UNIVERSITI PUTRA MALAYSIA

HYBRID SUBCARRIER MULTIPLEXING SAC-OCDMA DEPLOYING MSCODE OVER FREE SPACE OPTICAL LINK FOR MALAYSIA WEATHER CONDITION

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By

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Thesis submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to my husband who has supported me in all my work.

Abstract of the thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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August 2018

Chairman : Makhfudzah Mokhtar, PhD
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In recent years, free space optics (FSO) transmission systems are gradually being explored as alternatives to replace or to complement the available optical fibre and wired communication due to its low cost, ease of installation, higher data rate, larger bandwidth and licence-free installation.

As the aforementioned benefits come into the lime light, the large available bandwidth can essentially be benefited from, for multiple-user systems. Records have shown the effectiveness of a hybrid SCM-SAC-OCDMA in achieving greater capacity and enhanced security in FSO. Nevertheless, the available codes used suffered from many limitations such as dependency solely on prime numbers (as in the MQC code), code weight being limited to even numbers (as in the KS code) and rigid code construction as the number of users increases (as in the MD code).

The Multi-Service (MS) code has the advantage of flexibility and being dynamic as any number of code weights can be constructed without altering the wavelength of the existing light source. The code equally benefits from short length and sparsely located chips which could prevent cross-talk and hence could improve the performance of the system. Therefore, this research aims at investigating and improving multi-user FSO systems by proposing a hybrid subcarrier multiplexing SAC-OCDMA technique using the MS code with direct decoding technique. The performance are observed under different weather conditions which include clear, rain, and haze with Malaysia as a case study.

The investigation began by analysing the proposed system in mathematical modelling (using MATLAB) and simulation software (using OptiSystem) employing the Light Emitting Diode (LED) source. The subsequent works were then carried out using laser source as a result of the limitations in LED. The effects of increasing the number of code words as well as subcarriers at different distances and data rates were observed. The performance of the MS code based system was subsequently compared with KS, MD and MQC codes under clear, rainy and hazy weather conditions. Finally, the performances of the MS code under different angles of beam divergence and types of noise were evaluated based on bit error rate (BER), received power, eye diagram, and transmission distance.

At the bit rate of 1 Gb/s and BER threshold of 10^{-9} , heavy rain in the proposed system indicated the worse performance compared to clear weather and heavy haze as it reduced the transmission distance from 6.3 km (in clear weather) to 0.9 km. Nevertheless, under clear weather conditions with attenuation coefficient of 0.233 dB/km, the system designed using the MS code out-performed the KS, MD and MQC systems as it is capable of supporting up to 6.3 km, which is 0.8 km, 0.9 km and 1.5 km farther than KS, MD and MQC codes respectively in six-user channels. In conclusion, this study has provided a means of improving FSO communication which suits the weather conditions in Malaysia and other tropical zones.

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

HIBRID PEMULTIPLEKSAN SUBPEMBAWA SAC-OCDMA MENGGUNAKAN KOD-MS BAGI PAUTAN OPTIK RUANG BEBAS UNTUK KEADAAN CUACA MALAYSIA

Oleh

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Pada tahun-tahun kebelakangan ini, sistem penghantaran optik ruang bebas (FSO) secara beransur-ansur sedang dikaji sebagai alternatif utuk menggantikan atau melengkapkan komunikasi gentian optik dan berwayar sedia ada kerana kosnya yang rendah, kemudahan pemasangan, kadar data yang lebih tinggi, lebar jalur yang lebih besar dan pemasangan bebas-lesen.

Apabila faedah-faedah yang dinyatakan di atas menjadi lebih dikenali, lebar jalur yang besar boleh dimanfaatkan, untuk sistem berbilang-pengguna. Rekod-rekod telah membuktikan keberkesanan hibrid SCM-SAC-OCDMA dalam mencapai kapasiti yang lebih tinggi dan peningkatan keselamatan di dalam FSO. Walau bagaimanapun, kod sedia ada yang digunakan mengalami banyak batasan seperti kebergantungan semata-mata pada nombor perdana (seperti dalam kod MQC), berat kod terhad kepada nombor genap (seperti dalam kod KS) dan pembinaan kod yang tegar apabila bilangan pengguna meningkat (seperti dalam kod MD).

