A NOVEL ZERO CROSS CORRELATION CODE FOR OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEM

By

ANUAR MAT SAFAR
(0640810085)

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

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2012

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Authors Full Name :	**ANUAR BIN MAT SAFAR**
Date of birth :	**30TH DECEMBER 1971**
Title :	**A NOVEL ZERO CROSS CORRELATION CODE FOR OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEM**
Academic Session :	**2008 / 2009**

I, hereby declare that this thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be place at the University library. This thesis is classified as :

CONFIDENTIAL	☐	(Contains confidential information under the Official Secret Act 1972)
RESTRICTED	☐	(Contains restricted information as specified by the organization where research was done)
OPEN ACCESS	√	I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the Universiti Malaysia Perlis to reproduce this thesis in whole or in part of the purpose of research or academic exchange only (except during a period of ……. years, if so requested above).

	Certified by
……………………. **SIGNATURE**	……………………………………. **SIGNATURE OF SUPERVISOR**
711230-09-5035 ………………………………….. (PASSPORT NO. / NEW IC NO.)	PROFESSOR DR. SYED ALWEE ALJUNID BIN SYED JUNID ……………………………………………………………………… NAME OF SUPERVISOR
Date: ………………..	Date: …………………………

NOTES: * If there is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentially or restriction.

GRADUATE SCHOOL

UNIVERSITY MALAYSIA PERLIS

PERMISSION TO USE

In presenting this thesis in fulfillment of a post graduate degree from the Universiti Malaysia Perlis, I agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by my supervisor(s) or, in their absence, by the Dean of the Graduate School. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without any written permission. It is also understood that due recognition shall be given to me and to Universiti Malaysia Perils for any scholarly use which may be made of any material from my thesis.

Request for permission to copy or to make other use of material in this thesis whole or in part should be addressed to

Dean of Graduate School

Universiti Malaysia Perlis (UniMAP)

No. 112 & 114, Tingkat 1, Blok A, Taman Pertiwi Indah,

Jalan Kangar-Alor Setar,

Seriab, 01000 Kangar, Perlis.

ACKNOWLEDGEMENT

Alhamdulillah, this thesis would not have been possible without the help from Allah s.w.t. I wish to express my gratitude to my great supervisor, Prof. Dr. Syed Alwee Aljunid who was abundantly helpful and offered invaluable assistance, support and guidance. I would like to acknowledge the advice and guidance of Assoc. Prof. Dr. Mohamad Naufal Saad, my co-supervisor for all his advice and encouragement. Special thanks also to all my graduate friends, especially from optical communication group members for sharing the literature and invaluable assistance. I would also like to convey my thanks to the Ministry of Higher Education, Universiti Malaysia Perlis and the Dean of the School of Computer and Communication Engineering, Assoc. Prof Dr. R. Badlishah Ahmad for providing the financial means, laboratory facilities and all the supports. I wish to express my love and gratitude to my late parents (Al-Fatihah), my beloved wife, Pn Mas Zulaifa Mukhtaruddin and all my children; for their understanding and endless love, through the duration of my studies. Insyaallah, Allah will always bless you all.

Anuar Mat Safar

TABLE OF CONTENTS

CHAPTER 5 IMPLEMENTATION OF ZCC CODE IN NETWORK SYSTEM

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF ABBREVIATIONS

AWG	Array Wavelength Grating
BER	Bit Error Rate
CDMA	Code Division Multiple Access
DWDM	Dense Wave Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
FBG	Fiber Bragg Grating
FTTH	Fiber To The Home
Gbps	Gigabit per second
LED	Light Emitting Diode
MAI	Multiple Access Interference
Mbps	Mega bit per second
MFH	Modified Frequency Hopping
MQC	Modified Quadratic Congruence
NRZ	Non Return to Zero
NDSF	Non Dispersion Shift Fiber
OCDMA	Optical Code Division Multiple Access
ODLCs	Optical Delay Line Correlate's
OOC	Optical Orthogonal Code
OSNR	Optical Signal to Noise Ratio
DW	Double Weight
MDW	Modified Double Weight
EDW	Enhance Double Weight

