Design and development of sequential algorithm (SeQ) code for OCDMA system

By

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A thesis submittteed in fulfillment of the requirements for the degree of
Master of Science in Communication Engineering

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2018

ACKNOWLEDGEMENT

Thank Almighty, Who has continuously give me the strength to complete this research and guided me to the right path. I would also like to express gratitude to my supervisor, Dr. Mohd Rashidi Bin Che Beson for offering me this research opportunities. His great supervision and consistent support has enabled me to attain all the objectives to fulfill this research. Without his guidance, I wouldn't imagine I can go far this research.

I also would like to extend my gratitude to the Head of the Department Of Ace Optics Prof. Dr. Syed Alwee Aljunid Syed Junid, University Malaysia Perlis for his inspiration, cooperation and assistance in the completion of my research.

My deepest love and gratitude belong to my parents who have been the crucial sources of support not only throughout the period my studies but also in my life.

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
CDMA	Code Division Multiple Access
DCS	Dynamic Cyclic Shift
DDW	Diagonal Double Weight
DW	Double Weight
FBG	Fiber Bragg Grating
FCC	Flexible Cross Correlation
FRS	Fixed Right Shift
FTTH	Fiber to the Home
ITU	International Telecommunication Union
LAN	Local Area Network
LED	Light Emitting Diode
MAI	Multiple Access Interference
MCC	Minimum Cross Correlation
MDW	Modified Double Weight
MFH	Modified Frequency Hopping
MMF	Multimode Fibers
OCDMA	Optical Code Division Multiple Access
OTDMA	Optical Time Division Multiple Access
Optisys	Opti System

PD	Photo Detector
PIIN	Phase Induced Intensity Noise
PON	Passive Optical Network
PSD	Power Spectral Density
P_{sr}	Effective Received Power
QoS	Quality of Service
RIN	Intrinsic Noise
SAC-OCDMA	Spectral Amplitude Coding – Optical Code Division Multiple Access
SCM	Scheme of Subcarrier Multiplexing
SDH	Synchronous Digital Hierarchy
SeQ	Sequential Algorithm
SI	International System Units
SMF	Single Mode Fibers
SNR	Signal-to-Noise Ratio
SONET	Synchronous Optical Network
SPD	Single Photodiode Detection
STM	Synchronous Transport Module
TDMA	Time Division Multiple Access
WDM	Wavelength Division Multiplexing
WDMA	Wavelength Division Multiple Access

LIST OF SYMBOLS

τ_c	Coherence time of the resources
B	Electrical bandwidth
bps	Bit per Second
e	Electron's charge
h	Planck's Constant
K	Number of active users
K_b	Boltzmann's constant
N	Code length
R_b	Data transmission rate
R_L	Receiver load resistor
T_n	Total temperature
V_c	Central Frequency
W	Weight
$\Delta\lambda$	Broadband line width
η	PD quantum efficiency
λ_c	Cross-Correlation
I	Mean of photocurrent

