A NEW FLEXIBLE CROSS CORRELATION (FCC) CODE FOR OPTICAL CDMA SYSTEMS

by

MOHD RASHIDI BIN CHE BESON
(1140810644)

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2014

ACKNOWLEDGEMENT

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

Alhamdulillah, all praises to Allah SWT for the opportunity to complete this thesis. I am indebted and grateful to many people who have helped me during the course of this research project in one way or another. In particular, I would like to acknowledge and express my deepest gratitude to respected supervisor, Prof. Dr. Syed Alwee Aljunid Syed Junid to whom I am greatly indebted for giving me the opportunity to further PhD in UniMAP under his supervision. His door has always been opened and I could always discuss with him no matter how busy he is. I also would like to express my sincere thanks to my co-supervisors Prof. Dr. Farid Ghani, Ir. Dr. Anuar and Dr. Hilal Adnan Fadhil for their guidances, supports and encouragements. My heartiest thank you to both of my beloved parents who always continuously pray for my success and fully supported me along the way. I would also like to acknowledge my siblings for their moral support and always keep thinking positive side in me. My endless thanks and deepest appreciations to the one who is very patient no other than my caring wife, Shafida Wati Kasim without her support, I could never complete this journey. Not forgetting my daughter, Nurhidayah Husna thank you for all the joy and happiness that you bring into my life. My sincere appreciations for my colleagues, Dr. Amir, Dr. Junita, Mr. Abdul Rahman, Dr. Hamza, Mr. Abdullah and all CoE ACE-SCCE Optical group that has been involved in this work directly or indirectly for their assistance, ideas and contributions. Last but not least, I would like to acknowledge the Malaysian Ministry of Education and UniMAP for supporting my studies, financially. Amin.

Mohd Rashidi Bin Che Beson

TABLE OF CONTENTS

CHAPTER 4 DEVELOPMENT OF FCC CODE

CHAPTER 5 THE PERFORMANCE OF FCC CODE IN OCDMA SYSTEM

CHAPTER 6 CONCLUSIONS AND FUTURE WORKS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

N	Number of code length
W	Code Weight
λ_x	Auto-correlation
λ_{xy}	Cross-correlation
$\in$	Element
$=$	Equality
$\neq$	Inequality
$\lvert C \rvert$	Number of user for OOC code.
P	Prime number (Prime code)
β	Primitive element
H	Hadamard Code
R_p	Parallel resistance
R_s	Series resistance
i_{elec}	Electronics current
T_B	Absolute temperature
K_b	Boltzmann's constant
B	Electrical bandwidth
R_L	Receiver local resistance
τ_c	Coherence time
I	Average photocurrent
q	Electron charge 1.602×10^{-19} (coulombs)
$\sum$	Summation
X_i	Indicated as user X_I
Y_i	Indicated as user Y_I
T	Transpose Matrix
$\leq$	Inequality (subgroup)

LIST OF ABBREVIATIONS

OCDMA	Optical Code Division Multiple Access
MAI	Multiple Access Interference
TDMA	Time Division Multiple Access
WDMA	Wavelength Division Multiple Access
CDMA	Code Division Multiple Access
VOD	Video on Demand
BER	Bit Error Rate
PIIN	Phase Induced Intensity Noise
IPCC	In-phase cross-correlation
SNR	Signal to Noise Ratio
SAC	Spectral Amplitude Coding
MFH	Modified Frequency Hoping
PC	Prime Code
OOC	Optical Orthogonal Code
FCC	Flexible Cross Correlation
MDW	Modified Double Weight
OptiSys	Optical system software
FBG	Fiber Bragg Gratings
PSK	Phase Shift Keying
PN	Pseudo Noise
DSSS	Direct Sequence Spread Spectrum
LED	Light Emitting Diode
GF	Galois Field
LAN	Local Area Network
NRZ	Non-Return-to-Zero
FWM	Four Wave Mixing
RIN	Relative Intensity Noise
SMF	Single Mode Fiber
LPF	Low Pass Filter

P_{sr}	Effective Receive Power
QoS	Quality of Service
SSFBG	Superstructure Fiber Bragg Grating
SPECTS	Spectrally Encoded Time Spread
SLPM	Spatial Light Phase Modulator
FTTH	Fiber-To-The-Home
ITU	International Telecommunication Union