ZCC	Zero Cross Correlation
OOK	On-Off Keying
PD	Photo Diode
PIIN	Phase Induced Intensity Noise
PIN	Positive Intrinsic Negative
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
RF	Radio Frequency
SAC	Spectral Amplitude Coding
SMF	Single Mode Fiber
SPM	Self Phase Modulation
TDM	Time Division Multiplexing
WDMA	Wavelength Division Multiple Access
FDM	Frequency Division Multiplexing
VoD	Video-on Demand
CD	Chromatic Dispersion

KOD SILANG SEKAITAN SIFAR BARU BAGI SISTEM CDMA OPTIK

ABSTRAK

Teknik Berbilang Capaian Pembahagian Kod Optik (OCDMA) telah menunjukkan keupayaan luarbiasa dalam berkongsi berbilang pengguna secara serentak di dalam rangkaian capaian. Tujuan kajian ini adalah bagi membangunkan pengkodan amplitud spektum baru dalam kod OCDMA. Secara terperinci, kami cuba mengurangkan gangguan berbilang capaian (MAI), seterusnya mengecilkan hingar keamatan fasa teraruh (PIIN) dengan menggunakan kod baru yang mempunyai ciri silang sekaitan sifar dalam sifatnya. Kod ini akan diperiksa dan dianalisakan prestasinya di dalam sistem rangkaian. Sasaran lain adalah untuk mencari komponen dan parameter yang digunakan untuk mengoptimumkan prestasi kod tersebut. Akhir sekali, analisa tersebut akan disahkan dengan membuat perbandingan antara kajian secara teori dengan hasil simulasi. Kaedah penggabungan matriks telah diaplikasikan dalam membangunkan kod ZCC ini. Dengan menggunakan teknik SAC tidak koheren OCDMA, kami boleh mengurangkan kesan PIIN dalam prestasi sistem. Kajian tentang kaedah prestasi sistem dalam kod ZCC telah dilakukan dan digunapakai bagi menjana terbitan matematik untuk teori prestasi kod. Simulasi dijalankan dengan mengoptimumkan parameter yang terlibat bagi mendapatkan prestasi sistem yang terbaik. Pengesahan hasil teori diperakukan melalui analisa simulasi ini. Sumbangan kod ZCC yang terbesar sekali adalah tidak akan ada silangan bit antara pengguna dan ia semestinya ortogon bagi mana-mana bilangan pengguna dan pemberat. Struktur kod adalah boleh suai terutamanya dalam pertukaran parameter kod seperti bilangan pengguna dan bilangan pemberat. Kod ini menunjukkan keselamatan isyarat yang sangat bagus disebabkan struktur rawak kod. Analisa prestasi kami menunjukkan kod ZCC mempunyai prestasi yang lebih baik berbanding dengan kod lain yang sama kelas dalam SAC. Ianya juga dapat menampung lebih tinggi bilangan pengguna secara serentak. Sistem ini boleh menampung 110 pengguna serentak dengan kebenaran kadar ralat bit 10^{-9}. Kuasa diperlukan adalah lebih rendah di fotopengesan dengan erti lain sistem pengesan adalah lebih sensitif dengan aplikasi kod ini. Teknik pengesan langsung digunakan dalam sistem pengkodan ZCC boleh mengurangkan bilangan penapis, jadi ianya dapat mengurangkan kos sistem. Hasil ini telah menunjukkan dengan menggunakan teknik pengkodan ZCC akan mencapai kadar bit yang lebih tinggi sehingga 10 Gigabit sesaat berbanding teknik pengkodan yang lain. Pada prinsipnya, kesimpulan dapat dibuat di mana dengan hasil penemuan kod ZCC yang baru ini, ianya menyumbang kepada penyelesaian banyak isu dalam OCDMA seperti pengurangan MAI, penambahan bilangan pengguna yang ditampung, penambahan kuasa pengesan, penghantaran kadar bit yang lebih tinggi, meningkatkan ciri keselamatan dan mengurangkan kekompleksan dengan menggunakan teknik pengesanan langsung.