Kod Multi-Perkhidmatan (MS) mempunyai kelebihan kefleksibelan dan bersifat dinamik kerana sejumlah mana juga pemberat kod boleh dibina tanpa mengubah panjang gelombang sumber cahaya yang sedia ada. Kod tersebut sama-sama berfaedah dari kepanjangan kod yang pendek dan cip yang terletak dengan jarang yang boleh mencegah percakapan-silang dan oleh itu boleh memperbaiki prestasi sistem. Oleh itu, kajian ini bertujuan untuk mengkaji dan menambah baik sistem berbilang-pengguna FSO dengan mencadangkan teknik hibrid subpembawa pemultipleksan SAC-OCDMA menggunakan kod MS dengan teknik penyahkodan langsung. Prestasi ini diperhatikan

di bawah keadaan cuaca yang berbeza yang merangkumi cuaca cerah, hujan dan jerebu dengan Malaysia sebagai kajian kes.

Penyiasatan bermula dengan menganalisis sistem yang dicadangkan dari segi pemodelan matematik (menggunakan MATLAB) dan perisian simulasi (menggunakan OptiSystem) yang menggunakan sumber Diod Pancaran Cahaya (LED). Kerja-kerja seterusnya kemudian dijalankan menggunakan sumber laser berikutan daripada batasan LED. Kesan peningkatan bilangan perkataan kod serta subpembawa pada jarak dan kadar data yang berbeza diperhatikan. Prestasi sistem berasaskan kod MS kemudiannya dibandingkan dengan kod KS, MD dan MQC di bawah keadaan cuaca cerah, hujan dan jerebu. Akhirnya, prestasi kod MS di bawah sudut pencapahan alur dan jenis hingar yang berbeza dinilai berdasarkan kadar ralat bit (BER), kuasa yang diterima, gambar rajah mata, dan jarak penghantaran.

Pada kadar bit 1 Gb/s dan ambang BER 10^{-9}, hujan lebat bagi sistem yang dicadangkan menunjukkan prestasi yang lebih teruk berbanding cuaca yang cerah dan jerebu tebal kerana ia mengurangkan jarak penghantaran dari 6.3 km (dalam cuaca yang cerah) hingga 0.9 km.

Walau bagaimanapun, di bawah keadaan cuaca yang cerah dan pekali pelemahan 0.233 dB/km, sistem yang direka menggunakan kod MS mengatasi prestasi sistem KS, MD dan MQC kerana ia mampu menyokong sehingga 6.3 km, iaitu 0.8 km, 0.9 km dan 1.5 km lebih jauh daripada kod KS, MD dan MQC masing-masing dalam saluran enam-pengguna. Sebagai kesimpulan, kajian ini telah menyediakan satu cara untuk meningkatkan komunikasi FSO yang sesuai dengan keadaan cuaca di Malaysia dan zon tropika lain.

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Ghusoon Abdulameer Erhayem

This thesis was submitted to the Senate of University Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

FSO	Free Space Optics
RF	Radio frequency
BER	Bit Error Rate
CDMA	Code Division Multiple Access
FBG	Fiber Bragg Grating
Gbps	Gigabit per second
Mbps	Mega bit per second
bps	Bit per second
Hz	Hertz
mrad	mili radian
LED	Light Emitting Diode
KS	Khazani Syed
MQC	Modified Quadratic Congruence
MS	Multi-Service
MD	Multi Diagonal
MZM	Mach-Zehnder Modulator
NRZ	Non-Return to Zero
OCDM	Optical Code Division Multiplexing
OCDMA	Optical Code Division Multiple Access
QoS	Quality of Service
SAC	Spectral Amplitude Coding
WDMA	Wavelength Division Multiple Access
TDMA	Time Division Multiplexing Access
BPF	Band Pass Filter
LoS	Line of Sight
MAI	Multiple Access Interference
PD	Photo-detector

