UNIVERSITI PUTRA MALAYSIA

PERFORMANCE ANALYSIS OF FREE SPACE OPTICAL COMMUNICATIONS EMPLOYING DUTY CYCLE DIVISION MULTIPLEXING

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PERFORMANCE ANALYSIS OF FREE SPACE OPTICAL COMMUNICATIONS EMPLOYING DUTY CYCLE DIVISION MULTIPLEXING

By

MARYAM KHAZAALI

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

July 2015

DEDICATIONS

In the name of Allah, Most Gracious, Most Merciful
This thesis is dedicated to:

My beloved husband Mohammad, for his love, patience and constant support
And
My caring and devoted parents for their unconditional love and support

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

PERFORMANCE ANALYSIS OF FREE SPACE OPTICAL COMMUNICATIONS EMPLOYING DUTY CYCLE DIVISION MULTIPLEXING

By

MARYAM KHAZAALI

July 2015

Chair: Salasiah Binti Hitam, PhD
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Expanding request for more new broadband services everywhere, caused an explosive capacity growth in communication networks during past few years. Fiber optics is an enabler to provide high speed communications. However, in regions where fiber is not employable, Free Space Optics (FSO) system is proposed as one effective solution for last mile bottleneck. FSO is a wireless optical network which transmits high data rates by narrow laser beam between a pair of communicating transceivers through the air. Despite the fact that FSO is license free, cheap to implement, fast to install, and extremely directional with abundant bandwidth, the atmospheric factors have vigorous impact on its performance. FSO link range is highly limited by atmospheric attenuation. In this study, the effect of atmospheric attenuation such as turbulence, scattering, absorption, scintillation and spreading in different weather conditions is investigated based on gamma-gamma distribution with On-Off keying (OOK). Multiplexing is a technique where multiple data streams are transmitted simultaneously through a single link to increase the transmission capacity and reduce the system costs. The main contribution of this research can be considered as employment of Duty Cycle Division Multiplexing (DCDM) in FSO to transmit data for different users on the same laser beam. This way, more number of users are accommodated using less number of lasers which is more economical and cost effective. As a first step, DCDM architecture is designed for both single channel and multi-channel transmission. System performance is investigated analytically based on the design metrics such as optical received power, optical signal to noise ratio (OSNR), bit error rate (BER) and link range. Results show that adverse weather conditions confine the supported FSO link range dramatically, as much higher transmitter power is needed to cover a mile of distance under heavy Malaysian rain. Although using proposed DCDM to send multiple users on a single laser slightly reduces the link range, it also

introduces several advantages such as: higher optical received power efficiency, less number of required components and cost effective. Furthermore, two different design of proposed DCDM obtain significantly smaller OSNR (1.9 dB and 3.3 dB), and higher energy saving (18.78% and 31.63%) compared to conventional WDM.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah master sains