A NOVEL ZERO CROSS CORRELATION CODE FOR OPTICAL CDMA SYSTEM

ABSTRACT

Optical Code Division Multiple Access (OCDMA) techniques have shown outstanding capabilities in sharing multiple users simultaneously in access network. The purpose of this study was to develop a new spectral amplitude coding (SAC) in OCDMA code. In particular, we tried to minimize multiple access interference (MAI), consequently diminish the phase induced intensity noise (PIIN) by using this new code with the main characteristic of zero cross correlation in its property. This code was investigated and analyzed for its performance in the network system. Another aim was to find out the components and parameters used in order to optimize the performance of the code. Finally, the analysis was validated by comparing theoretical studies with the simulation results. The method of combinatorial matrix was applied in developing this zero cross correlation (ZCC) code. By using SAC incoherent OCDMA techniques, we were able to mitigate the PIIN effect in the system performance. The study of system performance methodology in ZCC code was conducted and used to generate the mathematical derivation for the code performance theoretically.The simulation was conducted with optimization of the parameters involved to obtain the best performance in the system. The validation of the theoretical results was confirmed through this simulation analysis. The great contribution of ZCC code was that there was no overlapping of bit '1' among users and absolutely orthogonal for any number of users and weights. The code structure was very flexible especially in changing code parameter such as the number of users and the number of weight. The code demonstrated an excellence in signal security due to the random code structure. Our performance analysis showed ZCC code has a better performance compared to other codes in the same class of SAC. It could also accommodate a higher number of users simultaneously. This system could support 110 users simultaneously with a permissible bit error rate of 10^{-9}*. Power required was lower at the photo detector which means the detection system required less power by applying this code. Direct detection technique used in the ZCC coding system reduced the number of filters, thus led to less system cost. The results showed that employing ZCC coding technique achieved higher bit rates up to 10 Gigabits per second compared to other coding techniques. The principal conclusion was that by the invention of the new ZCC code, it contributed to the solution of many issues in OCDMA such as reduction of MAI, increased the number of users accommodated, increased effective power at the detector, higher bit rates being transmitted, enhanced security and reduced the complexity by using a direct detection technique.*

CHAPTER 1

INTRODUCTION

1.1 Introduction

A great interest in optical communication was triggered since last the two decades due to a phenomenal increase exponentially in worldwide internet implications (Gambling, 2000; Hecht & Long, 2006; Keiser, 2000; Kolimbiris, 2004; Palais, 2005). Traditional communication links are incapable of satisfying the demand for information due to the limitations imposed by their bandwidth constraints. The more bandwidth, the more information a signal can carry. New services such as triple play services (data, audio and video) over internet protocol (IP) networks in education, medical, entertainment, shopping and many other applications have increased the demand for more bandwidth. Data transmission limitations of traditional links have been overcome since the introduction of optical fiber networks.

Optical fiber communication is the most popular type of data and computer communication network. Fiber is the best waveguide in light applications. It has lots of advantages, such as low loss, high bandwidth and high security. Conventional communication cable is short of these advantages. Optical communication has various ways of transmission techniques. Due to high frequency of light, if we could control and use light as the carrier of communication, capacity would be larger than conventional communication (W. Huang, Nizam, Andonovic, & Tur, 2000).

Another major advantage of fiber has always been its ability to transmit signals at higher speeds and over longer distances than other transmission media. The limited capacity offered by today’s networks will soon be insufficient and thus optical networks operating at higher bit rates than the network of today will be required. Long haul networks span distances up to hundreds to thousands of kilometers which connect a few metropolitan networks and among each other, extend the global connectivity and are mainly concerned with capacity. Optics has been widely deployed in long haul networks and allows for a large amount of information to be carried over long distances.