SCM	Subcarrier multiplexing
SNR	Signal to noise ratio
PT	Transmitter power
PSD	Power spectral density
LPF	Low pass filter
APD	Avalanche Photodiodes
FCC	Federal Communications Commission'
DD	Direct Detection
OOC	Optical Orthogonal code
EM	Electromagnetic interference
VCSEL	Vertical cavity surface emitting laser
UHF	Ultra high frequency
API	Air Pollution Index
SLD	Super Luminescent Diode
DW	Double Weight
MDW	Modified Double Weight

CHAPTER 1

INTRODUCTION

1.1 Background

Records have shown that various telecommunication media have been employed for efficient delivery of information between two or more communicating ends. Such media include physical cabling such as twisted pair cable, coaxial cable and fibre optics. Others are broadcast based technology, which include microwaves, satellite, radio and Free Space Optics (FSO) [1][2]. A number of literatures have identified the various challenges in copper-based technology, comprising twisted pair cable and coaxial cable [3][4] . These challenges include bandwidth limitation and high signal loss [3][5]. The latter is caused by incessant increase in inductive loss due to increasing electrical signal frequency that emanates whenever large amount of information is being transmitted [6]. Fibre optics cable has been proven to be one of the best communication technologies due to the various advantages it has over other links such as low attenuation, high speed and large bandwidth, high resistant to shock and its immunity to electromagnetic interference. Despite its numerous benefits, fibre optics is extremely expensive to deploy because; digging trenches in every street to lay fibre optic cables is exceptionally costly [7].

Due to the fact that installing copper and fibre optics require high cost and sometimes complicated configuration, medium in space, often referred to as broadcast communication, is preferred in many communication systems. This type of communication can be categorized into radio frequency (RF) communication, and optical wireless communication (OWC). The RF communications make use of frequency ranges in the radio wave spectrum, and are usually deployed in mobile, AM/FM radio, television transmission, radar, satellite and space communications. Although most of existing RF communication system technologies are full-fledged technologies, they have limited data transmission rates, require FCC licenses, and are expensive to implement compared to other technologies [8].

On the other hand, the OWC make use of optical spectrum in which unguided visible, infrared (IR), or ultraviolet (UV) light are exploited as signal carrier [9]. The OWC systems operating in the visible band (390–750 nm) are commonly referred to as visible light communication (VLC) [9][10]. In VLC systems, light emitting diodes (LEDs) are employed in various applications including wireless local area networks (WLAN), and wireless personal area networks (WPAN). Free space optics (FSO) system is a point-to-point terrestrial type of OWC system, operating at the near IR frequencies (750–1600 nm) [10][11] . FSO requires light, which can be focused by using either light emitting diodes (LEDs) or lasers (light amplification by stimulated emission of radiation). Lasers are deployed often to provide high data rates and as well as being a potential solution for the backhaul bottleneck [12]. While FSO system has been widely used, VLC system is also catching up for wider communication application [13][14]. In addition, a growing research on ultraviolet communication (UVC) operating within solar-blind UV spectrum (200–280 nm) has emerged due to recent development in solid state optical sources and detectors [10][11][15].

This research focuses on FSO systems, which are gradually being explored as an alternative to complement the available fibre optics and wired communication, due to its low cost and ease of installation. FSO communication can transmit large amounts of data at higher transmission speeds of up to 2.5 Gbps. Its average cost is about one-fifth the cost of installing fibre optics cable system. Some other benefits of FSO system are licence-free installation, licence-free frequency band, low risk investment and fast revenue generation [11], [12][15].

As the demand for FSO systems is becoming more popular, it is essential to cope with the increasing bandwidth by increasing the available number of network users. Subsequently, there have been many multiplexing strategies used to transmit multiples signals in FSO system. Some of the techniques are Wavelength Division Multiplexing (WDM) [16], subcarrier multiplexing (SCM) [17][18] and Optical Code Division Multiplexing Access (OCDMA) [19] . Among several others, OCDMA provides not only a multiplexing strategy but also considers the transmission security of the information. When OCDMA is implemented with Spectral Amplitude Coding (SAC), it can help to eliminate MAI noise while maintaining low cost and having simple architecture via direct decoding technique [19] [20][21]. The SAC-OCDMA used in combination with subcarrier multiplexing (SCM) offers efficient management of the optical channel, as multiple data can be transmitted on the same optical path [22][23]–[25]. A number of codes have been developed for SAC-OCDMA based system. These include Optical Orthogonal code (OOC) [26], Khazani Syed Code (KS) [27], Hadamard code [28], Modified Quadratic Congruence code (MQC) [29] and Multi-Service (MS) code [30].

