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PERFORMANCE ANALYSIS OF DIFFERENT SAC-OCDMA CODES FOR INDOOR VISIBLE LIGHT COMMUNICATION SYSTEM

YAHAYA IDRISS

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By

YAHAYA IDRISS

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

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YAHAYA IDRISS

May 2016

Chairman : Ratna Kalos Zakiah Sahbudin, PhD
Faculty : Engineering

Indoor visible light communications (VLC) are promising technology where light-emitting-diode (LEDs) are used to transmit data in the form of visible light (white-light) in free space. This technology gains several attractions due to its free licenses, and abundant unregulated bandwidth in the optical spectrum region. It is evident that indoor VLC systems are susceptible to ambient light noise that causes interference which tends to degrade communication channel. Recently, Hadamard matrix code was applied to the indoor VLC system in order to achieve a low error probability in LED-based system. However, with the results obtained, there is a need for improvement by analyzing other SAC-OCDMA code. Therefore, this research focuses on the performance analysis of different spectral amplitude coding optical code division multiple access (SAC-OCDMA) codes for an indoor visible light communication system. This is to provide a better quality of service (QoS) with a lower bit error rate (BER), high signal to noise ratio (SNR) for a long transmission distance for indoor use, under the influence of both direct sunlight with a filter and indirect sunlight without a filter. In order to achieve this, a proper choice of the system components such as a transmitter, modulation format, coding, filtering, and the receiver were made. This can be evaluated through computer simulations, by analyzing the bit error rate (BER), signal to noise ratio (SNR), received the optical power signal and the eye diagram performance. The results obtained from the simulation shows that among the three codes that were subjected to the influence of background light noise interference. KS code offers a significant improvement of 21.05% difference in term of propagation distance, by achieving a long transmission distance under the influence of indirect sunlight without a filter and direct sunlight with a filter at a bit rate of 622 Mbps, with also 11.76 % improvement in transmission distance with 1Gbps bit rate. It is evident from the result that KS code can perform better under the influence of indirect sunlight without a filter, which is the major source of ambient light noise interference in an indoor environment. Therefore, this research proposed a model that can be used as a solution for the next generation of indoor VLC system, employing SAC-OCDMA optical access network.

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ANALISIS PERLAKSANAAN KOD SAC-OCDMA YANG BERBEZA UNTUK SISTEM KOMUNIKASI CAHAYA NAMPAK DALAMAN

Oleh

YAHAYA IDRISS

Mei 2016

Pengerusi : Ratna Kalos Zakiah Sahbudin, PhD
Fakulti : Kejuruteraan

Komunikasi cahaya nampak dalaman (VLC) adalah teknologi yang berpotensi di mana Diod Pemancar Cahaya (LED) digunakan untuk menghantar data dalam bentuk cahaya yang boleh dilihat (cahaya-putih) dalam ruang bebas. Teknologi ini mendapat perhatian kerana tidak memerlukan lesen yang khas, dan kapasiti spectrum yang lebar di kawasan spektrum optik. Ini adalah jelas bahawa sistem VLC dalaman amat mudah terdedah kepada gangguan sinaran cahaya yang akan menyebabkan susutan kepada prestasi komunikasi. Terbaru, kod matrik Hadamard telah digunakan terhadap sistem VLC dalaman untuk mencapai kebarangkalian ralat yang rendah dalam sistem yang berasaskan LED. Bagaimanapun, hasil keputusan menunjukkan ada keperluan untuk menaik taraf dengan menganalisis teknik kod SAC-OCDMA yang lain. Penyelidikan ini memberi tumpuan kepada analisis prestasi dengan menggunakan teknik kod optikal pembahagi pelbagaiakses berasaskan kod amplitud tunggal(SAC-OCDMA) untuk sistem komunikasi cahaya nampak dalaman. Ini sekaligus dapat menyediakan kualiti perkhidmatan yang lebih baik (QoS) dengan kadar ralat bit (BER) yang lebih rendah, nisbah ralat isyarat (SNR) yang tinggi untuk jarak penghantaran yang lebih jauh bagi kegunaan dalaman, sama ada di bawah pengaruh ke sinaran cahaya matahari secara langsung dengan penapis dan simaran cahaya matahari tidak langsung tanpa penapis. Untuk mencapai matlamat ini, pemilihan peralatan yang sesuai seperti sebuah pemancar, format modulasi, teknik pengekodan, penapisan, dan unit penerima telah dibuat. Keputusan yang tepat boleh dinilai melalui simulasi komputer, dengan menganalisis kadar ralat bit (BER), nisbah ralat isyarat(SNR), penerimaan isyarat kuasa optik dan prestasi rajah mata. Keputusan yang diperolehi daripada simulasi menunjukkan bahawa tiga jenis kod mudah terpengaruh kepada gangguan cahaya latar sekeliling. Kod KS menunjukkan peningkatan yang ketara sebanyak 21.05% dengan penghantaran yang lebih jauh di bawah sinaran cahaya matahari tidak langsung tanpa penapis dan sinaran cahaya matahari langsung dengan penapis pada kadar lebih rendah 622Mbps iaitu peningkatan 11.76% pada jarak penghantaran dengan 1Gbps kadar bit. Ia adalah jelas daripada keputusan simulasi menunjukkan bahawa kod KS boleh mencapai prestasi penghantaran yang lebih baik didalam persekitaran yang terlindung dari sinaran cahaya matahari, yang merupakan sumber utama gangguan cahaya dalam persekitaran dalaman.