To deliver high speed data content to a growing broadband user population, intense research and development have focused on the techniques for providing bandwidth efficient multiple access formats and protocols (Fouli & Maier, 2007). In long haul optical fiber transmission links and networks, the information consists of a multiplexed aggregate data stream originating from many individual subscribers and normally is sent in a precise-timed synchronous format (Keiser, 2000). There are two major multiple access techniques: each user is allocated a specific time slot in time-division multiple-access (TDMA) or a specific frequency (wavelength) slot in frequency or wavelength division multiple-access (F/WDMA). The design goal 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, 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 (Borella, Jue, Banerjee, Ramamurthy, & Mukherjee, 1997; Brackett, 1990; Fujiwara, Suzuki, Teshima, & Iwatsuki, 2002; Iwatsuki, Kani, Suzuki, & Fujiwara, 2004; Tucker, Eisenstein, & Korotky, 1988).

Alternatively, optical code-division multiple-access (OCDMA) is receiving increasing attention (Azizoglu, Salehi, & Li, 1992; Kwong, Perrier, & Prucnal, 1991; J. A. Salehi, 1989; Salehi, Weiner, & Heritage, 1990) due to its potential for enhanced information security, simplified and decentralized network control, improved spectral efficiency and increased flexibility in the granularity of bandwidth that can be provisioned.

The OCDMA system has been investigated for about two decades and received a lot of interest. The OCDMA system has the advantage of providing multiple users to access the same bandwidth simultaneously without employing high-speed electronic data processing circuits that are necessary in the optical TDMA networks. In addition, it also has the advantage of providing high-level security during transmission.

The principle of OCDMA is based on spread spectrum techniques that have been widely used in wireless communication systems (Dixon, 1994). OCDMA has been recognized as one of the most important technologies for supporting many users in shared media simultaneously and in some cases can increase the transmission capacity of an optical fiber. OCDMA achieves multiple access by assigning a unique code to each user and to communicate with another node, users imprint their agreed upon code onto the data (Maric, Moreno, & Corrada, 1996). At the receiver end, it decodes the bit stream by locking onto the same code sequence. This is how it preserves the security properties in optical systems besides having additional support in electrical security.

1.2 Motivation of OCDMA

Since optical fiber is a very different medium compared to radio links, one would expect OCDMA systems to have similarities, as well as differences from its radio version. This research aims at finding the most suitable form of OCDMA coding systems that can be applied to optical fiber links, as an alternative way to the multiplexing of optical signals for further improvements. The potential benefit and difficulties of existing OCDMA systems will also be studied.

The primary reasons that have motivated the communications community to examine the potential of OCDMA in optical networks are the asynchronous access capability and the inherent security in transmission offered. These characteristics distinguish OCDMA from other more standard multiplexing schemes such as optical TDMA or WDMA, which are based on time or wavelength allocation. Conventional WDMA using stable laser sources has a high cost and complexity, depending on the requirement of time synchronization, can be classified into synchronous and asynchronous systems (Lin, Wu, Tsao, & Y, 2005).

OCDMA are getting more attractive as multiple users can access the network asynchronously and simultaneously with a high level of transmission security (R. K. Z. Sahbudin, M. K. Abdullah, M. D. A. Samad, M. A. Mahdi, & M. Ismail, 2008). One of the key issues that must be resolved in moving from a single user communication system to a multi-user communication system is how we can efficiently divide the available transmission medium among all users. OCDMA allows multiple users to utilize the same overlapping spectrum through the use of orthogonal codes that obviate interference between simultaneous users on the channel. One of the considerations in designing OCDMA systems is the coding.

