DEVELOPMENT OF A NEW TECHNIQUE TO SUPPRESS FOUR WAVE MIXING EFFECTS IN SAC-OCDMA SYSTEM

By

Ibrahim Fadhil Radhi
(1030210516)

A thesis submitted in fulfillment of the requirements for the degree of Master of Science (Computer Engineering)

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

(2013)

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name	:	……IBRAHIM FADHIL RADHI…………………………….……..........................
Date of birth	:	8^{th} June 1987
Title	:	DEVELOPMENT OF A NEW TECHNIQUE TO SUPPRESS FOUR WAVE MIXING EFFECTS IN SAC-OCDMA SYSTEM
Academic Session	:	2012/2013

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. 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 UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____years, if so requested above).

Certified by:

SIGNATURE **SIGNATURE OF SUPERVISOR**

(NEW IC NO. / PASSPORT NO.) **NAME OF SUPERVISOR**

G2502570 Professor Dr. Syed Alwee Aljunid

Date :_________________ Date : _________________

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

Acknowledgements

All praises and thanks are to Allah. Uncountable thanks to my supervisor Prof.Dr.Syed Aljunid for his guidance and support over the course of my graduate studies. I have been fortunate to work with somebody whose love for research is contagious. I sincerely hope that Prof. Syed knows the difference he has made on my career as a graduate student. Above all, I thank him for the great trust he has always placed in me. I am also grateful to my co-supervisor Dr. Hilal Adnan Fadhil for his kindness and help. He also provided me the opportunity to conduct the research in this field. I sincerely appreciate it. His ability to simplify difficult problems always amazes me. There is still a lot for me to learn from him.

This achievement would have not been possible without the love and support of my family. Your sacrifices to provide me a better life here in Malaysia are now rewarded. Thank you my mother, my father, and my brothers Mustafa and Radwan, for being there for me anytime I needed you.

My appreciation also goes to my colleagues in our lab postgraduate students the useful discussions and their encouragement really feels so proud working hand in hand with them throughout my study.

Finally, I would also like to thank my friends who without them, life would have been so much harder to face. Special thanks to University Malaysia Perlis (UniMAP) for providing to me the suitable environment to make this project better.

Ibrahim Fadhil Radhi

University Malaysia Perlis (UniMAP).

ibraheem_fadhil2005@yahoo.com

TABLE OF CONTENTS

LIST OF TABLES

No		PAGE

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASE	Amplified Spontaneous Emission
AWG	Array Wavelength Grating
BER	Bit Error Rate
CDMA	Code Division Multiple Access
DCF	Dispersion Compensating Fiber
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
FBG	Fiber Bragg Grating
FFH	Fast Frequency Hopping
FWM	Four Wave Mixing
FWHM	Full Wave Half Maximum
FTTH	Fiber To The Home
Gbps	Gigabit per second
GF	Galois Field
IM/DD	Intensity Modulation/ Direct detection
LED	Light Emitting Diode
MAI	Multiple Access Interference
Mbps	Mega bit per second
MD	Multi Diagonal
MFH	Modified Frequency Hoping
MQC	Modified Quadratic Congruence
NRZ	Non Return to Zero
NDSF	Non Dispersion Shift fiber
OCDMA	Optical Code Division Multiple Access
OOC	Optical Orthogonal Code
OSNR	Optical Signal to Noise Ratio
OOK	On-Off Keying
QoS	Quality of Service
P2P	Point-to-Point
P2MP	Point-to-Multipoint
PD	Photo Diode
PIIN	Phase Induced Intensity Noise

PIN	Positive Intrinsic Negative
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
RF	Radio Frequency
RD	Random Diagonal
SAC	Spectral Amplitude Coding
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SLD	Super Luminescent Diode
SPM	Self Phase Modulation
TDM	Time Division Multiplexing
TLS	Tunable Laser Source
WDMA	Wavelength Division Multiple Access
VoD	Video-on Demand

Pembangunan Teknik Terkini Untuk Memadamkan Percampuran Kesan Empat Gelombang Dalam Sistem SAC-OCDMA

