NEW SPECTRAL AMPLITUDE CODING OCDMA SYSTEM USING ADAPTIVE MULTICARRIER MODULATION FOR NEXT GENERATION NETWORK

by

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BS	Brillouin Scattering
CDMA	Code Division Multiple Access
CD	Chromatic Dispersion
CSK	Code-Shift-Keying
CP	Cyclic Prefix
CW	Continuous Wave
DPSK	Differential Phase-Shift Keying
DQPSK	Differential Quaternary Phase Shift Keying
DMUX	De-Multiplexer
EDFA	Erbium Doped Fiber Amplifier
EDW	Enhanced Double Weight
FBG	Fiber Bragg Grating
FCC	Flexible Cross Correlation
FFT	Fast Fourier Transform
FSO	Free Space Optics
FTTH	Fiber To The Home
FWM	Four Wave Mixing
Gb/s	Gigabit per second
ICI	Inter-Carrier Interference
IFFT	Inverse Fast Fourier Transform
IMD3	Third Intermodulation Distortion

ISI	Inter-symbol Interference
LAN	Local Area Network
LED	Light Emitting Diode
LiNbO3	Lithium-Niobate
MAI	Multiple Access Interference
Mb/s	Mega bit per second
MCM	Multi-Carrier Modulation
MD	Multi Diagonal
MDW	Modified Double Weight
MFH	Modified Frequency Hoping
MOD	Modulator
MQC	Modified Quadratic Congruence
MSM	Multiple-Subcarrier Modulation
MUX	Multiplexer
MZ	Mach-Zehnder
NRZ	Non Return to Zero
OOC	Optical Orthogonal Code
OEM	Optical Electrical Modulator
OCDMA	Optical Code Division Multiple Access
OOK	On-Off Keying
OFDM	Orthogonal Frequency Division Multiplexing
OSCDM	Optical Spectrum Code Division Multiplexing
PAPR	Peak-to-Average-Power Ratio
PIIN	Phase Induced Intensity Noise
PIN	Positive Intrinsic Negative

PMD	Polarization Mode Dispersion
PON	Passive Optical Networks
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
QoS	Quality of Service
QAM	Quadrature Amplitude Modulation
RD	Random Diagonal
RF	Radio Frequency
RoF	Radio Over Fiber
RZ	Return to Zero
SAC	Spectral Amplitude Coding
SCM	Subcarrier Multiplexing
SC	Single Carrier
SLD	Super Luminescent Diode
SMF	Single Mode Fiber
SNR	Signal to Noise-Ratio
SSM	Single-Subcarrier Modulation
SPC	Spectral Phase Coding
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
PSK	Phase-Shift Keying
PPM	Pulse-Position Modulation
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing
WDMA	Wavelength Division Multiple Access

Sistem Baru Spektrum Amplitud Pengekodan OCDMA Menggunakan Adaptive Multicarrier Modulation Untuk Rangkaian Generasi Masa Depan

