PERFORMANCE ANALYSIS OF TWO-DIMENSIONAL WAVELENGTH/TIME OCDMA SYSTEM FOR OPTICAL NETWORK

By

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A thesis submitted in fulfilment of the requirements for the degree of Master of Science in Communication Engineering

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2017

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Academic Session : 2017

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ACKNOWLEDGEMENS

In the name of Allah the Most Compassionate, the Most Merciful and the Salawat with Salam always for Prophet Mohammed (P.B.U.H). Alhamdulillah for giving me courage, passion, inspiration and support me with many people that take my hand to finish this project. It is a pleasant aspect that I have the opportunity to express my gratitude to all of them. First, I would like to express my appreciation and thankful for my supervisor, Professor. Dr. Syed Alwee Al Junid who raise me up when I feel down, supporting me by ideas and his instructions to be better. I would like to thank my co-supervisor Dr. Mohd Rashidi for his kind support and suggestions. Their interest and confidence in me was the reason for all the success I have made. Also, my thanks extend to the Dean of the School of Computer and Communication Engineering Professor Dr. R. Badlishah Ahmed at University Malaysia Perlis (UniMAP) for providing the students with laboratory facilities.

Above all, I am blessed to have caring parents. I convey my deepest gratitude to my parent and my kids for their invaluable love, affection, encouragement and supports. My great thankful for Dr. Rasim Aziz for his supporting and advising since I started my research.

My appreciation also goes to my colleagues in our lab postgraduate student's Centre of Excellence cluster research group especially my friend Nui for their the useful discussions and their encouragement really feel so proud working hand in hand with them throughout my study.

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Specially dedicated
To my dear husband Layth Adnan who always puts me at the top of his priorities
Thank you for patience, support and encouragement
Great appreciation for being in my life
I hope I could make you proud of me

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LIST OF ABREVIATIONS

APD	Avalanche Photodiode
ASE	Amplified Spontaneous Emission
AWG	Additive White Gaussian
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CL	Code Length
CW	Code Weight
DD	Direct Detection
DEMUX	Demultiplexer
E/D	En/Decoders
EDW	Ehanced Double Weight
FTTH	Fiber-To The Home
Gbps	Gega Bit per Second
IM	Intensity Modulation
LAN	Local Area Network
LED	Light Emitting Diode
LPBF	Low Pass Bessel Filter
MAI	Multiple Access Interference
Mbps	Mega Bit per Second
MD	Multi-Dimensional
MDW	Modified Double Weight
MFH	Modified Frequency Hopping
MPC	Modified Prime code

MQC	Modified Quadratic Congruence
MRR	Micro-Ring-Resonator
M-Sequence	Maximum-Length Sequence
MUX	Multiplexer
MW	Multi Weight
NRZ	Non-Return to Zero
OCDMA	Optical Code Division Multiple Access
OOCs	Optical Orthogonal Codes
OOK	ON/OFF Key
OOSP	Optical Orthogonal Signature Patterns
PD	Perfect Difference
PIIN	Phase Induced Intensity Noise
PIN	Positive-Intrinsic Negative
PLC	Planar Lightwave Circuit
PON	Passive Optical Network
PSD	Power Spectral Density
RD	Random Diagonal
RZ	Return to Zero
SAC	Spectral Amplitude Coding
SLPM	Spatial Lightwave Phase Modulator
SNR	Signal to Noise Ratio
SPC	Spectral Phase Coding
SPECTS	Spectrally Phase En-Coding Time Spread
SPR	Single Pulse per Row
SSFBG	Super Structure Fiber Bragg Grating

TDMA	Time Division Multiple Access
TPC	Temporal Phase Coding
TS	Time Spreading
W/T	Wavelength/Time
WDM	Wavelength Division Multiplexing
WDMA	Wavelength Division Multiple Access
WHTS	Wavelength Hopping Time Spreading
ZCC	Zero Cross-Correlation
1-D	One-Dimension
2-D	Two-Dimension

Analisis Prestasi Sistem OCDMA 2-Dimensi (2D) Panjang Gelombang/ Masa untuk Rangkaian Optik.