ABSTRAK

Pelbagai teknik pengaksesan yang diperlukan untuk memenuhi permintaan untuk komunikasi berkelajuan tinggi dan berkapasiti besar dalam rangkaian optik, yang membolehkan beberapa pengguna berkongsi jalur lebar dalam rangkaian gentian jalur lebar tersebut. Walau bagaimanapun, kesan tak-linear dalam gentian optik telah menjadi satu bidang penyelidikan akademik yang mana ianya menjadi tumpuan besar dalam sistem berasaskan gentian optik. Kesan Pencampuran Empat gelombang (FWM) merupakan salah satu tak linear yang menggambarkan keselerakan tak-elastik yang berlaku hasil dari perubahan-perubahan indeks biasan di dalam sesuatu gentian. FWM berlaku apabila dua atau lebih gelombang dirambatkan pada arah yang sama di dalam gentian yang sama. Tesis ini menganalisa kesan FWM tersebut ke atas sistem jerayun kod spektral (SAC) untuk pembahagian kod optik akses pelbagai (OCDMA). Terdahulu, terdapat banyak kod-kod telah dicadangkan untuk sistem SAC-OCDMA seperti Kod "*Optical Orthogonal"* (OOC), Kod "*Modified Quadratic Congruence"* (MQC), Kod "*Modified Frequency Hopping"* (MFH*),* dan Kod *"Double Weight"* (DW). Motivasi kajian ini adalah untuk menghadkan pengaruh FWM ke atas SAC-OCDMA sekaligus meningkatkan prestasi sistem. Dalam kajian ini, satu teknik baru telah dicadangkan untuk menghadkan kesan FWM. Selain itu, idea utama teknik ini adalah berdasarkan penambahan kod ideal ketika pembinaan kod untuk mengawal kesan FWM di jalursisi isyarat dan menapis hanya segmen data di bahagian saluran untuk menghadkan kuasa FWM daripada kuasa asal. Teknik ini digunakan untuk kedua-dua kod SAC iaitu Kod Random Diagonal (RD) dan Kod Multi Diagonal (MD) kerana berdasarkan kertas kerja sebelumnya, kod-kod RD dan MD telah dianggap sebagai yang terbaik di kala ini berbanding dengan kod-kod lain. Selain itu, dari segi kos, penggunaan teknik ini dianggap kos efektif kerana penggunaan LED sebagai sumber cahaya untuk menjana kod jalursisi. Hasil penyelidikan menunjukkan bahawa kesan FWM menurun sekitar 30dB selepas menggunakan teknik ini. Sebagai contoh, dalam kod RD, sebelum penggunaan teknik in, kuasa FWM pada jarak gentian 40km dengan mengenakan kuasa input 15dBm dan menggunakan jenis gentian SMF adalah kira-kira -55dBm, akan tetapi, selepas menggunakan teknik ini, pada nilai-nilai parameter yang sama, kuasa FWM adalah kira-kira -90dBm . Dalam erti kata lain, untuk kod MD, kuasa FWM sebelum menggunakan teknik ini ialah kira-kira -61dBm, tetapi, selepas aplikasi teknik ini, nilai kuasa FWM adalah kira-kira -81dBm. tambahan pula, hasilan keputusan mempengaruhi Kadar Ralat Bit (BER), sebagai contoh, sebelum mengaplikasikan teknik ini, pada jarak gentian 35km dan kuasa input -10dBm, nilai BER dalam kod RD adalah 1.6×10^{-23}, dan selepas menggunakan teknik, nilai BER menjadi 4.05×10^{-28}. Di samping itu, untuk kod MD, nilai BER sebelum penggunaan teknik adalah 9.4×10^{-22}, dan selepas menggunakan teknik nilai BER ialah $7.4{\times}10^{-31}$.

Development of a New Technique to Suppress Four Wave Mixing Effects in SAC-OCDMA System

ABSTRACT

Multiple access techniques are required to meet the demand for high-speed and large-capacity communications in optical networks, which allow multiple users to share the fiber bandwidth. However, nonlinear effects in optical fiber have become an area of academic research and of huge interest in the optical fiber-based systems. The Four Wave Mixing (FWM) effect is one of the nonlinearities that represent the inelastic scattering that occurs as a result of changes in the refractive index inside the fiber. The FWM occurs when two or more waves are propagated in the same direction in the same fiber. In this thesis, the FWM effect in the Spectral Amplitude Coding (SAC) Optical Code Division Multiple Access (OCDMA) system has been analysed. Many codes have been proposed for SAC-OCDMA systems, such as Optical Orthogonal Code (OOC), Modified Quadratic Congruence Code (MQC), Modified Frequency Hopping Code (MFH), and Double Weight Code (DW). The motivation of this research is to suppress the FWM power in SAC-OCDMA to enhance the system performance. In this research, a new technique is proposed for suppressing the FWM. Moreover, the main idea of the proposed technique is based on adding idle code at the code construction to control the FWM at the sidebands of the signal and filtering the data segment only at the channel part to suppress the FWM power from the original power. This technique is applied for both SAC codes, Random Diagonal Code (RD) and Multi Diagonal Code (MD) because in previous published papers, RD and MD codes were considered recent best performance compared with others. Moreover, in terms of cost, the reported technique is considered cost-effective as the LED light source is used to generate the sideband codes. The results show that the FWM fell approximately 30dB after using the technique. For example, in RD code the FWM power at 40km for fiber length and input power of 15dBm using the SMF fiber type is approximately -55dBm before using the technique; after using the technique at the same parameter values, the FWM power is approximately -90dBm. In other words, with MD code the FWM power before using the technique is approximately -61dBm, after using the technique the value of the FWM power is approximately -81dBm. Moreover, these results have an impact on the Bit Error Rate (BER) well, for example, the value of BER in RD code at the input power -10dBm and 35km fiber length before using the technique was 1.6×10^{-23}, and after using the technique the value of BER became 4.05×10^{-28}. In addition, with MD code the BER value before using the technique was 9.4×10^{-22}, and after using the technique the value of BER was 7.4×10^{-31}.