ABSTRAK

Teknik pengekodan kod optik spektrum Amplitud multi capaian (SAC-OCDMA) membolehkan ramai pelanggan untuk berkongsi rangkaian yang sama serentak dan tak serentak dengan memperuntukkan satu kod yang khusus untuk setiap pelanggan. Prestasi sistem SAC-OCDMA ditentukan oleh pelbagai parameter seperti kadar data, jumlah pengguna serentak, kuasa pemancar dan penerima, dan jenis kod. Oleh itu, sistem SAC-OCDMA mempunyai had dalam bilangan pengguna dan kadar bit kerana gangguan multi capaian (MAI), yang dianggap sebagai faktor kemerosotan dominan dalam sistem SAC-OCDMA. Dalam kajian ini, satu pendekatan baru kepada sistem SAC-OCDMA dengan penyesuaian modulasi multicarrier (OFDM) telah dibangunkan untuk menampung jumlah pengguna yang besar, meningkatkan keupayaan sistem, dan mengurangkan degradasi sistem. Sistem yang dicadangkan itu telah dibina menggunakan kod dari keluarga MDW, yang mempunyai pelbagai kelebihan berbanding kod lain termasuk pembinaan kod yang mudah, reka bentuk pengekod/penyahkod yang mudah, kewujudan abgi setiap nombor asli n, korelasi-balas ynag sesuai(λ = 1) dan SNR yang lebih tinggi . Rangka kerja baru matematik untuk mengira SNR dan BER sistem SAC-OCDMA menggunakan penyesuaian modulasi berbilang pembawa (OFDM) telah dibangunkan dan dianalisis berdasarkan teknik AND pengesanan. Ia menyediakan penggunaan spektrum yang lebih baik, menjana jumlah yang lebih tinggi daripada sub-pembawa, dan meningkatkan kadar penghantaran menggunakan komponen optik kos rendah oleh modulasi M-ary pada sub-pembawanya. Selain itu, model matematik dan hasil, berdasarkan kod dan teknik pengesanan yang sama untuk menguji semua reka bentuk yang mungkin, telah dihasilkan untuk sistem SCM/SAC-OCDMA . Berdasarkan pengiraan matematik, sistem SAC-OCDMA dengan penyesuaian modulasi berbilang pembawa (OFDM) telah menunjukkan prestasi yang membanggakan berbanding SCM/SAC-OCDMA dan sistem SAC-OCDMA konvensional. Keputusan teori dan simulasi telah dinilai berdasarkan BER dan bilangan pengguna dan juga jumlah kuasa dikekalkan. Perisian Optisys (Versi 12) telah digunakan untuk mensimulasikan sistem yang direka. Sistem yang dicadangkan memberi prestasi yang lebih baik dengan mengekalkan lebih kurang 40% kuasa serta meningkatkan bilangan pengguna dua kali ganda berbanding dengan sistem SCM/SAC-OCDMA. Pembesaran prestasi, dari segi bilangan pengguna, untuk SAC-OCDMA dengan modulasi multicarrier penyesuaian (OFDM) berbanding dengan sistem SCM/SAC-OCDMA adalah dua kali dan tiga kali berbanding sistem SAC-OCDMA konvensional berdasarkan kod MDW. Pembangunan sistem baru ini telah menyumbang kepada peningkatan sistem SAC-OCDMA dengan mengurangkan gangguan, meningkatkan kadar data saluran, mengekalkan kuasa, dan meningkatkan bilangan pengguna. Oleh itu, sistem ini boleh menjadi penyelesaian mutlak untuk rangkaian akses kapasiti yang tinggi simetri kerana kecekapan spektrum yang tinggi, keberkesanan kos, fleksibiliti yang baik, dan keselamatan yang dipertingkatkan. Ciri-ciri ini menjadikan ia calon menarik bagi rangkaian jalur lebar akses generasi akan datang.

New Spectral Amplitude Coding OCDMA System Using Adaptive Multicarrier Modulation for Next-Generation Networks

ABSTRACT

The spectral amplitude coding optical code division multiple access (SAC-OCDMA) technique enables many subscribers to share a network simultaneously and asynchronously by allocating a specific code to each subscriber. The performance of the SAC-OCDMA systems is governed by numerous parameters such as the data rate, number of simultaneous users, the powers of the transmitter and receiver, and the type of codes. Therefore, a SAC-OCDMA system has limitations in the number of users and bit rate because of multiple access interference (MAI) which is considered to be the dominant degradation factor in SAC-OCDMA systems. In this work, a new approach to the SAC-OCDMA system with Rf-subcarrier such as adaptive multicarrier modulation (OFDM) has been developed, to accommodate a large number of users, enhance the system capacity, and decrease the system degradation. The proposed system has been built using the modified double weight (MDW) code family, which has various advantages over other codes including easy code construction, simple encoder/decoder design, existence for every natural number n, ideal cross-correlation ($\lambda = 1$) and a higher SNR. A new mathematical framework to calculate the SNR and the BER of the SAC-OCDMA system using adaptive multi-carrier modulation (OFDM) has been developed and analysed based on the AND detection technique. It provides better spectrum use, generates a higher number of sub-carriers, and increases transmission rates using low-cost optical components by M-ary modulation on its sub-carriers. In addition, mathematical models and results, based on the same code and detection technique in order to test all possible design, have been generated for the Rf-SCM/SAC-OCDMA system. Based on the mathematical calculations, the SAC-OCDMA system with adaptive multi-carrier modulation (OFDM) has shown superior performance compared to Rf-SCM/SAC-OCDMA and conventional SAC-OCDMA systems. The theoretical and simulation results have been evaluated based on the BER and number of users as well as on the amount of power maintained. Optisys (version 12), software was used to simulate the designed system. The proposed system gave better performance and maintained approximately 40% of power as well as increased the number of users twofold compared to Rf-SCM/SAC-OCDMA system. Augmentation in performance, in terms of the number of users, for SAC-OCDMA with adaptive multicarrier modulation (OFDM) compared to a conventional SAC-OCDMA systems based on MDW code is more than three times. The development of this new system has contributed to SAC-OCDMA system improvement by mitigating the interference, enhancing the channel data rate, maintaining the power, and increasing the number of users. Thus, this system could be a promising solution to symmetric high capacity access networks because of its high spectral efficiency, cost effectiveness, good flexibility, and enhanced security. These features make it an attractive candidate for next-generation broadband-access networks.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Currently, telecommunication systems and networks are extended to provide a variety of multimedia applications such as video streaming, voice-over-IP and gaming. The resulting demand for bandwidth requires a network infrastructure that has a large capacity and is reconfigurable. Optical fibres can fulfil the bandwidth demand of future information networks through optimizing the available bandwidth by multiplexing low-rate data streams onto optical fiber. For this purpose, multiple access schemes, such as Time Division Multiple Access (TDMA), Wave Division Multiple Access (WDMA), and Optical Code Division Multiple Access (OCDMA), are required for multiplexing and demultiplexing data flow.

