size of the aerosols (eddies), link range, phase offset error are investigated and results are extracted. Receiver sensitivity and BER form the comparative analysis of input/performance parameters versus the output parameters are used to conclude the objectives.

The finding of this work is summarized and concluded in Chapter 5. The performances of the proposed utilization are detailed in this chapter. Moreover, it includes the contribution of this thesis and the recommendation for further research work

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