CHAPTER ONE

INTRODUCTION

1.1 Background

Optical Code Division Multiple Access (OCDMA) is a technique in which user uses a specific unique code rather a specific wavelength or a time slot. The OCDMA uses the spread spectrum technique of CDMA combined with the optical link for transmission of data. The OCDMA provides the large communication bandwidth along with the capability of secure data transmission. The key advantage of OCDMA is the multiple access technique which allows many users to share the same optical link simultaneously (Gurmeet Kaura, et al. 2009), and (C.F. Wehmann, et al. 2005). This is done by giving each user a specific code which can be decoded only by the required user. The OCDMA has many unique features that make it favorable data transmissions. Its characteristics make it suitable to increase the capacity and number of users in bursty networks. The OCDMA can accommodate a large number of channels on a single carrier frequency. It can utilize the bandwidth effectively through coding system. The OCDMA systems provide high degree of scalability and security. It provides high noise tolerance (Singh, H, et al. 2008). Fiber nonlinearities represent the fundamental limiting on the amount of data that can be transmitted on optical fiber. Nonlinearities of optical fiber can be divided into two categories. The first category encompasses the nonlinear inelastic scattering processes. These are Stimulated Brillouin Scattering (SBS) and Stimulated Raman Scattering (SRS). The second category of nonlinear effects arises from intensity-dependent variations in the refractive index in optical fiber. This produces effects such as Self- Phase Modulation (SPM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM) (Fuad A. Hatim, et al. 2009). When a high-power optical signal is launched into a fiber, the linearity of the optical response is lost. One such nonlinear effect, which is due to the third-order electric susceptibility, is called the optical nonlinear effect. In addition, FWM occurs when light of three different wavelengths is launched into a fiber, giving rise to a new wave (known as an idler), the wavelength of which does not coincide with any of the others. FWM is a kind of optical parametric oscillation (Osamu Aso, et al. 2000) and (S. A. Aljunid, et al. 2004). In other words, the FWM has been widely studied with various kinds of optical fibers. In particular, FWM has been investigated as a technique of realizing wavelength tunable light sources, and as a means of measuring fiber properties, such as the third order nonlinearity in a fiber (Lor, K. P, et al. 1998).

1.2 Problem Statement

Optical waveguides do not always behave as completely linear channels whose increase in output optical power is directly proportional to the input optical power. In OCDMA, as the number of weight increases, the possibility of overlapping wavelength occurs, and thus FWM is generated, especially when the input power is high. However, the generated FWM affects the BER of the overall system performance (Djafar K. Mynbaev, et al. 2006). All of these system requirements give rise to FWM effects that can severely limit the performance of multi-channel communication systems through the transfer of energy between the channels at different wavelengths (Buck, J. A. et al, 1995). Particularly, Spectral Amplitude Coding OCDMA (SAC-OCDMA) systems are expected to be significantly limited due to FWM effects. In any SAC-OCDMA system, multiple chips propagate simultaneously at different wavelengths into the fiber. Therefore, code selection is important in SAC-OCDMA systems, not only for reliable transmission with a BER less than 10^{-9}, but also to neglect the FWM generation. Moreover, in OCDMA systems the number of wavelengths (number of 1's) is much higher than the Wavelength Division Multiple Access (WDMA) system, which means that the possibility of FWM power being generated will be high. Based on these reasons, the FWM must be considered in SAC-OCDMA system. During that, the FWM process affects those chips by inducing power depletion from shorter- to longer-wavelength chips resulting in a spectral tilt in the transmitted chips. FWM-induced effects evolve as fiber length decreases. Therefore, input power, transmission distance, and other FWM parameters such as dispersion and effective area that can be supported by an SAC-OCDMA system are significantly limited by FWM effects. The main motivation behind this research is the need to understand the FWM effects in OCDMA transmission systems. Specially, most studies that study nonlinear effects are based on WDMA systems, and there is no real attention paid to investigate this issue in OCDMA systems. Therefore, this work is attempting to understand the FWM effects on the performance of OCDMA systems as a function of system parameters, and hence, the new technique is proposed to suppress the FWM in SAC-OCDMA systems using RD and MD codes.