While analyzing the FSO system performance, it is important to identify some factors that affect the system behavior. These factors are considered as the signal challenges prior to the signal arrival at the receiver. Among them are misalignment errors, geometric losses, background noise, weather attenuation losses and atmospheric turbulence [31].

1.2 Problem Statement

As the demand for FSO increases, it is equally essential to utilize the bandwidth by increasing the available number of network users. Records have shown the effectiveness of sub-carrier multiplexing (SCM) in achieving greater capacity at low cost, while Spectral Amplitude Coding – Code Division Multiple Access (SAC-OCDMA) has also been introduced to offer more secured communication link at higher capacity. By combining SCM with SAC-OCDMA, a greater capacity system with extended security have been achieved.

Nevertheless, the available codes used suffered from many limitations such as; dependency on prime number (as in MQC code), code weight limited to even number (as in KS code) and rigid code construction as the number of users increases (as in MD code).

Multi-Service (MS) code has advantage of flexibility and being dynamic as any number of code weights can be constructed without altering the wavelength of the existing light source. The code equally benefits from short length and sparsely located chips which could prevent cross talk and hence could improve the system performance. Other benefit is its ability to be implemented for different quality of service without manually altering the code structure. Therefore, application of the code in improving the performance of hybrid SCM SAC-OCDMA in FSO would therefore be investigated in this work.

1.3 Research Objectives

The objectives of this research are:

- To investigate the suitability of MS-code with direct decoding technique in hybrid SCM SAC-OCDMA over FSO system using mathematical and simulation model.
- To compare the performance of MS-code in hybrid SCM SAC-OCDMA system with other SAC-OCDMA codes which are; KS, MD and MQC codes under clear, rain and hazy weather conditions.
- To evaluate the performance of MS-code in hybrid SCM SAC-OCDMA system at different angles of beam divergence and different types of noises.

1.4 Significance of Study

This research aims at investigating and improving multi-user FSO systems by proposing a hybrid subcarrier multiplexing SAC-OCDMA technique using MS code with direct decoding technique. Multi-Service (MS) code has advantage of flexibility in choosing the code weight. More so, the code is dynamic as the number of users can be increased while still using the same range of light source frequency. As the proposed code has the advantage of having flexible and dynamics code weight, it is expected to preserve the use of existing technology with the development of current needs.

1.5 Scope of Study

Figure 1.1 shows the theoretical research framework and the scope of work. This work focuses on FSO communication using MS-code in hybrid SCM SAC-OCDMA under different weather conditions in Malaysia, which include clear, rain and haze at different attenuation coefficient. The suitable light source was explored for the implementation. In the work, mathematical analyses has been carried out by using MATLAB® while simulations was done on Optisys® software. The mathematical modelling and simulation setup has been carried out under standard performance parameters such as received power, SNR and bit error rate (BER).

The systems performance were analysed from different contribution of noise sources that contains thermal, shot and IMD noise. As the direct detection technique was used in both mathematical modelling and simulation works, the PIIN noise was not considered in the noise analyses. The system design parameters involved are adapted from existing commercial systems to make the simulations as close to the mathematics as possible. As far as the scope of work of this study is concerned, the simulation and mathematics results are expected to be sufficient to prove the viability of the code using the direct detection technique.