ANALISIS PRESTASI KOMUNIKASI OPTIK RUANG BEBAS MENGGUNAKAN PEMULTIPLEKSAN PEMBAHAGI KITARAN DUTI

Oleh

MARYAM KHAZAALI

Julai 2015

Pengerusi: Salasiah Binti Hitam, PhD
Fakulti: Kejuruteraan

Pertambahan permintaan untuk perkhidmatan jalur lebar baru di mana-mana, menyebabkan letusan pertumbuhan kapasiti dalam rangkaian komunikasi semenjak kebelakangan ini. Gentian optik adalah penggerak untuk menyediakan komunikasi berkelajuan tinggi. Walau bagaimanapun, di kawasan-kawasan di mana gentian tidak boleh digunakan, system Optik Ruang Bebas (FSO) dicadangkan sebagai satu penyelesaian berkesan untuk kesesakan batu terakhir . FSO adalah rangkaian optik tanpa wayar yang menghantar kadar data yang tinggi oleh pancaran laser sempit antara sepasang penghantar dan penerima melalui udara. Walaupun FSO adalah lesen percuma, murah untuk dilaksanakan, cepat untuk pemasangan, dan amat terarah dengan lebar jalur yang besar, faktor-faktor atmosfera memberi kesan yang kuat pada prestasinya. Jarak pautan FSO amat terhad oleh pengecilan atmosfera. Dalam kajian ini, kesan pengecilan atmosfera seperti pergolakan, penyerakan, penyerapan, sintilasi dan rebakan dalam keadaan cuaca yang berbeza disiasat berdasarkan taburan gamma-gamma dengan kekunci buka-tutup (OOK). Pemultipleksan adalah satu teknik di mana beberapa aliran data disebarkan secara serentak melalui satu pautan untuk meningkatkan keupayaan kapasiti penghantaran dan mengurangkan kos sistem. Sumbangan utama kajian ini ialah penggunaan Pemultipleksan Pembahagi Kitaran Duti (DCDM) dalam FSO untuk menghantar data pengguna yang berbeza dalam pancaran laser yang sama. Dengan cara ini, lebih bilangan pengguna dapat ditempatkan menggunakan kurang bilangan laser yang lebih menjimatkan dan kos yang efektif. Sebagai langkah pertama , seni bina DCDM direka untuk kedua-dua saluran tunggal dan penghantaran berbilang saluran. Prestasi sistem disiasat secara analisis berdasarkan metrik reka bentuk seperti kuasa menerima optik, isyarat optik kepada nisbah bunyi (OSNR), kadar ralat bit (BER) dan jarak pautan . Keputusan menunjukkan bahawa kuasa pemancar dalam keadaan cuaca bu-

ruk mempengaruhi jarak pautan FSO secara mendadak, kuasa pemancar lebih tinggi diperlukan untuk menampung jarak yang lebih jauh di bawah hujan lebat di Malaysia. Walaupun cadangan menggunakan DCDM untuk menghantar beberapa pengguna pada laser tunggal mengurangkan jarak pautan, ia juga memperkenalkan beberapa kelebihan seperti: kecekapan kuasa optik yang diterima lebih tinggi kurang penggunaan komponen yang diperlukan dan kos yang lebih efektif. Sebagai tambahan, dua reka bentuk DCDM yang dicadangkan mendapat OSNR lebih kecil (1.9 dB dan 3.3 dB), dan penjimatan tenaga yang lebih tinggi (18.78% dan 31.63%) berbanding konvensional WDM.

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I certify that a Thesis Examination Committee has met on **07/07/2015** to conduct the final examination of **Maryam Khazaali** on her thesis entitled "**PERFORMANCE ANALYSIS OF FREE SPACE OPTICAL COMMUNICATIONS EMPLOYING DUTY CYCLE DIVISION MULTIPLEXING**" 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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This is to confirm that:

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LIST OF ABBREVIATIONS

AM	Amplitude Modulation
ADC	Amplitude Distribution Controller
ANSI	American National Standards Institute
APDCDM	Absolute Polar Duty-Cycle Division Multiplexing
BER	Bit Error Rate
CW	Continuous Wave
CDM	Code Division Multiplexing
CDR	Clock and Data Recovery
CRC	Clock Recovery Circuit
DC	Duty Cycle
DD	Direct Detection
DFB	Distributed Feed Back
DCDM	Duty Cycle Division Multiplexing
EM	Electrical Method
EDC	Edge Detecting Circuit
EDFA	Erbium Fiber Amplifier
ERFC	Error Function
E-DCDM	Electrical Duty Cycle Division Multiplexing
FSO	Free Space Optics
GL	Geometric Loss
IR	Infrared
IEC	International Electrotechnical Commission
ILECs	Incumbent Local Exchange Carriers
IM/DD	Intensity Modulation / Direct Detection
LD	Laser Diode
LAN	Local Area Network