Rekabentuk dan Pembagunan Kod Algoritma Berturut (SeQ) untuk Sistem OCDMA

ABSTRAK

Tesis ini membentangkan kaedah untuk membangunkan satu objektif baru dalam Sistem Pelbagai Akses Pembahagian Kod Optik (OCDMA) dengan menggunakan Pengekodan Amplitud Spektrum (SAC). Kod yang dicadangkan ialah Kod Algaritma Berturut (SeQ). Berdasarkan teori, kaedah yang dicadangkan adalah untuk membina kod optik dengan gabungan matrik pepenjuru dan mengenal pasti kod matrik. Kod SeQ ini dibina dengan pembinaan kod ringkas untuk bilangan pengguna dan berat, pelbagai korelasi silang dan mempunyai minimum panjang kod. Kod SeQ telah direka dengan korelasi silang bersamaan dengan sifar dan satu disebabkan oleh kesan Gangguan Akses Pelbagai (MAI) untuk mengelakkan daripada bertindih spectrum oleh setiap pengguna. Kod ini mudah dibina, ringkas dan mempunyai prestasi gangguan yang lebih baik berbanding dengan kod optik yang sedia ada seperti kod Fleksibel Silang Korelasi (FCC), Peralihan Kitaran Dinamik (DCS), Peggantian Kekereapan Berkubah (MFH) dan Pengubahsuaian Berat Kedua (MDW). Kod SeQ dibina untuk meningkatkan prestasi Kadar Ralat Bit (BER) di dalam sistem OCDMA. Prestasi kod SeQ telah dilakukan melalui analisis teori dan analisi simulasi melalui perisian simulasi komersial, Optisistem oleh Optiwave™. Prestasi sistem adalah merujuk pada ciri – ciri kadar ralat bit, nisbah isyarat – ke – ganguan (SNR), kadar bit dan kuasa yang diterima. Kajian ini mendapati prestasi SeQ lebih baik apabila dibandingkan antara analisis teori dan simulasi dan hasilnya adalah berpadanan antara satu sama lain. Oleh itu, kod SeQ telah meningkatkan sistem OCDMA lebih baik daripada kod sedia ada.

Design and Development of Sequential Algorithm (SeQ) Code for OCDMA System

ABSTRACT

In this thesis, presents a method for development of a new novel in optical code for Optical Code Division Multiple Access (OCDMA) system using Spectral Amplitude Coding (SAC). The proposed code is called Sequential Algorithm (SeQ) code. From theory, the proposed method is to construct optical codes with a combination of tridiagonal matrix and identify matrix code. This SeQ code is constructed with simple code construction for any number of users and weight, various cross correlation and having minimum code length. SeQ code has been designed with cross correlation is equaling to zero and one due to the effects of Multiple Access Interference (MAI) thus to prevent from overlapping of spectra from each users. These codes are easy to construct, simple and have better noise performance compared with existing optical codes such as Flexible Cross Correlation (FCC), Dynamic Cyclic Shift (DCS), Modified Frequency Hopping (MFH) and Modified Double Weight (MDW) code. The requirement in OCDMA systems to enhanced performance of BER is the reason why these codes has been designed. The performances of SeQ code has been done via theoretical analysis and simulated performances analysis via utilizing commercial simulation software, *Optisystem* by *Optiwave*^{TM}. The performance of the systems was characterized by referring the Bit Error Rate (BER), signal-to-noise ratio (SNR), bit rate and effective received power. This research finds strong performance of SeQ code when compared between theoretical and analysis performance and the result was proportional each other. Therefore, SeQ code has enhanced the OCDMA system better than existing codes.

CHAPTER 1: INTRODUCTION

1.1 Research Background

A communication system transfer information from one station to another, whether, short or long-haul. Communication is usually supported by an electromagnetic carrier wave that frequently ranges from a few to more than a few hundred megahertz (MHz) (Bhusari, Deshmukh, & Jagdale, 2016). Optical communication systems utilizes high carrier frequency in the observable section of electromagnetic range. Fiber optic communication approaches are using lightwave optical fiber system that facilitate the signal transmission (Maystrenko, Bogachkov, Kopy, Lyubchenko, Lutchenko, & Castillo, 2016).

In principle, optical communication systems differs from microwave systems in term of carrier wave that used to transmit the communication information. An enhancement to the information capacity in optical communication systems by a factor of up to ten thousand is expected simply because of the high carrier frequencies used for lightwave system (Aldhaibani, Aljunid, Anuar, & Nordin, 2016). This enhancement can be identified based on the bandwidth of the controlled courier capable of up to a little percentage of the carrier frequency. For example, take 1% as the controlling value, optical communication system has a possibility of transmitting information at bit rate of ~1Tb/s. This larger bandwidth of optical communication systems bandwidth is powerful for international improvement and utilization of the lightwave systems (Maiti, & Brandt-Pearce, 2015).