Oleh itu, kajian ini mencadangkan satu model yang boleh digunakan sebagai penyelesaian untuk generasi akan datang sistem VLC, iaitu dengan menggunakan rangkaian akses optik SAC-OCDMA.

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I certify that a Thesis Examination Committee has met on 19 May 2016 to conduct the final examination of Yahaya Idriss on his thesis entitled "Performance Analysis of Different SAC-OCDMA Codes for Indoor Visible Light Communication System" 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.

Members of the Thesis Examination Committee were as follows:

Mohd Adzir bin Mahdi, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Makhfudzah binti Mokhtar, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Zulfadzli Yusoff, PhD
Associate Professor
Multimedia University
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 23 August 2016

This thesis was submitted to the Senate of Universiti 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:

Ratna Kalos Zakiah bt Sahbudin, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Barirah binti Ahmad Anas, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Salasiah binti Hitam, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
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BUJANG BIN KIM HUAT, PhD
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Signature: _____
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Signature: _____
Name of Member of Supervisory Committee: Associate Professor Dr. Siti Barirah binti Ahmad Anas

Signature: _____
Name of Member of Supervisory Committee: Associate Professor Dr. Salasiah binti Hitam

TABLE OF CONTENTS

IST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1D	One-dimensional code
2D	Two dimensional-code
3D	Three dimensional-code
ADC	Analogue to digital converter
ANSI	American national standard for use of laser
APD	Avalanche photodiode
AVR	Automatic voltage regulator
AWGN	Additive white Gaussian noise
BER	Bit error rate
CHS	Conventional hybrid system
CLB	Circular Lambertian Beam
COWA	Center on Optical Wireless Application
CSK	Color shift keying
DAC	Digital to analogue converter
DC	Direct current
DH-PIM	Dual header-pulse interval modulation
DMT	Discrete Multitone modulation
EHz	Exahertz
ELB	Elliptical Lambertian Beam
EPSRC	Engineering and Physical Research Council
FCC	Flexible Cross Correlation code
FFT	Fast Fourier transformation
FOV	Field of view
FP7	Seven Research Framework Program

FSO	Free space optics
Gbps	Giga bit per second
GHz	Gigahertz
HC	Hadamard code
ICI	Inter-channel interference
IEC	International Electro technical commission
IFFT	Inverse fast Fourier transformation
IM/DD	IM/DD: Intensity modulation with direct detection
IrDA	Infrared Data Communication
ISCA	Infrared Communication System Association
ISI	Intersymbol interference
MFH	Modified frequency hopping

CHAPTER ONE

INTRODUCTION

1.1 Background

There is widely increasing in wireless data connectivity globally due to advancement in the development of technology that reduces the cost of portable handheld devices to enable users to transfer information easily. Nowadays, people can transmit and receive messages and data to laptops, personal digital assistance (PDAs) and other digital devices through wireless or cellular network technology, this is based on radio frequency (RF) wireless access technology. Such technology provides an easy access to indoor and outdoor to wireless mobile device users, apart from voice calls, broadband services are available wirelessly. However, RF technologies have some limitations like radio bandwidth, inadequate transmission rate and channel capacity of the desired frequency ranges. Likewise, the size and volume of data files continue to increase exponentially, for instance, wireless access of Web based multimedia services, such as demands of movies and television[1][2]. With the aforementioned short-comings of RF technology, an optical wireless communication (OWC) system can be a powerful alternative to its counterpart radio wave which can be a potential solution to the global spectrum shortage. In addition, in an indoor environment, OWC can be applied for wireless data transmission for short-range and mobility applications [3][4].