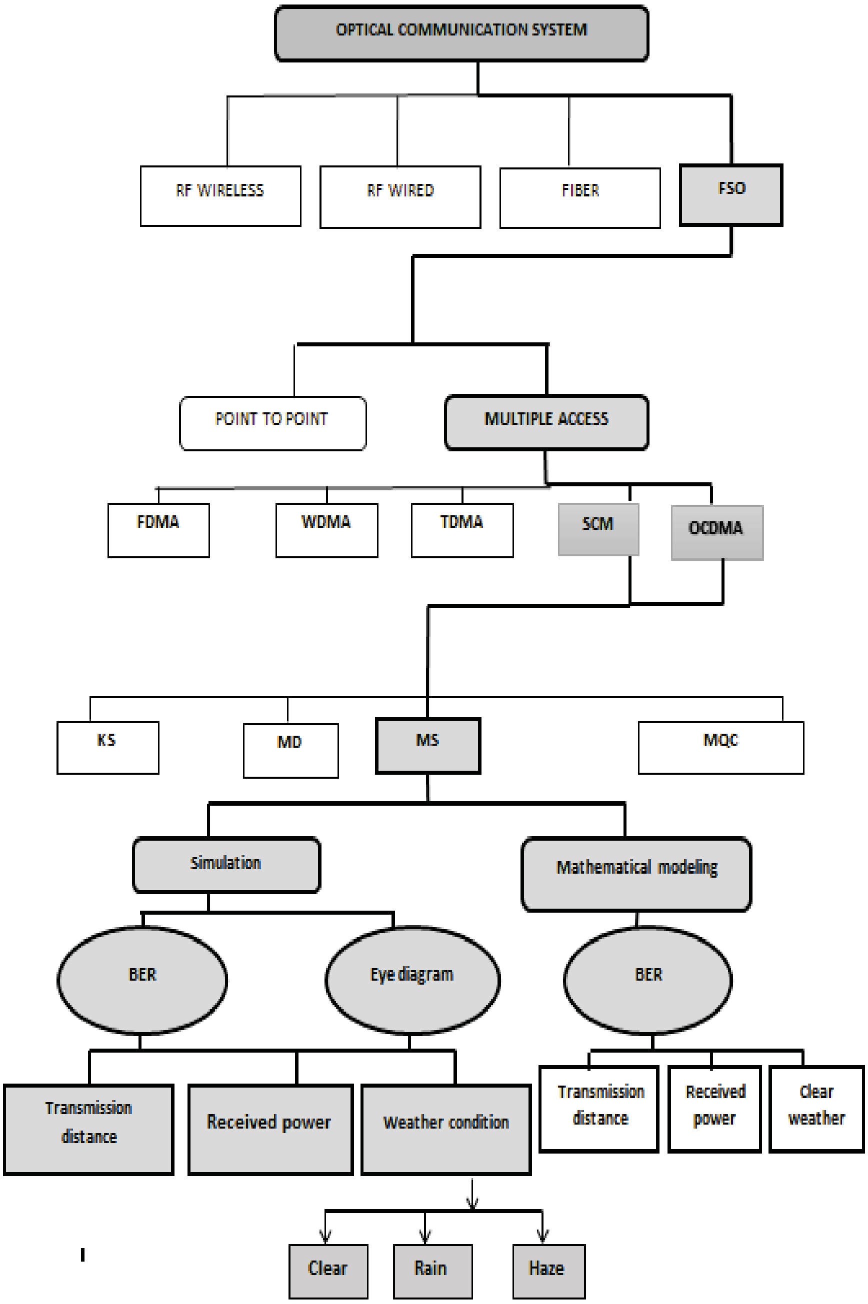

Figure 1.1: Theoretical framework of the research and scope of work

1.6 Thesis Outline

Chapter 1 presents the introduction, research problem statement and its significance that calls for the need for this research followed by objectives and the scope of study.

Chapter 2 discusses the literature review for FSO communication systems. It describes basic FSO systems, multiplexing techniques involved in the FSO systems including hybrid SCM SAC-OCDMA, different OCDMA code techniques, as well as different weather conditions and their effects on FSO communication system.

Chapter 3 presents methodology adopted in this research which includes mathematical modelling and simulation. This chapter presents a detailed explanation of the hybrid SCM-SAC-OCDMA system using the Multi-Service (MS) code via both the mathematical modelling and simulation setup. It also explains all the related FSO system design and performance parameters.

Chapter 4 discusses the results and the performance analysis of the proposed system using the MS code and demonstrates the feasibility of the system in rainy and hazy weather conditions. It also presents the proposed systems performance in comparison with other SAC-OCDMA codes such as KS, MD and MQC codes. The analysis of different size of beam divergences and different types of noise are also explained in this chapter.

Chapter 5 concludes the thesis by summarising the most important ideas, contributions and future works.

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