Kod Silang Kolerasi Fleksibel (FCC) Baru Untuk Sistem Optik CDMA

ABSTRAK

Kecenderungan terhadap teknologi multi-akses pembahagian kod (CDMA) untuk di aplikasikan ke dalam sistem komunikasi gentian optik semakin mendapat perhatian yang sangat luas. Kebolehan teknik ini ialah ianya merupakan salah satu skim akses pelbagai di mana kecemerlangan pencapaiannya seperti kepelbagaian penempatan slot, operasi yang tidak segerak, peningkatan tahap privasi dan kapasiti yang tinggi di dalam rangkaian. Prestasi multi-akses pembahagian kod optik (OCDMA) bergantung kepada keadaan syarat-syarat kod yang di bangunkan. Di dalam tesis ini, kod baru yang di bangunkan di kenali sebagai kod Silang Kolerasi Fleksibel (FCC) untuk sistem OCDMA untuk tujuan penambahbaikan dan mengatasi kelemahan-kelemahan pada kod OCDMA yang sedia ada. Kod FCC mempunyai ciri-ciri seperti ketidaktetapan fungsi korelasi silang dengan kod yang tidak panjang, mudah untuk di bina, dan berkeupayaan untuk meningkatkan jumlah pengguna dan kod pemberat secara serentak. Kod FCC di reka berdasarkan kombinasi matrik di mana matrik tripepenjuru telah di adaptasikan demi membangunkan algoritma kod FCC ini. Di dalam kajian ini, aspek teori dan simulasi ialah daripada sumber cahaya jalur lebar dan menggunakan teknik pengesan penolakan AND pada bahagian penerima. Hasil keputusan yang diperolehi, kod FCC mampu untuk meningkatkan jumlah pengguna sebanyak 150 di mana ianya berlaku peningkatan peratusan sebanyak 66%, 172%, 650% dan 900% dengan perbandingan jumlah pengguna sebanyak 90, 55, 20 dan 15 bagi kod Anjakan Kitar Dinamik (DCS), kod Dwi Pemberat Diubahsuai (MDW), Frekuensi Berharap Diubahsuai (MFH) dan kod Hadamard pada kadar ralat bit (BER) yang di benarkan iaitu 10^{-9}. Kod FCC juga menunjukkan kadar kuasa pada penerima ialah $P_{sr} = -25$ dBm, lantas menjadikan sistem pengesanan lebih sensitif jika menggunakan kod FCC ini. Selain itu, prestasi kod OCDMA di simulasikan dengan perisian *OptiSystem* dari *Optiwave*^{TM}. Prestasi sistem OCDMA ini di rujuk berdasarkan kriteria-kriteria seperti BER, kadar bit, kadar kuasa penerima P_{sr} dan juga jarak gentian optik. Keputusan simulasi menunjukkan bahawa kod FCC mempunyai keputusan yang baik di mana kod FCC mampu untuk capai jarak sejauh 45 km berbanding kod MDW hanya mampu capai pada jarak 21 km dengan kadar bit 155 Mbps dan BER 10^{-9}. Dalam hasil penyelidikan ini, teknik pengesan penolakan AND di adaptasikan pada bahagian akhir penerima bagi tujuan mengurangkan kepadatan pada bahagian penerima selain meningkatkan prestasi sistem dari segi jarak dan jumlah pengguna aktif secara serentak. Keputusan teori dan simulasi telah membuktikan bahawa dengan menggunakan teknik pengesan penolakan AND telah meningkatkan prestasi sistem dengan sangat ketara sekali. Berdasarkan pengesahan keputusan teori dan simulasi melalui kaedah penghantaran belakang-ke-belakang (B2B), perbezaan kuasa penerima ialah −36 dB pada kadar bit 155 Mbps dan BER 10^{-9} pada jarak optik 10 km.