Figure 1.1: Common optical communication system (Nandan, & Chattopadhyay, 2014)

Figure 1.1 above shows a common block diagram of an optical communication system. There are three elements common to all communication systems. It consists of a transmitter, a communication channel and receiver. An optical communication system can be divided into two categories which are bounded and unbounded (Guan, Tulino, Winzer, & Soljanin, 2015). As the name implies, in the case of bounded lightwaves system, the optical beam emitted by the transmitter remains spatially confined. Since all bounded optical communication systems currently use optical fibers, the commonly used term is fiber optic communication system. The lightwave system is also sometimes used for the fiber optics communication system, although it should generally include both bounded and unbounded systems (Guan et al., 2015).

As for unbounded optical communication systems, the optical beam emitted by the transmitter spreads in space, similar to the spreading of microwave (Abd, Ajunid, Fadhil, Ahmad, & Junita, 2012). However, unbounded optical system are less suitable for broadcasting applications compared to microwave systems because optical beams spread mainly in the forward direction. It generally requires accurate pointing between the transmitter and the receiver (Abd et al., 2012). Application of the optical fiber communication is general possible in any area that requires transfers of information from one place to another location. Since fiber optic communication systems have been developed mostly for telecommunications applications (Kumari, & Sarangal, 2014).

Multiple access techniques are used to allow a large number of mobile users to share the allocated spectrum in the most efficient manner. As the spectrum is limited, sharing is required to increase the capacity to cell or over a geographical users. Thus, it must be done in such way such that the quality of service doesn't degrade among the existing users (Parikh, & Paliwal, 2015). One of the keys issues that must be resolved in moving from single user to a multi-user communication system is how the efficiently divide the available transmission medium among all users (Parikh et al., 2015).

OCDMA has been recognized as one of the most important technologies for supporting many users in shared media. Some cases can be accommodated by an increase in the transmission capacity with a greater bandwidth by utilizing an optical fiber (Ahmed, Aljunid, Fadil, Ahmad, & Rashid, 2012). OCDMA 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 large number of asynchronous users (Ahmed et al., 2012).

OCDMA is assigns the transmission by code separation for data transmission. In this research, the new class of code has proposed, called SeQ code. This code is constructed according to combination between tridiagonal matrix codes and identify code matrix with minimum code length and various cross correlation to enhance the OCDMA system.

1.2 Problem Statement

In OCDMA system, the weaknesses of current multiple access techniques have encouraged the quest for better ones. Many codes has proposed for system enhancement.

OCDMA was born somewhat prematurely almost two decades ago (Djeffal, Aljunid, Rashidi, Aldhaibani, & Messaoudene, 2016). From the previously constructed codes, principal attention is towards the unacceptable code constructed and expanding synchronous user number reduce the OCDMA system performance due to the current MAI. There are similar number of noise resources arising from the physical properties of the arrangement scheme, for example phase induced intensity noise (PIIN), thermal and shot noise. PIIN occurrence is severely related to MAI because of the overlapping spectra of many users (Rashidi, Aljunid, Fadhil, & Anuar, 2013). It cannot be enhanced by increasing the transmitted power or additional amplification at the receiver part. Meanwhile, signal amplification is continuously accompanied by an equivalent noise volume. It cannot increase the ratio of signal power to noise power. MAI is the restriction from another user transmission at the same time, which will bind the operation error possibility with the real noise in the general system (Rashidi et al., 2013).

A few of the operative resolution for PIIN destruction are to reduce the number of restrictions among the signals of other users, whereas the value of cross-correlation must be minimum to be acceptable. Thus, the OCDMA coding scheme must have an effective address code arrangement for the fixed cross-correlation (Kakaee, Kharazi, Anas, Fadhil, Sahbudin, & Mokhtar, 2012). The cross-correlation controls the MAI which is the overall and main subject in the OCDMA systems. The more cross-correlation between any two code words, the more robust the MAI and much more inaccurate resolution. Hence, the correlation properties of the code address important measure in the operation of OCDMA systems (Abd, Aljunid, Fadhil, Radhi, & Saad, 2015). The code length develops a restriction to the number of synchronous users that the OCDMA systems be able to support. Most codes have been proposed for SAC-OCDMA system such as DCS, FCC, MFH and MDW. However, all these codes have several limitations such as complicated code construction, lengthy codes and unsuitable cross correlation (Othman, Jesen, Zhang, & Monroy, 2011).