1.3 Research Objectives

The main goal of this research is to propose the new technique in SAC-OCDMA systems for suppressing the FWM effects. The objectives of the research are as follow:

1- To develop a new technique in SAC-OCDMA system to suppress the FWM effects.

2- To evaluate the technique in SAC-OCDMA system based on RD and MD codes.

3- To study the performance of the SAC-OCDMA system using RD and MD codes before and after using the proposed technique.

1.3 Scope of the Project

This thesis is focused on FWM nonlinear effects in OCDMA transmission systems. The design parameters involved in this thesis are input power, fiber length, and data rate. Multiple access and multiplexing issues are focused on through studies performed at the physical layer. SAC-OCDMA system is used with RD, and MD codes throughout this study. For a new technique development to suppress the FWM effects in SAC-OCDMA system, the study focuses on the performance of these SAC-OCDMA systems and the fundamental transmission limits in the presence of FWM effects. Nevertheless, this thesis also includes the applications to make the study more complete. The scope of focus in code application is on local networks as these are the areas that are predictable to be better ready for the implementation of OCDMA technology. It is important to note that, almost all current research works in OCDMA focus on the code structure constructions activity. The main idea of the proposed technique is based on adding idle code at the sideband of the code construction to control the FWM at the sides of the signal and filtering the data segment only at the channel part to suppress the FWM power from the original power.

1.4 Thesis Outline

This thesis is structured into five chapters, which are the introduction, literature review, methodology, results, and conclusions. Chapter 1 discusses the project background, problem statement, objective, and scope of the project. Chapter 2 presents the multiple access techniques, OCDMA, and SAC-OCDMA. In addition, this chapter explains the nonlinear effects in optical fiber and explains the FWM effect in detail, well as illustrating the recent nonlinear studies. Chapter 3 discusses the research methodology of the technique that suppresses the FWM in SAC-OCDMA system design. Chapter 4 presents the simulation results of the proposed technique. The relation of FWM power with the fiber length and the FWM power with the input power are studied in the RD and MD codes before and after using the proposed technique. And the relation of the BER with the fiber length and the data rate for the both codes before and after using the technique. Finally, Chapter 5 explains the conclusions and future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter discusses in details the Optical Code Division Multiple Access (OCDMA) and the Four Wave Mixing (FWM) nonlinear effects. It starts with a discussion on multiple access techniques such as, Time Division Multiple Access (TDMA), Wave Division Multiple Access (WDMA), and Code Division Multiple Access (CDMA), OCDMA, OCDMA attributes, OCDMA systems (coherent and incoherent), SAC-OCDMA codes, nonlinear phenomena, FWM, and the recent of the nonlinear researches in optical fibers systems.

2.2 Multiple Access Techniques

The utmost utilization of an optical fiber offering a large bandwidth can only be achieved if the techniques of multiple accesses are adequately and sufficiently effective. Different users will get connected by sharing a communication medium via a multiple access technique. The time division multiple access (TDMA), wavelength division multiple access (WDMA), and code division multiple access (CDMA) are the commonest multiple access techniques known.

2.2.1 Time Division Multiple Access (TDMA)

Figure 2.1 illustrates the basic TDMA technique, in which time is equally and successively divided into periods, with each divided into an integer number of time-intervals. A user is allocated with an interval in order to transmit the frame of bits. The user must wait during other time-intervals intended for other users once his/ her dedicated time-interval has ended. The transmission will only be continued when the interval in the following period is started. Users are already permanently allocated with the time intervals, even when they may not require the time allocated. In a period, the number of users using the same channel must be equal to the number of time intervals.