1.2 Typical optical wireless links

Optical wireless communications may be categorized into two major classes. These are indoor and outdoor optical wireless communication [5]. Usually, indoor optical wireless communication is considered for short range communications link with devices such as smart phones, laptop, and desktop computers. While to solve the last-mile problem outdoor optical wireless is mostly employed for medium range communications where the link exists between buildings, a vehicle to vehicle communications, spacecraft communication in outer space and outdoor advertisement [6][7][8].

There are three major optical wireless links topology used in an indoor optical wireless communication system. These are Line of Sight (LOS), Non-line of Sight (Non-LOS) and the Hybrid[9][10]. Figure 1.1 shows the basic configuration LOS and Non-LOS link.

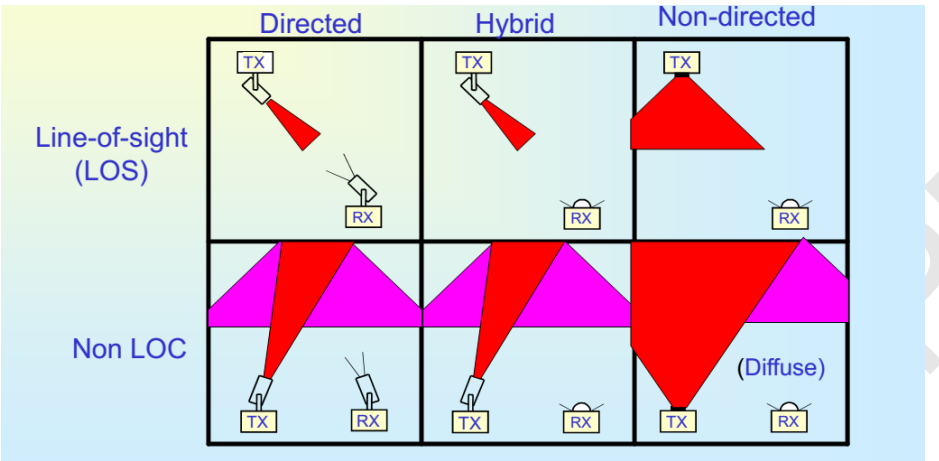

Figure 1.1: Link Topology for OWC System [11]

It can further be categorized according to the degree of directionality between the transmitter and receiver. In the LOS link configuration, the transmitter beam is the position within the receiver field of view (FOV) angle. This provides a dedicated link with a narrow beam from the transmitter and smaller FOV from the receiver. This link increases the power efficiency by reducing the path loss and interference of background ambient light noise. Furthermore, it eliminate multipath distortion and is good for point to point communications. LOS link can equally support mobility by introducing tracking and steering capabilities. Also, multiple transmitter and multiple receiver configuration systems could provide an alternative for achieving good room coverage with lower blocking probability[12][13]. In contrast, Non-LOS link design has a wide transmitter's beam angle and large FOV receivers, alleviating a need for accurate pointing as in the directed link so as to achieve large coverage area, while at the expense of large path loss**.** The Non-LOS link depends mostly on the reflection of the light from the ceiling or some other diffusely reflecting surfaces within the room. This enables the link to operate even when an obstacle, such as people or cubicle partitions, stand between the transmitter and receiver. Since in the Non-LOS link the path loss is usually much larger, thus, the multipath distortion induces intersymbol interference (ISI). This is caused by signal reflections from walls and other objects within the room[14]. Hybrid configuration, this topology combines the advantages of directed LOS link and Non-directed LOS link to provide user mobility and less path loss when compared with the non-directed LOS link. The transmitter has a narrow beam that is within the wide FOV of the receiver. The transmitter sends narrow divergence beams of signal towards the ceiling where it get reflected back and intercepted by the receiver [9].