ABSTRAK

Faktor penghalang yang terbesar di dalam sistem capaian pelbagai bahagian kod optik (OCDMA) ialah ganguan bising di dalam bentuk ganguan secara capaian yang pelbagai (MAI), yang mana mendorong berlakunya kadar kesalahan pada bit (BER). Fasa dorongan gangguan bising yang teramat (PIIN) ini adalah ganguan kebisingan yang sangat kerap berlaku pada penerima juga berkait rapat dengan MAI. Penggunaan kod yang ideal atau tepat dengan korelasi silang yang minima akan mengurangkan MAI, mengurangkan PIIN, dan mengembangkan kod yang berskala. Terdapat banyak kod yang telah dicadangkan untuk sistem 1-dimensi (1-D). Ini melibatkan exploitasi panjang gelombang atau sumber masa. Walaubagaimanapun, terdapat beberapa kod yang bersifat tetap atau korelasi silang kosong yang boleh menghapuskan MAI. Walaubagaimanapun, prestasi juga boleh dipengaruhi oleh PIIN. Kod 1-dimensi (1-D) memerlukan kod yang sangat panjang apabila ianya mempunyai kardinaliti tinggi. Dengan yang demikian, tujuan tesis ini, pertamanya, menyiasat kod OCDMA bagi meningkatkan prestasi dan mengurangkan panjang kod, seperti kod 2-D perbezaan yang sempurna (PD), dan 2-D panjang gelombang atau masa (W/T) yang diubahsuai secara wajaran berganda (MDW). Kedua, pelaksanaan dan penganalisis terhadap kod 2-D bagi sistem OCDMA melalui simulasi. Tesis ini dimulai dengan pembangunan eksplisit yang tidak koheren terhadap sistem 2-D MDW OCDMA dengan memperuntukkan sumber dimensi panjang gelombang dan juga masa untuk mencapai target prestasi dan reka bentuk parameter-parameter yang digunakan. Pembelajaran tentang kod-kod sangat menekankan aspek-aspek saintifik dengan menganalisis pelbagai jenis parameter seperti isyarat keluaran spektrum dan BER dengan panjang serat, bilangan pengguna, kadar data, penggunaan pengesan gambar avalanche (APD) pada penerimaan dan keberkesanan kuasa penerimaan P_{sr}. Kedua, kod 2-D MDW untuk kod OCDMA direka bentuk di dalam bentuk simulasi. Rekaan ini dibuat menggunakan sistem perisian Optiwave, versi 11.0, untuk pelbagai jenis format data modulasi yang berbeza-beza, APD and PIN foto diod, dan teknik pengesanan yang berbeza-beza. Kerja ini kemudiannya dilakukan untuk membezakan antara 2-D kod PDC dan MDW secara teori dan melalui simulasi. Di dalam analisis matematik, kardinal yang tinggi boleh diperolehi dengan menggunakan pengesan foto APD, yang mana boleh mencapai sebanyak 4000 pengguna dengan kadar data sebanyak 622Mbps. Kod 2-D MDW memperbaiki kardinal sebanyak 199% berbanding dengan kod 2-D PDC. Pada kadar bit yang tinggi 2.5Gbps, P_{sr} akan menjadi -24dBm. Ini menunjukkan prestasi yang baik dengan kuasa keberkesanan yang rendah. Di dalam simulasi, sifat-sifat yang bagus terhadap keputusan korelasi silang dengan penindasan PIIN secara optimum, dan mengesahkan kebolehnyataan kod pada kadar bit yang tinggi, kuasa penerimaan yang berkesan, jarak penghantaran dan dengan menggunakan pelbagai format modulasi data, ketidakpulangan kepada kosong (NRZ) dan kepulangan kepada kosong (RZ), untuk siaran ruangan. Perbandingan ini dibuat dengan mempelbagaikan BER dengan nilai parameter-parameter yang digunakan. Sistem OCDMA dengan format data NRZ adalah lebih baik bila dilaksanakan berbanding RZ. NRZ boleh mencapai prestasi BER=10^{-9} pada jarak penghantaran sejauh 23km, dengan P_{sr} nilai bersamaan (-5dBm). Kod 2-D MDW berjaya mengurangkan MAI dengan mengunakan pengesanan penolakan AND dan teknik pengesanan yang terus. Teknik pengesanan yang terus telah digunakan untuk kod 2-D MDW kerana sifat kod korelasi silang ini sangat sesuai dan lebih baik berbanding pngesanan penolakan-AND. Ia boleh mencapai 50km pada kadar 622Mbps dan kadar bit yang tinggi 1.25Gbps, jarak penghantarannya ialah 35km dengan