The multiplexing technique is the process whereby several optical signals are combined before being transmitted through a fiber optic (Kolimbiris, 2004). In other words, multiplexing techniques are multiple access communication systems whereby a number of users share a common transmission media to transmit their messages to a number of destinations.

In recent years, OCDMA has been an emerging research area that has attracted a lot of research interest because of the demand for OCDMA application in optical networks. It offers a large bandwidth, security, and flexibility in high speed access networks. Moreover, OCDMA has some unique advantages such as, asynchronous transmission with low latency access, dynamic bandwidth assignment, soft capacity on demand, random and simultaneous access protocols, simplified network control, effective bandwidth utilization, increased flexibility in quality of service control

(Prucnal, Santoro, & Fan, 1986) and enhanced network security (Chung, Salehi, & Wei, 1989). Different multiplexing techniques are discussed in more detail in chapter 2.

1.2 Problem Statement

Huge demand for multimedia data, higher data speeds (such as for high-definition video) and an increasing number of users are putting pressure on optical transmission systems and network vendors to offer higher data rates (Shaddad, R. Q., et al., 2012). Reducing this pressure could be achieved by using optical techniques that can provide sufficient bandwidth for these applications (Elmagzoub, M. A., et al., 2014). Therefore, there is a search for a sufficient optical approach that enables the necessary bandwidth to accommodate a large number of users, high data rates, and intensive applications at a cost-effective rate. For this purpose, multiple access schemes such as OCDMA, optical TDMA and optical WDMA, are required for multiplexing and demultiplexing data flow. The operation of an OTDMA system is limited by the time-serial nature of the technology. Each receiver should operate at the total bit rate of the system. The OTDMA system requires synchronization and centralized control. The users are allocated a specific time slot. However in OCDMA system, users can operate asynchronously and access the network independently.

In WDMA systems, the available optical bandwidth is divided into fixed wavelength channels that are used concurrently by different users. Thus, an issue with WDMA is that wavelength-cardinality is limited, in that the WDMA systems can only handle traffic on an optical channel of the wavelength path. This may waste wavelength resources.

In recent years, OCDMA has received more attention because of its potential for enhanced information security, simplified and decentralized network control, allowing many users to share the same transmission medium synchronously and simultaneously as well as for increased flexibility in the granularity of bandwidth that can be provisioned (Sahbudin, et al., 2009; Salehi J A, 2007; Stok & Sargent, 2002a; Weng & Wu, 2001).

There are several challenges, such as multiple access interference (MAI), which results from other users transmitting at the same time and on the same common channel (Aljunid, Ismail, et al., 2004a). Furthermore, there are other noises arising from the physical effect of the system design itself, such as phase induced intensity Noise (PIIN), thermal noise, and shot noise (Shin-Pin & Jingshown, 2010). The PIIN is related to the MAI because the overlapping (cross-correlation function) of the spectra from different users (Aljunid, Ismail, et al., 2004a). Moreover, increases in cardinality (number of simultaneous users) results in long code length and weight. As a consequence, the (PIIN) increases, causing deterioration in BER and system performance. In addition, the spectral amplitude coding optical division multiplexing (SAC-OCDMA) is needed to improve the spectral efficiency. There are several optical modulation techniques used in an OCDMA system such as on-off keying (OOK) but it is not efficient at very small duty cycles. Consequently, it is more appropriate to code the information into the position of the pulse such as in pulse-position modulation (PPM). PPM imposes more system complexity than OOK because both slot- and symbol-level synchronizations, critical to system performance, are required at the receiver. Multipath propagation induces inter-symbol interference (ISI) and PPM is particularly sensitive to the dispersive effects of the optical channel due to the required bandwidth (Audeh, M. D. 1996).

To avoid ISI channels, single carrier (SC) pulsed modulation is used, but it results in severe performance penalties. Several equalization techniques, for example, using linear and decision feedback equalizers (DFEs), are considered to mitigate the effects of ISI at high data rates and it, as well, is required for detecting the aggregate high-speed bit stream. The drawbacks of SC pulsed modulation are overcome by using an alternative modulation technique—multiple-subcarrier modulation (MSM).