LOS	Line of Sight
LPF	Low Pass Filter
LASERCOM	Laser Communication
MAN	Metropolitan Area Network
MIMO	Multiple Input Multiple Output
MZM	Mach-Zehnder Modulator
MFD	Mode Field Diameter
NRZ	Non-Return-to-Zero
N-T-N	Null-To-Null
NOAA	National Oceanic and Atmospheric Administration
OM	Optical Method
OMA	Optical Modulation Amplitude
OBPF	Optical Band Pass Filter
OOK	On-Off Keying
OCDM	Optical Code Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing
OTDM	Optical Time Division Multiplexing
O-DCDM	Optical-Duty Cycle Division Multiplexing
PD	Photo Detector
PLL	Phase Lock Loop
PMP	Point To Multipoint
PTP	Point-To-Point
PDF	Probability Density Function
QoS	Quality of Service
RZ	Return-to-Zero
RF	Radio Frequency

TDM	Time Division Multiplexing
UV	Ultra Violet
UAV	Unmanned Airborne Vehicle
WDM	Wavelength Division Multiplexing

CHAPTER 1

INTRODUCTION

1.1 Background

The huge development of internet data traffic and also concurrent expand on computation capacity has prompted a double-state of high speed networks in the core of the internet, during this manner, putting a gap in the area of providing access that is a part of these two super fast phenomenon. This access area, conspicuously called the first mile area (the last mile) could be a business sector portion seeing extraordinary development even in bearish time [1]. Therefore, the offered services to the users get more complex. Subsequently, the network has to provide extremely bigger data rates to take care of the requested service. Optical innovation is an option to provide such a huge data rates.

Although, fiber is the respectable optical solution for ultra-high data delivery rate, but there are some requisitions for which fiber might not be a suitable answer. For the reasons that either the atypical land for fiber installation, or short time network is required that no justification for the expensive fiber substructure [2].

A ubiquitous geographic reach is Wireless technology, which can go wherever fiber cannot. However, the spectrum of wireless has limited bandwidth [3]. As a result, another possible answer is the free space optics (which is known as fiberless) and called open-air optical communications and optical wireless [2]. This technology of FSO in the first mile is replicated instead of both fiber and wireless solution by considering the comparable performance with fiber and much more than bandwidth in terms of characteristic of wireless.

FSO utilizes a narrow laser beam that causes much difficulty in detection, jamming and interception when taking security into account [3]. Also, FSO has more encouraging characteristics, as it comes with simple installation and useful links, because of its innate durability to electromagnetic waves and license-free operation [4]. Despite, the main drawback is the manner of light propagation is changed by environmental effects [3]. Space communications like deep space and inter-satellite, and terrestrial communications like last-mile access network, enterprise connectivity and backup links, are contained as various application scenarios for FSO which can be successfully employed as shown in Figure 1.1.
By way of the terrestrial FSO system is capable to be the beneficiary when used in high speed access networks in addition to provide connectivity to remote radio antennas, its usage is limited to short distances (in km), and it bridges two separate fiber links for further applications [4]. Although, FSO has less limitation in bandwidth; but an appropriate and sensible option for high-speed transmission has not been regarded nowadays, such as those of the terrestrial networks.

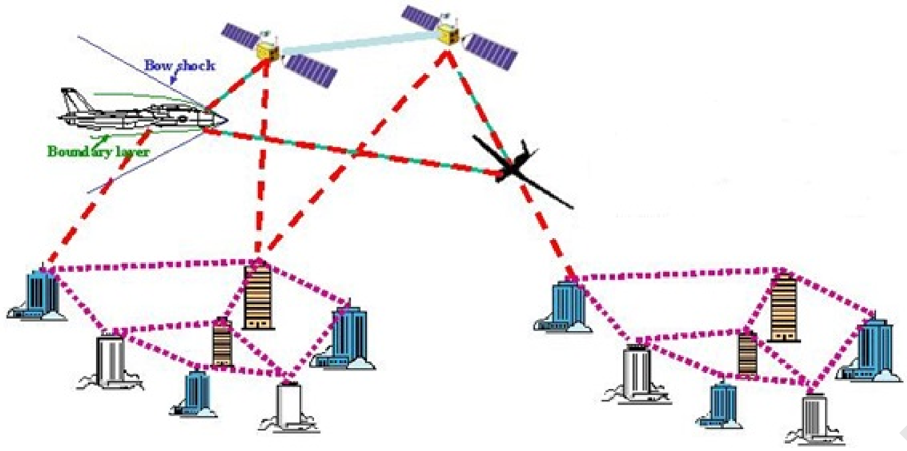

Figure 1.1: FSO Link.