BER= 10^{-9} dan P_{sr} = -21 dBm. Pendek kata, kod 2-D MDW OCDMA mencapai pengurangan PIIN dan MAI dengan kardinaliti tinggi, mengurangkan keberkesanan kuasa penerima P_{sr} untuk kadar bit yang tinggi dan juga jarak penghantaran yang jauh.

Performance Analysis of Two-Dimensional Wavelength/Time OCDMA System for Optical Networks

ABSTRACT

The major interference factor in an Optical Code-Division Multiple-Access System (OCDMA) is the noise in the form of Multiple Access Interference (MAI), which induces the occurrence of Bit Error Rate (BER). Phase Induced Intensity Noise (PIIN) is the dominant noise in the receiver that is closely related to MAI. The use of an ideal code with minimum cross-correlation will mitigate MAI, reduce PIIN, and expand code scalability. Many codes have been proposed for One-Dimension (1-D) systems. These involve exploiting the wavelength or time resource. However, some of these codes have fixed or zero cross-correlation property which cancels out the MAI. However, the performance is still affected by the PIIN. 1-D codes need a very long code length when there is a high cardinality. Therefore, the objectives of the thesis are, first, investigate the OCDMA codes to enhance the performance and decrease the required code length, such as the 2-D Perfect Difference (PD) code, and Wavelength/Time (W/T) 2-D Modified Double Weight - MDW), second the implementation and analysis of two-dimensional (2-D) codes for an OCDMA system via simulation. The thesis starts with an explicit construction of an incoherent 2-D MDW OCDMA system with the allocation of wavelength and time dimensions resource to achieving performance goals and design parameters. The study of the properties of the code include a consideration of the scientific functions of the performance by analyzing various parameters such as the output signal spectrum and BER versus the length of the fibre, the number of users, data rate, the use of Avalanche Photo-Detectors (APD) in the receiver, and the effective received power (P_{sr}). Secondly, the 2-D MDW OCDMA code is designed in simulation. This is implemented on the Optiwave system software, version 11.0, for different data modulation formats, APD and PIN photodiodes, and different detection techniques. The work then makes a comparison between 2-D PDC and 2-D MDW codes, both theoretically and via simulation. In the mathematical analysis, a high cardinality can be achieved by using APD photo-detectors, which achieve 4000 users at a 622 Mbps data rate. The 2-D MDW code improves the cardinality by 199% compared with the 2-D PDC code. At a high bit rate of 2.5 Gbps, the P_{sr} will be -24 dBm. This means a good performance with low effective power. In simulation, the good property of the cross-correlation results in an optimum PIIN suppression, and validates the realization of the code for high bit rate, effective received power, transmission distance and, by using the different data modulation formats, Non-Return to Zero (NRZ) and Return to Zero (RZ), for the space channel. The comparison is done by varying the BER with a number of parameters. It is found that the OCDMA system with NRZ data format implementation is better than RZ. NRZ can achieve a good performance of BER=10^{-9} at a transmission distance of 23 km, with P_{sr} equal to -5 dBm. The 2-D MDW code has successfully mitigated MAI by the use of AND-subtract detection and direct detection techniques. Direct detection techniques have been used for 2-D MDW code because the code cross-correlation property is suitable and better compared to AND-Subtract detection. The first can achieve more than 50 Km at 622 Mbps and, for a high bit rate of 1.25 Gbps, the transmission distance is 35 km with BER = 10^{-9} and P_{sr} = -21 dBm. In short, the 2-D MDW OCDMA code successfully suppressed PIIN and mitigated MAI which results in