1.3 Problem statement

It is well known that indoor VLC system are vulnerable to ambient light noise. This tend to degrade the performance of the communication channel. Much attentions were given on how to improve the indoor VLC system performance by employing different link configuration such as LOS, NLOS and hybrid. Various approaches were also made in improving the limited bandwidth of white light LED and combating the effects of noise

on the system such as modulation techniques, equalization and filtering. Recently, Hadamard coded modulation (HCM) was used as an alternative to OFDM technique in order to achieve a low error probabilities in LED-based VLC system that required high average optical power for illumination[15]. Also, Hadamard error correcting code was applied in mitigating the effect of background noise by improving the transmission distance[16].

However, the target of this work is to improve on the recent Hadamard code modulation that was applied to indoor VLC by carrying out the performance analysis of different SAC-OCDMA codes for indoor VLC system. The performance of Hadamard code[17] will compare with the other SAC codes such as Khazani-Syed (KS) code[18], flexible cross correlation (FCC) code[19] and modified quadratic congruence (MQC) code[20]. Furthermore, to investigate among these codes which can performed better and can support a longer transmission distance with a low bit error rate (BER). The code will be considered suitable for indoor VLC system designed.

1.4 Significance of the study

The requirement for high-speed data transmission cannot be over emphasized due to high demand for multimedia contents that has been growing tremendously high. This is as a result of an increase in production of wireless devices like tablets, laptops and smartphones in every year. It has been reported that the main sources of wireless data traffic are produced from the indoor environment because of the availability of wireless access network in offices and homes[21]. Therefore, there is an urgent need for transmission band that can supplement the present global spectrum crises that are being faced by the traditional RF spectrum. Indoor VLC system with SAC-OCDMA network can be a good alternative. Since it possesses unlimited bandwidth in optical band and the license is free. Also, SAC-OCDMA technique can contribute to achieving an increase in the spectral efficiency of the optical bandwidth.

With the aforementioned merits, SAC-OCDMA with indoor VLC system can provide an alternative means of communication for indoor communication, with the help of inexpensive front end LEDs as a transmitter that are already in use in our offices and homes. Therefore, this research proposed a model that can be used as a solution for the next generation of indoor VLC system, employing SAC-OCDMA optical access network.

1.5 Research objective

This work is focused on the performance analysis of different SAC-OCDMA codes for the indoor VLC system by achieving the following:

1) To model and simulate SAC-OCDMA for indoor VLC system with direct LOS link using OptiSystem software for communication channel.

2) To evaluate the performance of these codes by analyzing which code can support a longer propagation distance with the lowest BER under the influence of two different ambient light noise on the communication channel.

3) To investigate the performance of these codes on the ambient light noise on both received optical power, signal power level and noise power level with the variation of transmission distance on the communication channel.

1.6 Scope of the study

For the purpose of making this study more convenient and manageable, this research is confined mainly toward investigating the applications of optical code division multiple access in an indoor visible light communication system. And provide theoretical analysis and simulations for spectral amplitude coding-optical code division multiple access (SAC-OCDMA) systems by comparing four different codes of KS code, Hadamard code, FCC code and MQC code operating in realistic environments.

The specific scopes of this thesis are:

- Understanding the basic principle of indoor VLC system channel model technique.
- Modeling and Simulation of SAC-OCDMA for the indoor VLC system by using OptiSystem Software.
- Performance analysis of the design system in terms of bit error rate (BER), Signal-to-noise ratio (SNR) and output power.

1.7 Thesis organization

Chapter 1 provides an overview of the OWC and its merits over RF, it also presents different OWC links-configuration with their benefits. More so, the problem statement and the objective of the research was discussed here. Chapter 2 highlights on the quick literature discussion of Indoor visible light communication systems. It presentsbrief on IM/DD with other modulation formats. The introduction of OCDMA techniques is briefly outlined with the working principles of spectral amplitude coding and enumerates the properties of KS, HC, FCC and MQC code. Chapter 3 presents the method use in analyzing different codes for SAC-OCDMA for theindoor visible light communication system based on the performance of bit error rate, optical power received, and signal-to-noise ratio. An encoder/decoder design is proposed for the performance analysis of the four different codes for optical code division multiplexing system. The general parameter for the simulation is presented here. Chapter 4 presents the results and discussion based on work carried out. Different graphs of BER versus communication distance were plotted. Likewise, the graphs of total received power against transmission distance were equally plotted. Additionally, signal power and noise power against propagation distance and signal to noise ratio (SNR) were similarly plotted. Finally, in Chapter 5, conclusions were drawn from the results obtained in the thesis by outlining the summary, contribution and future directions.

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