A New Flexible Cross Correlation (FCC) Code for Optical CDMA Systems

ABSTRACT

There are tremendous interest in applying code division multiple access (CDMA) techniques to fiber optic communication systems. This technique is one of the multiple access schemes that is becoming popular due to its channel allocation flexibility, asynchronously operation, enhanced privacy, and increased capacity in bursty networks. The performance of optical CDMA (OCDMA) systems are highly dependable on code designed properties. In this thesis, a new Flexible Cross Correlation (FCC) code for OCDMA system is designed, simulated and validated. The FCC code has numerous features such as unfixed cross correlation function with shortest code length, easy to build, and adaptability to accommodate variance number of users and weights. The FCC code is designed based on matrix combinatorial where the tridiagonal code matrix was adopted in developing the algorithm of this FCC code. This research examines the theoretical and simulation aspects in the case of incoherent signal from the broadband light source utilizing AND subtraction detection technique at the receiver side. The results revealed that the FCC code can accommodate 150 users, where FCC code offers 66%, 172%, 650% and 900% improvement as a contrast to 90, 55, 20 and 15 numbers of users for Dynamic Cyclic Shift (DCS), Modified Double Weight (MDW), Modified Frequency Hoping (MFH) and Hadamard codes, respectively, for a permissible bit error rate (BER) of 10^{-9}. The FCC code indicates optical received power P_{sr} of -25 dBm, thus, the detection system is more sensitive via utilizing FCC code. The performance of OCDMA codes were simulated using *OptiSystem* software from *Optiwave*^{TM}. The performance of the systems were characterized by referring to the BER, bit rate, optical received power P_{sr} and fiber length. The results shown that the FCC code performs adequately for 45 km as opposed to 21 km for MDW code within bit rate of 155 Mbps and BER of 10^{-9}. In this work, AND subtraction detection technique is employed at the receiver end in order to reduce the receiver complexity, and improve the system performance in terms of distance and number of active users. It has been shown through theoretical and simulation results, the performance of the system with AND subtraction detection technique improved significantly. Based on the validation of theoretical and simulation results employing back-to-back (B2B) transmission, a receiver's power marginal of -36 dB is obtained at a bit rate of 155 Mbps and BER of 10^{-9} over 10 km fiber length.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Telecommunication systems and networks are expected to provide a variety of integrated broadband services to the customers. Optical fiber is one of the most popular type of optical transmission medium. Fiber is the best waveguide in light applications. It has lots of advantages such as high bandwidth, less loss and inherent security of data transmission (Wei Huang, 2000). Due to that, an optical fiber provides high bandwidth utilization for multiple access operations where a number of users can access a single channel simultaneously for a one time transmission.

There are two major multiple access techniques where each user is allocated at a specific time slot in time division multiple access (TDMA) and a specific frequency (wavelength) slot in frequency or wavelength division multiple access (F/WDMA). The design of optical TDMA is to ensure maximum use of the available optical fiber bandwidth, for information transmission since the multiplexed information stream requires very high capacity links. To increase the capacity further, F/WDMA techniques that make use of the wide spectral transmission window are employed. Both techniques have been extensively explored and utilized in optical communication systems (Castaneda-Camacho, J. & Lara-Rodriguez, D., 2005).

In optical code division multiple access (OCDMA) technology was steadily growing during recent decades ago due to tremendous demand for bandwidth utilization, internet services including electronic commerce and tele-networking (Fouli, K., & Maier, M., 2007). The first proposal appeared almost immediately following or concurrently with those in wireless communications. The motivation was the promise to accommodate a high number of users at low bit rate to communicate simultaneously through the fiber. In OCDMA system, each user is identified by different codes or addresses where it is an exciting development in short-haul optical networking because it can support both wide and narrow bandwidth applications on the same network and can have a large number of asynchronous users (Laura Cottatellucci, 2010).

The principles of spread-spectrum were implemented in optical signal is to spread the energy over the frequency band that is much wider than the minimum bandwidth required to send a bit of information (HongXi Yin & David J. Richardson, 2009). Many researchers have attempted to implement code division multiple access (CDMA) techniques in optics after such techniques have been established in wireless communication technologies. These efforts have become the first implementations of optical CDMA (OCDMA) techniques. However, researchers have encountered severe difficulties in the practical implementation of OCDMA techniques and the developed systems are unable to display comparable success with those implemented in wireless technologies. This result can be mainly attributed to the fundamental difference between CDMA and OCDMA environments. For example, in OCDMA, auto-correlation is fixed, whereas in-phase cross-correlation can be controlled to achieve a reliable code length (bandwidth), thus ensuring that a good correlator, efficient bandwidth utilization and an original signal are discernible at the receiver end. By contrast, in a CDMA source, in-phase cross-correlation cannot be controlled and a complex architecture is required for an access communication system. Given these challenges, research on OCDMA is becoming increasingly attractive to develop novel encoding methods for achieving CDMA objectives. The problems encountered in OCDMA systems are discussed in detail in next Section 1.2.