1.3 Objective of Research

The main goal of this research is to develop a new class of OCDMA encoder / decoder which can be improved the performance of OCDMA communication system. The objectives of this research are:

i) To formulate a new algorithm for PIIN and MAI cancellation properties by using SeQ code.

ii) To design a new encoder / decoder based SeQ code on purposed new algorithm with various cross correlation.

iii) To validate this new proposed code between theoretical and simulation.

1.4 Scope of Research

Figure 1.2 shows the scope of research that focused on the code enlargement to the multiple access technique of OCDMA network system. The proposed codes were focusing on mathematical preliminaries to design codes for a given number of users and weights to achieve a minimum code length. A new class of various cross correlation was proposed in this thesis to significantly improve system performance of OCDMA systems.

The code is developed by incoherent, which are binary 1, 0 and focus on 1-Dimension spectral amplitude coding. The fundamental of this code is combination between a tridiagonal matrix code and identity code matrix approach code for OCDMA network system. Nevertheless, to complete the code development, the code performance has been analyzed by utilizing *Optisys* software by *Optiwave*^{TM}.

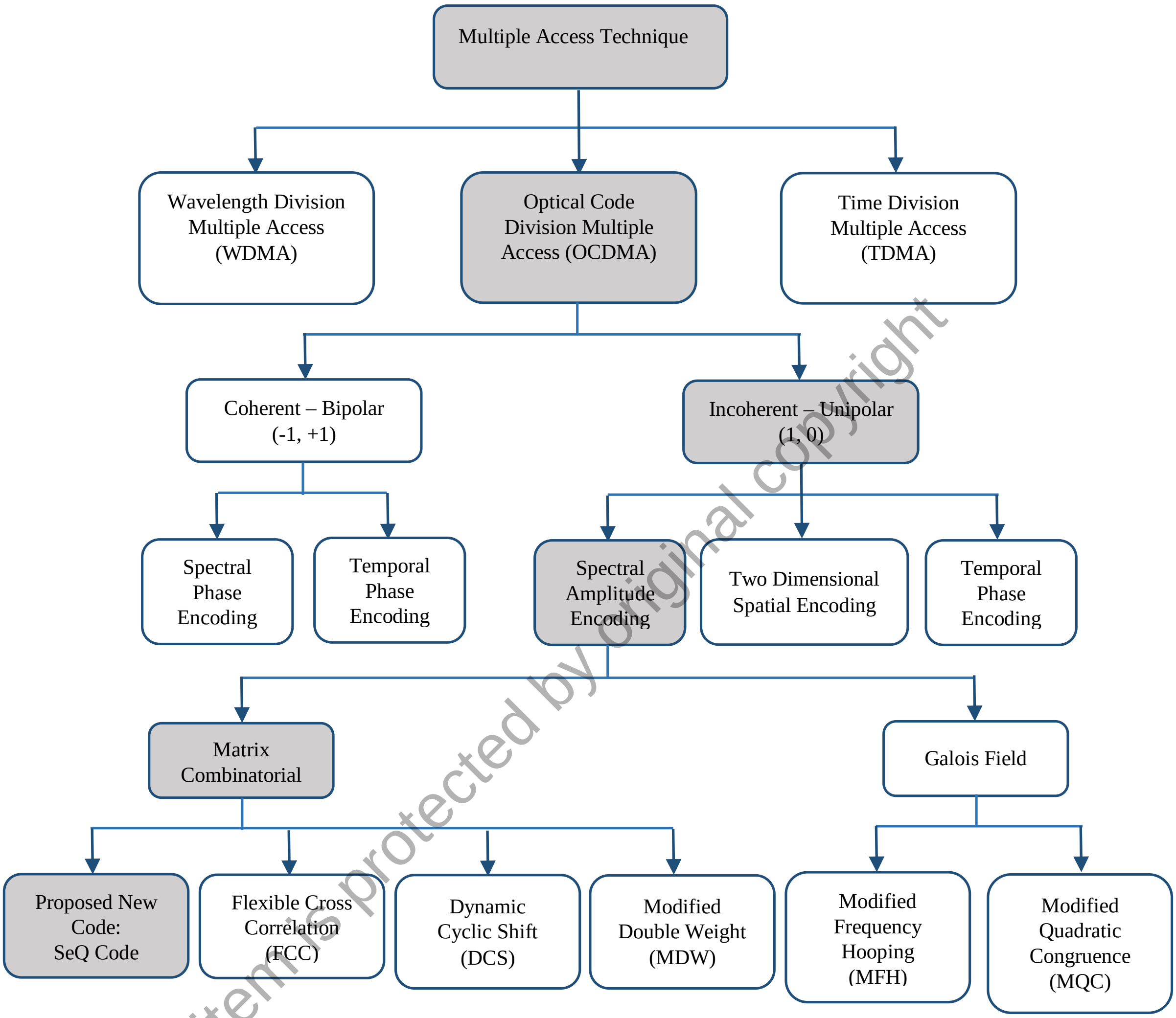

Figure 1.2: General of research scope

1.5 Thesis Outline

Overall, this thesis consists of five chapters which cover introduction, literature reviews, methodology, results, and discussion as well as conclusion. The research background, problem statement, objective of research and the scope of research are further clarified in chapter one.

Chapter two describes the literature review that explains the multiple access in a communication system which comprises Wavelength Division Multiple Access (WDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA) techniques. This chapter also explains the existing code and the detection techniques in OCDMA network systems.

Chapter three emphasizes the methodology for this research covering the designs, code development and simulation process by utilizing the simulation software, *Optisys* by *Optiwave*^{TM}. This chapter provides the design parameters in theoretical and simulation results. Furthermore, Chapter 3 also includes the detection that was used in this proposed code.