The effective signal-to-noise ratio (SNR) in OCDMA systems is limited by the interference resulting from the other users transmitting at the same time on a common channel, known as Multiple Access Interference (MAI). MAI is a major source of noise in OCDMA systems (H. Zou & Ghafouri-Shiraz, 2002). Thus, a proper design of the code sequences is important to mitigate the deleterious effect of MAI. There are also intrinsic noises sources arising from the physical effects of the system design itself, such as relative intensity noise (RIN), phase induced intensity noise (PIIN), thermal noise and shot noise. PIIN is closely related to the MAI due to the overlapping of the spectrum from the different users (H. Zou & Ghafouri-Shiraz, 2002). The key to an effective OCDMA system is efficient address codes with zero cross-correlation properties (A Stok & E. H Sargent, 2000). This property not only ensures that each code sequence can be easily distinguished from the other code sequences, but also suppresses any limitations owing to MAI and PIIN. One of the crucial issues in OCDMA is to devise a coding system that can suppress the effects of co-channel interference, in doing so, yielding a better system performance.

The cross-correlation dominates the MAI which is a general and important issue of the multiple access systems. The higher the cross-correlation between any two code words, the stronger the MAI and the greater the probability of erroneous decisions, hence the poorer the system performance in terms of the BER. Therefore, the correlation property of the signature codes plays a key role in the performances of OCDMA systems and is one of factors worthy of note when searching the signature codes. In addition to the correlation property, another two noticed issues are 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 (Wen, Jhou, Lin, & Li, 2006).

One of the major problems that currently prevent OCDMA from becoming more practical is the presence of PIIN. It arises when multiple light signals are combined and the detector is used to convert the optical power to an electrical signal. Incoherent OCDMA schemes suffer the most from this noise, since multiple pulses from the desired transmitter and the MAI are combined in a receiver. PIIN noise also affects coherent schemes, since the electrical fields of the recovered signal from the desired user and the interference signals are added together before detection by the photo detector in the receiver.

Additionally the prospect of performing the encoding/decoding functions all-optically and therefore achieving real transparent networks, could potentially lead to network throughput of the rate of Terabits/second (Karafolasa & Uttamchandani, 1996). Although significant progress has been achieved in understanding the theoretical characteristics of OCDMA networks, such networks have yet to be realized and fully characterized experimentally and there remains a general caution about the prospect of CDMA in the domain of optical networks.

With the techniques used in synchronous OCDMA, it is very difficult to achieve even two OCDMA users at 10Gbps in a truly asynchronous environment (Sotobayashi, W, & Kitayama, 2002). In other applications, the limitations of some OCDMA codes present in terms of the number of network subscribers might be a disadvantage. Security has been mentioned as one of the advantages about OCDMA in various publications. The main apparent reason is that only the intended receiver has the knowledge of the spreading sequence that is necessary to de-spread the received signal. It is found that the spreading methods used in all of the current OCDMA schemes are just multiple-access techniques used to suppress MAI rather than security features (Shake, 2005).

1.3 Thesis Objectives

The main aims of this research are as follows:

- To identify various OCDMA codes classification and their properties.
- To propose a set of code with minimum cross correlation between users in order to suppress MAI effectively.
- To produce a theoretical analysis based on the newly invented code performance characteristics.
- To validate the performance of a new OCDMA code family using simulation and compare with the theoretical results.

1.4 Thesis Organization

The remainder of this dissertation is organized as follows. Chapter 2 provides a review of optical multiple access techniques. It will be discussed based on the classification of OCDMA coding techniques. Literature on OCDMA strengths and issues will be reviewed in this chapter. A few examples in optical spectral amplitude coding will be listed at the end of this chapter.

Chapter 3 discusses the methodology of the research which is divided into three; code design methodology, code performance analysis methodology and simulation. Section 3.2 and 3.3 investigates the existing code methodology while section 3.4 discusses on code performance analysis methodology. Section 3.5 and 3.6 are used to detail the parameter