Wavelength Division Multiplexing (WDM) is the transmission strategy, that shares the transmission medium among multiple users by multiplexing different wavelengths and is can provide high speed connectivity. WDM offers a wide range of bandwidth. It has independent bit rate and perfectly can be upgraded. It guarantees High Quality of Service (QoS) in the transparent FSO system as well [2].

Furthermore, lack of reliability because of the environmental impacts among the transmission path, difficult light collimation and beam tracking issues are ultimate constraint of FSO technology, which is a prevention of using the high capacity application [4]. To avoid the interference of signal propagation and increase the transmission capacity, employing a multiplexing strategy and modulation scheme highly influences the spectrum utilization in every communication system. Duty-cycle division multiplexing (DCDM) transmits multiple channels over a single wavelength division multiplexing (WDM) channel [5] as another multiplexing technique [6]. Therefore, this thesis is concentrated about further explore of this novel concept and its potential to become among the techniques to support high capacity networks in FSO.

1.2 Motivation and Problem Statements

DCDM enables simultaneous data transmission on a single spectrum for different users, with a various return-to-zero (RZ) duty cycles [6]. RZ line coding in terms of level transition, is the most commonly used formats with high speed communication system. Implementing RZ line coding in DCDM brings benefits such as lower frequency and higher transition. From the primary form of DCDM described by Abdullah [7], DCDM technique suffers from other problems. Since the various versions of DCDM have introduced over fiber link, the most reported weakness is not used for FSO system.

The implementation of the conventional WDM, non-return-to-zero (NRZ) and RZ on-off keying (OOK) needs n number of the laser diode (LD), modulators and demodulators at transceivers side for n WDM channels which is not economically efficient. In addition, there is limitation about using more lasers, related to interference between divergence of beam propagation and the size of the antenna. Consequently, DCDM is the expected solution to these negative issues that will be discussed in more details in this thesis.

1.3 Aims and Objectives

This research aims to offer an effective solution to FSO technology to enhance the system performance referring to data transmission rate with acceptable BER and data recovery with suitable power on the receiver side to cover the last mile distance. The key contribution of this work is to perform a multiplexing technique to transmit more data over the medium by considering the cost effectiveness and power consumption features. To achieve this goal, DCDM is proposed to design an efficient model and analyze its performance over FSO communication. The objectives of this study are as follows:

1. To investigate the FSO propagation under atmospheric effects.
2. To design and optimize single and multiple channel DCDM system in FSO communication.
3. To analyze the performance of multiple channel DCDM and multi-channel WDM over FSO communication.

1.4 Scope of the Thesis

This work conducts a review on the significant works on DCDM considering its bit error rate (BER) estimation. The improvement of DCDM technique over FSO medium in the last mile transmission is also discussed among atmospheric attenuation and turbulence. The work was carried out via modeling, theoretical analysis and simulation with MATLAB and OptiSystem.

The chosen strategy to conduct this study as shown in figure 1.2 illustrates the scope of this research work. The study module presents the related literature together with the employed methodology and purposed results. Solid lines determine the direction of this research toward achieving the predefined objectives. On the other hand, dashed boxes show the other areas which have not been covered in this thesis.