Chapter four provides the SeQ code performance analysis, in the form of theoretical performance analysis in mathematical preliminaries, SNR and bit error rate (BER) derivation. Besides that, this chapter also demonstrates the simulation result by utilizing *Optisys* from *Optiwave*^{TM}. The results proved that, the SeQ code is superior performance compared to existing code. This chapter reveals the encoder/decoder design of the proposed code for OCDMA network system. Moreover, the theoretical and simulation results for this SeQ code were validated.

Lastly, chapter five states overall summary for this research. It also discusses the research finding and the future research direction utilizing this SeQ code for OCDMA network system.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A multiple access technologies are communication system where a number of users share a common medium to send messages to a number of destinations. One of the key issues that must be resolved by moving from a single user to a multi – user communication system is how effectively divides the available transmission medium between all users simultaneously with finite bandwidth with least possible degradation of the system performance. Multiple access techniques represent one of the essential functions of networks. There are three basic multiple access that can be accessing which can be achieved. The three basic schemes of multiple access are wavelength division multiple access (WDMA) also known as F/WDMA, time division multiple access (TDMA) and code division multiple access (CDMA). In these three schemes, receivers discriminate among various signals by the wavelength channels, time slots and use different codes respectively.

Optical fibers provides access bandwidth for multiple access operations, permitting many users to simultaneously communicate over the same medium by partitioning and allocating time, bandwidth or some other features of the transmitted signal (Idachabe, Ike, & Hope, 2014). A multiple access is required for combining and separating traffics on a shared physical medium when the users are not at the same location. There are three major multiple access schemes available such as TDMA, WDMA and OCDMA (Durand, Filho, & Abrao, 2012).