high cardinality, reduces the effective received power P_{sr} for a high bit rate and for a long transmission distance.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The two primary obstacles in the scaling of the hardware networks are limited transmission capacity of the communication medium and speed of data transaction. To overcome these constraints, optical communication was proposed as a modern system. The modern form of data communication uses optical pulses as a carrier to transmit data through optical fibers (Hecht, 2015). Optical fiber offers most extreme usage of an accessible data transfer capacity to fulfil the gigantic transmission capacity interest of future data systems. The optical communication systems are beginning to accept this is an essential requirement as all comprehensive data structures will be subject to upheaval. CDMA or Code Division Multiple Access is a type of communication using multiplexing. It provides a means of multiple access to a physical medium (Kaur, Goyal & Rani, 2016). The advantages of CDMA urged the analysts to apply it to optical communication.

This innovation was initially introduced in optical fiber correspondence in the mid-1970s and was experimentally demonstrated in 1986 (Prucnal, Santoro & Fan, 1986), where encoding and decoding operations were implemented in the optical domain. The Optical CDMA plan is more reasonable for giving a high system limit and adaptability in getting to the network in all optical local area networks. OCDMA is an exciting development in the short haul optical networks, because it can support both wide and narrow bandwidth application on the same network. It connects a large number of synchronous users and has low latency and jitter, and enables quality of service guarantees to manage the physical layer, provides robust security and the signal is a simplified network topology.

OCDMA additionally empowers different users to get to the same transmission capacity at the same time without requiring fast electronic information preparing circuits that are important on other multiple access networks (Kaur et al., 2016). In addition to that, the progress in optical systems empowers the acknowledgment of the topology to the end users. The operation of other multiple access, such as Time Division Multiple Access (TDMA) systems, requires synchronisation and centralised control where clients are assigned to a specific time slot, whereas with the optical CDMA system, the users can operate asynchronously and access the networks individually. Even for Wavelength Division Multiple Access (WDMA), which has an advantage of wide bandwidth, optical CDMA networks offer the smartest application compared to TDMA and WDMA.

The OCDMA framework execution is influenced, for the most part, by the Multiple Access Interference (MAI) and Phase Induced Intensity Noise (PIIN). Commonly, OCDMA systems can be divided into non-coherent, where the process of encoding and decoding depends on the Intensity Modulation and Direct Detection (IM/DD), and coherent where the phase is significant and employed in the encoding and the detection of the transmitted bits. Yet, the coherent system has a better performance than the incoherent system, but the use of direct detection in the employment of the non-coherent system receiver makes it simple, financially attractive and more appropriate. Therefore, the noncoherent system is a good application that can be used in optical networks such as a Passive Optical Network (PON). Non-coherent OCDMA can be categorised according to the coding ways into first, temporal coding (Sahuguede, Julien-Vergonjanne & Cances, 2010). Temporal coding is implemented by splitting the data bit time interval into a number of smaller time intervals (called chips) matched to the code length. Each user has a unique signature code with ones and zeros where ones represent the chips that an optical pulse transmits and the zeros represent no data. Second, Spectral Amplitude Coding (SAC) (Zaccarin & Kavehrad, 1994) is similar to temporal coding but the splitting is done on the wavelength where the broadband light source is sliced into spectral slots. Spatial coding uses multi-fiber or multi-core fibers to create spatial forms, where the optical pulses of each user are distributed spatially over the fibers and finally, hybrid coding (Abd, Aljunid, Fadhil, Ahmad, & Saad, 2011; Park, Mendez & Garmire, 1992). Hybrid coding is a multi-dimensional coding using more than one resource simultaneously in which the light pulses are encrypted in a combination of wavelength, time, polarisation and space. Therefore, two dimensional, three dimensional and four-dimensional codes can be created.