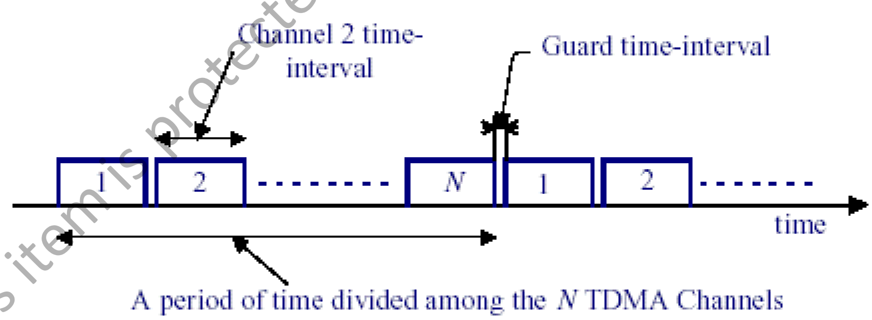

Figure 2.1 Frame and Slot Structure in a TDMA System

In this system, users are assigned with the same capacity of the basic TDMA, i.e., one slot per frame. In this way, the transmittable number of traffic in a slot must be adequate so as to accommodate users, mainly when one generates the most traffic. Nevertheless, users who generate lesser traffic waste a lot of capacity. To overcome this issue, more generalized TDMA protocols have been created to allow users to use more than one time slot per frame, and at the same time, enable the slots in the same frame to have different durations. On the contrary, if users will waste the capacity they do not transmit anything during their allocated time slots (Dutton, et al. 1998), (Green, et al. 1993), (Pierre, et al. 2000), (Tanenbaum, et al. 1996).

2.2.2 Wavelength Division Multiple Access (WDMA)

One highly potential approach which allows the exploitation of huge bandwidth of optical fiber is the Wavelength Division Multiple Access or WDMA (Hou Fenfei, et al. 2004). Figure 2.2 exhibits that the optical transmission spectrum in WDMA is divided into a number of non-overlapping wavelength bands (also known as frequency bands), of which every wavelength supports one communication channel functioning at the highest electronic speed.

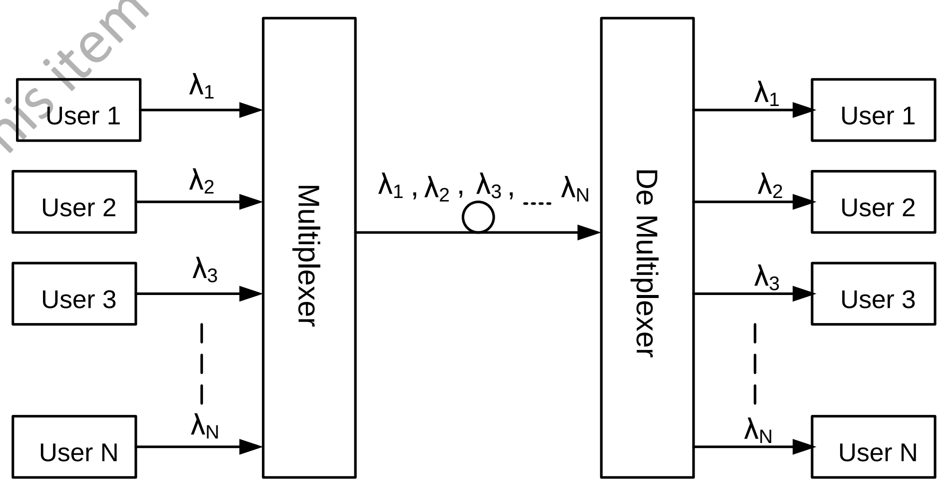

Figure 2.2 WDMA Channels Propagating in a Single Optical Fiber

Based on the figure, the Wavelength Division Multiple Access (WDMA) usually employs multiple coherent lasers, modulators, detectors and filters, which are tuned to different wavelengths, leading to the planning of the network, as well as provisioning operations disadvantages in the fast-changing metro environment. As such, the WDMA has to be sophisticated and adaptive to be able to support a distinguishable and large numbers and power levels of signals at various wavelengths.

In the WDMA networking system, various issues need to be considered. These include adjusting the signals into their allocated wavebands, stabilizing the wavelength of the wavelength sensitive components, aligning the cascaded filters, controlling the non-linear effects, dispersion, cross talk and noise produced by the system (Dutton, et al. 1998).

2.2.3 Code Division Multiple Access (CDMA)

The latest invention in the multiple access technique is known as Code Division Multiple Access (CDMA), which had been initially proposed in the optical domain because of its capability the wireless communication (Peterson, R. L et al 1995) and (Cooper G. R. 1986). As shown in figure 2.3, every user in CDMA is identified by a different code which also represents its address. Before a transmission is carried out, a CDMA user needs to key in a code (or address) in each data bit. As such, the system only permits those who possess the code used in the transmission to decode the message. Those users without the specific code will not be allowed to collect the desired data.