Hybrid subcarrier multiplexing (SCM) has increased the number of users and enhanced the channel data rate for OCDMA systems, but an SCM/OCDMA system has the disadvantage of being limited, by the available bandwidth of the electrical and optical components, in the maximum subcarrier frequencies and data rates. Adaptive multi-carrier OFDM modulation avoids these problems by generating a huge number of sub-carriers, as it is more accurate to assign a limited number of sub-carriers for each user. Moreover, OFDM is an effective solution to inter-symbol interference caused by a dispersive channel.

1.3 Research Objectives

The aim of this research is to develop a new spectral amplitude coding OCDMA system using adaptive multicarrier modulation for next-generation networks which can be superior to the performance of SAC-OCDMA systems. To achieve the aim of this research, the following objectives can be summarized as:

- To develop a new approach to SAC-OCDMA systems with OFDM modulation to enhance the system capacity and decrease the system degradation.
- To develop a mathematical model of the new SAC-OCDMA system using OFDM modulation based on an AND detection technique.

- To analyse the theoretical and simulated performance of the SAC-OCDMA system using OFDM modulation.

- To analyse the performance of an SCM/SAC-OCDMA system based on the MDW code family with the AND detection technique.

1.4 Scope of Work

Currently, internet network architecture can be divided into several different layers according to, each layer's specific function, components, and protocols. The scope in this research is the physical layer—which defines the physical specifications for devices—and the relationship between a device and a transmission medium. In the case of fiber-optical networks, the transmission medium is optical fiber. The physical layer is involved in converting electronic data into modulated light signals and transmitting it through the optical fiber. To transmit the data for multiple users, multiplexing, multiple access techniques are used here. Standard parameters that are considered here are the bit-error rate (BER), signal to noise ratio (SNR), and receiver power and loss. In this work the focus is on the security issues of the physical layer. A spectrum amplitude code division multiplexing technique (SAC-OCDMA) is used and applied to secure and protect the data transmitted through networks and to conduct decryption of the received data before passing it to the application layer. Also, here there is a focus on OFDM modulation techniques to increase the overall performance of the system based on an MDW code family. In addition to using subcarrier multiplexing with the SAC-OCDMA system, the subcarrier techniques are compared with conventional systems as well as the comparison between hybrid SCM and OFDM modulation techniques with conventional SAC-OCDMA system.

In this work, Firstly, a new optical orthogonal frequency division multiplexing (OFDM) modulation with spectrum amplitude coding optical code division multiple access (SAC-OCDMA) system is developed. Secondly, developing the mathematical model for a new SAC-OCDMA system using adaptive OFDM modulation and comparing it with both hybrid SCM/SAC-OCDMA and conventional SAC-OCDMA systems. Considering back to back systems, which mean no effect of the distance impairment. Lastly, the performance simulation of the SAC-OCDMA system using adaptive OFDM is provided. Optisys software was used for the simulation.

1.5 Contributions of This Research

A new approach for spectral-amplitude coding systems is developed to enhance the performance of OCDMA systems using OFMD modulation. The proposed contributions are summarized in the following:

I. A new SAC-OCDMA system with adaptive multicarrier modulation (OFDM) was developed.

II. A new mathematical model of the SNR and BER for the new system with an AND detection technique based on MDW code family has been developed and thoroughly analyzed.

III. Development of a SCM/SAC-OCDMA system and its mathematical model of SNR and BER based on an MDW code family with same detection technique were performed.

1.6 Thesis Outline

This thesis comprises of six (6) chapters, and it is organized as follows:

i. Chapter 1 is an overview and problem statement that clarifies the driving force and motivating aspect, together with the objectives, scope of work, contributions and thesis layout.

ii. Chapter 2 a literature review of OCDMA communication systems and optical hybrid multiple access and optical modulation techniques. In addition, some optical modulations such as optical orthogonal frequency division multiplexing (OFDM) and pulsed modulation techniques are described.

iii. In chapter 3 the research methodology is described and a detailed explanation of the design of codes used for the spectral amplitude coding OCDMA system, known as the modified double weight (MDW) code and flexible cross-correlation (FCC) code is given. The OFDM modulation with direct detection technique also described and simulation analysis.

iv. In chapter 4 the proposed signal-to-noise ratio (SNR) mathematics for a SAC-OCDMA system using OFDM modulation and a SCM/SAC-OCDMA system based on MDW code is presented.

v. In chapter 5 the results and the performance analysis of the new system using MDW and FCC codes are discussed and the feasibility of the system is demonstrated.

vii. Chapter 6 is the conclusion of the thesis; the most important ideas are summarized, and ideas for future work are given.