2.1.1 Wavelength Division Multiple Access (WDMA)

WDMA system uses a multiplexer at the transmitter to join the several signals together and demultiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that simultaneously does both and be able function as an optical add-drop multiplexer (Baziana, 2015). WDMA system are popular with telecommunications companies because it is allow them to expand the network capacity without laying additionally more fiber. By using WDMA and optical amplifiers, they can accommodate several generations of technology development in their optical infrastructure without having to overhaul the backbone network (Baziana, 2015). Capacity of given link can be expended simply by upgrading the multiplexers and demultiplexer at each end.

WDM systems are divided into three different wavelength patterns such as normal (WDMA), course (CWDMA) and dense (DWDMA). Normal WDMA uses two normal wavelength 1310nm and 1550nm on one fiber (Khaki & Singh 2012). CWDMA provides up to 16 channels across multiple transmission window of silica fibers. DWDMA uses the C-band 1530nm to 1565nm transmission window but with a denser channel spacing. Channel plan varies, but a typical DWDMA system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are even capable of 12.5 GHz spacing (Khaki et al., 2012). CWDMA in contrast to DWDMA uses increased channel spacing to allow less sophisticated and thus cheaper transceiver designs. To provide 16 channels on a single fiber CWDMA uses the frequency band spanning the transmission window 1310nm/1550nm) (Khaki et al., 2012).

In literature, WDMA is frequency band separated into minor frequency channels and various channels are distributed to different users like in FM radio. Multiple users can transmit data at the same time but on different frequency channels (Chan, Tong, Chen, Cheung, & Kong, 1990). WDMA is a channel access scheme operated in multiple-access procedures as a channelization protocol. WDMA provides users a single distribution of one or several frequency bands, or channels. It is mainly placed in satellite communication. WDMA is like other multiple access system and organize access among multiple users (Chan et al., 1990).

WDMA technique has been proven to be the most preferable and widely used technique to divide the inefficient high fiber data rates, each corresponding to a different optical wavelength (Lu & Kleinrock 1992). Moreover, WDMA technique utilization in conjunction with a variety of WDMA strategies that have been proposed for optical networks, without objection had given the opportunity to increase the total throughput achieved comparatively to the single channel system of the same bandwidth.

Similar to any multi-channel network, there are two main reasons for packet loss in WDMA networks. First, packets are destroyed if two or more stations transmitting are overlapped in time. This phenomenon is referred as WDMA channel collisions, and it is distinguished into two main categories control channel collision and data channel collisions, depending on the type of packet transmission over each channel category (either control or data packet). Second, additional packets are aborted in the case of WDMA receiver collisions phenomenon (Lu et al., 1992). In most instances, a receiver collision occurs if a data packet that has been successfully transmitted over a WDMA data channel cannot be picked up by the intended destination station because its tunable receiver is currently tuned to another source station.

Nowadays, the main challenge when designing local and metropolitan area networks is to guarantee the Quality of Service (QoS) to an ever increasing number of network services that require consistently excess bandwidth. In optical networks, the WDMA technique has been proven to be the most preferable solution in order to divide the larger fiber bandwidth into several parallel channels, each operating in lower data rate, which can serve the multiple network services (Baziana, 2015).

In literature, researcher may find various access protocols suitable for WDMA networks of passive star topology. Many of these WDMA protocols coordinate the transmission in a random way. In such protocol in (Habbab, Kavehrad, & Sundberg, 1987), the lack of any arbitration rule to arrange the packets transmission provides essential performance limitations due to the contention nature of the transmission strategies. Thus, these access protocol suffer from packet collisions over the control and/or data channels which results in limited bandwidth utilization (Habbab et al., 1987).

It can be well understood that in WDMA protocol that does not need to coordinate the transmission prior to the transmission phase, the influence of the propagation delay latency is usually not considered. On the other hand, the propagation delay parameter will be given strong consideration in WDMA protocols with pre-transmission coordination scheme in order to schedule collision-free transmission (Baziana, 2015).

2.1.2 Time Division Multiple Access (TDMA)

TDMA is a channel access method for shared-medium networks. It allows several users to share the same frequency channel by dividing the signal info different time slots. TDMA allows multiple number of stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity (Funnell, Shi, &