The top layers demonstrate the effects of the propagation environment in FSO transmission. In addition, the system design focuses on DCDM as the selected method, among all relevant multiplexing techniques (TDM, WDM, OCDM, DCDM and OFDM), which is considered in detail in methodology chapter. The model identifies with the configuration development of multiplexer and demultiplexer which involves a lower number of modulators in transmitter side and capable to recover and demultiplex the delivered signal at receiver side correctly. To evaluate and analyze the proposed model, design parameters such as distance, bit rate, input power, number of users per channels, transmission wavelength and bit format using (RZ) are investigated. The performance parameters are selected as Bit Error Rate (BER), Optical Signal Noise Ratio (OSNR) and received power.

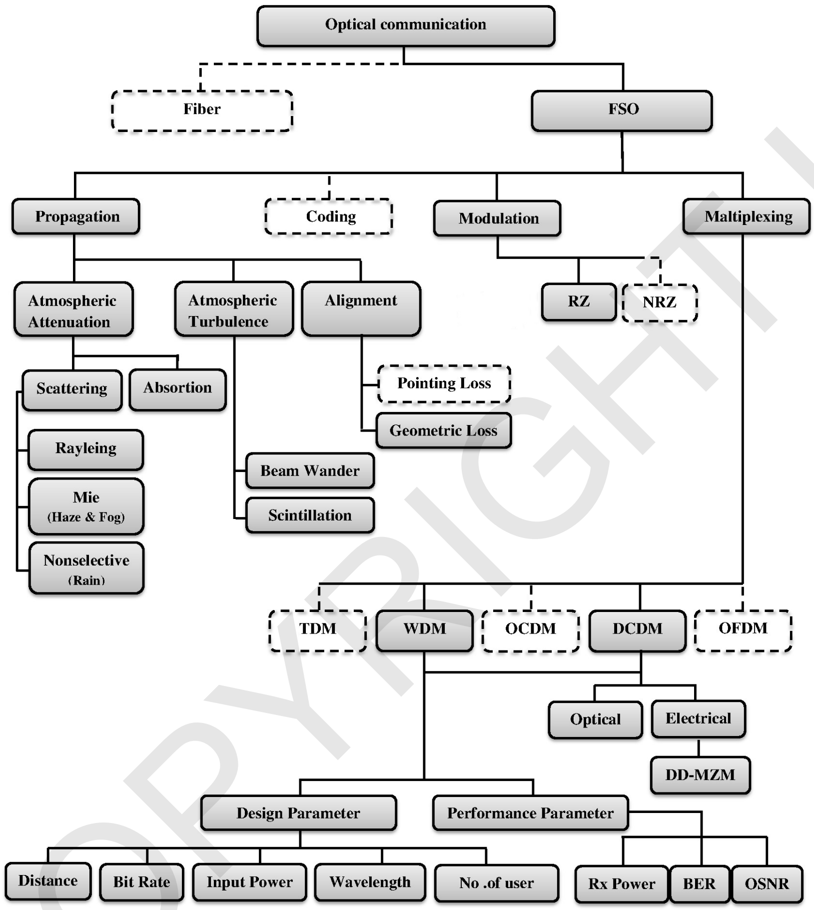

Figure 1.2: Study module.

1.5 Thesis Organization

This section presents the organization of this document. This dissertation will proceed as follows:
Chapter 1 introduces free space optics systems together with a short review on the newest issues in multiplexing. After that, objectives, problem statement and scope of this research are discussed.

Chapter 2 talks over the fundamentals of FSO technology and factors affecting on this medium followed by a discussion on the impairment of FSO. On the other hand, different multiplexing techniques are reviewed and the brief comparison is provided. Moreover, related subject such as optical modulator, line code and software used which are applied in the system design, is explained in this section.

The methodology of this study is presented in Chapter 3. Principle of DCDM and its properties is defined in detail such as BER estimation, and level spacing optimization. In addition, this chapter gives a mathematical description of FSO affected factors to achieve link margin analysis.

Chapter 4 includes a brief explanation of simulation setup and presentation of the simulation results of the proposed system layout when the design and performance metrics are considered. The efficiency of the proposed system is also examined in contrast with another technique.

Finally, Chapter 5 concludes the findings and recommends future research directions of this research.

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