1.2 Problem Statements

In OCDMA system, the most important consideration is the code design where inappropriate code designed and more simultaneous users can be seriously degraded the system performance due to existing of multi access interference (MAI) (Anuar, M. S., 2009). MAI is the interference from other users transmitting at the same time, which will limit the effective error probability with the exist noise in the overall system. Thus, an intelligent code design and suitable detection at the receiver is important to eliminate the effect of MAI (Abd, T. H., 2012).

There are also several intrinsic noise sources arising from the physical effects of the system design itself, such as relative intensity noise (RIN), phase induced intensity noise (PIIN), Thermal and Shot noises, respectively. PIIN is deeply related to MAI due to overlapping spectra from different users. This noise is due to spontaneous emission of the broadband light source. PIIN depends on the number of interfering users and cannot be improved by increasing the transmitted power or added amplification at the receiver side since, signal amplification is always accompanied by an equal amount of noise and cannot improve the ratio of signal power to noise power.

One of the effective solutions for PIIN suppression is to decrease the number of interferences between the signals of different users while the value of cross-correlation should be kept as small as possible (Zou Wei & Ghafouri-Shiraz, H., 2002). Therefore, the OCDMA coding system should have an efficient address code sequence with reliable cross-correlation. Unsuitable cross-correlation among the address sequences will cause PIIN between code sequences increased (Anuar, M. S., 2009).

In terms of the correlation properties, high auto-correlation and low cross-correlation are the main of spreading sequences designed. The cross-correlation dominate the MAI which is a general and an important issue in the OCDMA systems. The higher the cross-correlation between any two code words, will produce stronger impact of the MAI and erroneous decisions which will degrade the system performance of BER (Karbassian & Kueppers, 2010). Therefore, the correlation properties of the code addresses play a significant part in the performances of OCDMA systems. Furthermore, when it involves the correlation properties it also noticed issues of the code size and the code length. The code length has a limitation to the number of simultaneous users that the OCDMA systems can accommodate (Chi Shun Weng & Jingshown Wu, 2003).

Most codes have been proposed for the OCDMA systems such Dynamic Cyclic Shift (DCS), Modified Frequency Hopping (MFH), Modified Double Weight (MDW) and Hadamard codes (Abd, T. H, 2012; Zou Wei, Ghafouri-Shiraz, H., & Shalaby, H. M. H., 2001; Aljunid, S. A., 2004; Smith, E. D. J., 1998). However, these codes have several limitations such as the code is either too long (e.g. MFH code), construction is complicated (e.g. DCS code), or poorer cross-correlation (e.g. Hadamard code) and fixed an even natural number for MDW code. Finally, the longer code length had limited the flexibility of the codes since it will need a wide bandwidth source (e.g. MDW, Hadamard, MFH codes). It is highly expected that the new proposed OCDMA code sequence will improve system performance in term of high number of active users, an optimum auto and cross-correlations, enhance the BER error floor, which limited by the impacts of the MAI and PIIN noises.

1.3 Research Objectives

The main aims of this research are as follows;

a) To study various OCDMA codes and their properties such as code length, weight and cross-correlation.

b) To develop a new class of OCDMA codes that have the following properties: the code is optimum in the sense that the code length is shorter for any given number of users, weights and cross-correlation function.

c) To develop a new mathematical model for the OCDMA coding system based on the newly proposed code characteristics and evaluates the performance with the presence of different noises.

d) To analyze the theoretical and simulated results based on the new proposed code.

1.4 Scope of Research Works

Figure 1.1 shows a scope of the research works model which is focused on code development for multiple access technique in OCDMA systems. The development of the proposed codes was focusing on incoherent 1-D spectral amplitude coding based on the matrix combinatorial method which is previously used in former OCDMA codes such as MDW, Hadamard and DCS codes. The performance of new proposed code has been compared with former OCDMA codes such as DCS, MDW, MFH and Hadamard codes, respectively.

Nevertheless, as far as the scope of research works is concerned the software simulation is expected to be sufficient to prove the viability of the proposed code and their superior performance. During the development of a new proposed code, deeply research and study need to be done for mathematical derivation, codes properties design and an ability to differentiate between worst and average condition in the system performance most require and must understand well.