1.2 Problem Statement

The main degradation factor on the performance of the OCDMA system is the multiple access interference, which is due to interference from the overlapping chips of undesignated users' signals. In addition, the arrival signals of the same wavelength from different users at the photo-detector produce noise, which is called phase induced intensity noise. There are many approaches adopted in the OCDMA systems based on the number of the used resources in the code design where one or multi-dimensional code can be constructed. In One-Dimensional (1-D) OCDMA network, a single resource is used such as time or wavelength. Many code families were proposed for the 1-D OCDMA system such as Modified Quadratic Congruence code (MQC), Modified Frequency Hopping (MFH) (Wei & Ghafouri-Shiraz, 2002; Wei, Shalaby & Ghafouri-Shiraz, 2001), Modified Double Weight code (MDW) (Ahmed, Aljunid, Fadil, Ahmad & Rashidi, 2013; Aljunid, Ismail, Ramli, Ali, &Abdullah, 2004a). Enhanced Double Weight code (EDW) (Hmud, Hasson, & Shaari, 2010; Keraf, Aljunid, Arief, & Ehkan, 2015), Zero Cross-Correlation (ZCC) code (Anuar, Aljunid, Arief, Junita & Saad, 2013; Anuar, Aljunid, Saad & Hamzah, 2009; Panda & Bhanja, 2016). Random Diagonal code (RD) (Fadhil, Aljunid & Ahmed, 2010; Kakaee et al., 2012). Multi Weight (MW) (Abdullah, Aljunid, Safar, Nordin & Ahmad, 2012; Djordjevic, Vasic & Rorison, 2004;) and Multi-Dimensional (MD) code (Abd et al., 2011; Kumar, Pathak & Chakrabarti, 2009). Flexible Cross Correlation (FCC) code for Spectral-Amplitude-Coding (SAC) OCDMA approaches (Rashidi, Aljunid, Ghani, Fadhil & Anuar, 2013). 1-D OCDMA codes require large signature sequence lengths with high weight to overcome the degradation of system performance linked to Bit Error Rate (BER) and MAI. Wide bandwidth sources are required to accommodate more subscribers in the network that reduce the spectral efficiency.

However, the type of used code is a major factor influencing the performance of any OCDMA system, the codes of fixed in phase cross correlation were a success at fully cancelling the effect of MAI.

Two-Dimensional (2-D) OCDMA code is investigated as a solution for large cardinality where two resources are exploited simultaneously. Moreover, 2-D OCDMA code has the capability of suppressing PIIN noise and mitigating MAI, accommodating a large number of active users at high data rates, and increasing spectral efficiency. Two-dimensional codes operate in both time and wavelength domain and can be a good solution to the limitations offered by one-dimensional code. Various approaches have been suggested for the design of 2-D codes. The performance analysis of an OCDMA system using 2-D codes is used for the increase in a number of users on the transmitter side. Most arguments advocating OCDMA for secure communication against eavesdropping in the research literature are qualitative and vague. Various approaches have been suggested for enhancing the network security mechanisms in order to protect the network from attack by unauthorised users. Three schemes presented in this approach are Wavelength Hopping Time Spreading (WHTS). Many codes were proposed for the WHTS systems such as Optical Orthogonal Codes 2-D OOC/OOC (Feng & Chang, 2013), 2-D MQC (Yin, Ma, Li & Zhu, 2010) and 2- D MDW code (Arief, Aljunid, Anuar, Junita, & Ahmed, 2013) codes. The 2-D Wavelength/Time (W/T) MDW code sequence was improved in the optical channel utilisation high cardinality, optimising cross-correlation and auto-correlation and enhancing the performance. However, the 2-D W/T MDW code is considered to be a good candidate but this code is still in the early stages because it needs more studies and investigations on the mathematical model and the simulation model in order to prove the ability of the implementation of this code in a real system.

1.3 Objectives

The main goal of this research work are to study and investigate the performance of the 2-D W/T MDW code in the 2-D W/T OCDMA network to make improvements in optical channel application.

- To investigate the 2-D W/T MDW OCDMA code properties of cross-correlation between users and the ability to cancel MAI at the receiver.
- To analyse the performance of 2-D W/T MDW code for different parameters such as the number of users, code sequence length, received power and type of photo-detector, fiber length and different detection techniques.