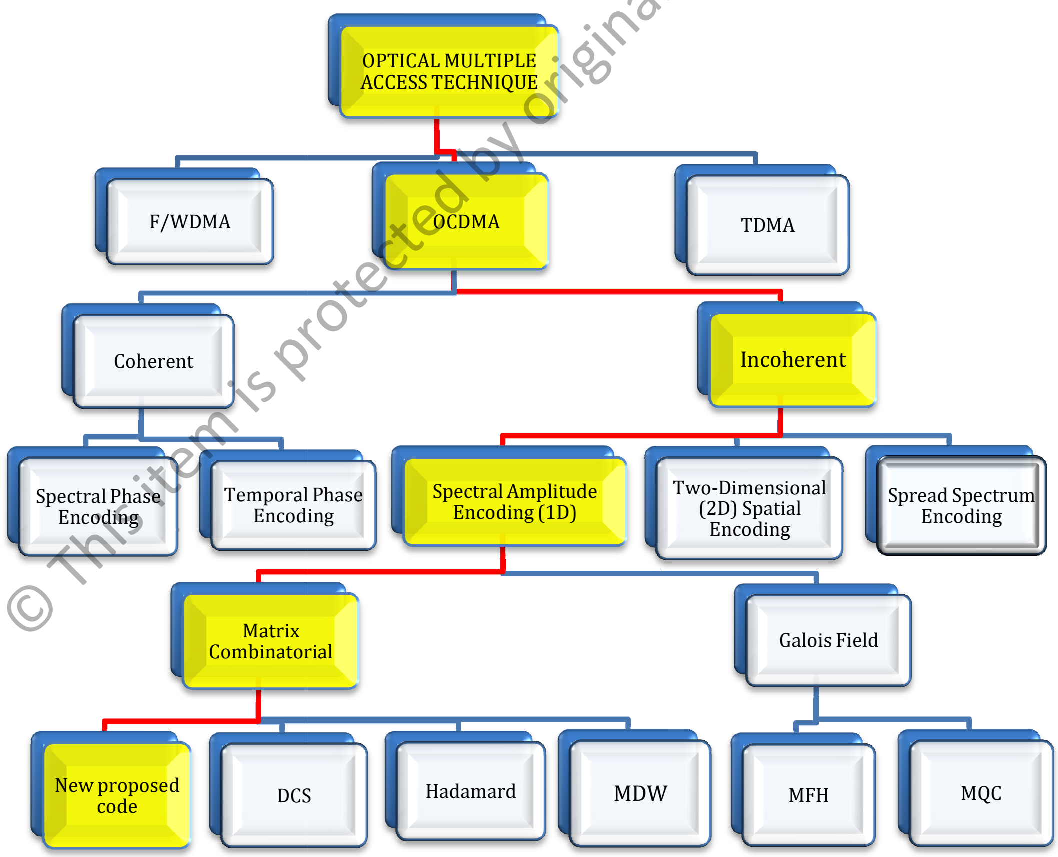

Figure 1.1: General model scope of works.

1.5 Thesis Outline

Chapter 1 provides an introduction to this study and an overview of each succeeding chapter. Chapter 2 reviews the optical multiple access and detection schemes of OCDMA systems. This chapter also includes a discussion on OCDMA coding techniques and presents a few examples of existing spectral amplitude coding OCDMA codes.

Chapter 3 describes the research method for developing OCDMA codes and compares existing codes in terms of characteristics and techniques. Section 3.3 provides the design and performance parameters involved in the theoretical and simulation results. Sections 3.7 and 3.8 elaborate on the different types of modulation techniques and the AND subtraction detection technique that will be used for the proposed code. Section 3.9 describes the receiver components that will be used in the proposed system. Chapter 4 presents the proposed code algorithm, performance analysis, and code comparison in terms of the length of various OCDMA codes. Moreover, this chapter elaborates on the encoder–decoder design of the proposed code for the simulation results.

The first three sections of Chapter 5 (Sections 5.1 to 5.3) discuss interference and the occurrence of different noises. Section 5.4 provides a brief background of theoretical performance analysis in mathematical preliminaries, signal-to-noise ratio (SNR) and bit error rate (BER) derivation. Section 5.5 reviews the theoretical results of the proposed code by using the provided typical related parameters. The simulation results are discussed in detail in Section 5.6. In Section 5.7, the theoretical and simulation results for the proposed code are validated.