PERFORMANCE ANALYSIS OF DCO OFDM AND DCO WOFDM SYSTEMS IN MMF OPTICAL LINKS

ANOUSH MIRBADIN

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To my beloved father *Dr. Alireza Mirbadin* and mother *Fereshteh Mostaghim*

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a Multi Carrier Modulation (MCM) technique which has been known as a powerful tool to overcome Inter Symbol Interference (ISI) caused by a dispersive channel. Since optical communication channels are dispersive environments, during last decades optical OFDM has been proposed for compensating modal and chromatic dispersion in the optical communication systems. The purpose of this study is to analyze and compare the performances of DC biased Optical Orthogonal Frequency Division Multiplexing (DCO OFDM) and DC biased Optical Wavelet based Orthogonal Frequency Division Multiplexing (DCO WOFDM) systems in Multi Mode Fiber (MMF) optical links. Mach Zehnder Modulator (MZM) was utilized as the optical modulator. The simulations were carried out using Optisystem software. Bit Error Rate (BER) versus transmission distance curves as well as Optical Signal to Noise Ratio (OSNR) versus transmission distance curves were used as criterions for evaluating the performances of the simulated systems. Simulation results show that DCO WOFDM system offers considerable improvement in BER performance compared to DCO OFDM system. It was found that error free transmission distance for DCO OFDM and DCO WOFDM occurred at 330 m and 360 m, respectively. The achieved BER by DCO WOFDM at a 375 m link distance is 23 times smaller than the achieved BER by DCO OFDM at the same link distance. Even though, the bandwidth of DCO WOFDM signal is twice the bandwidth of DCO OFDM signal. Sensitivity of DCO WOFDM signal to noise is slightly better than the sensitivity of DCO OFDM signal to noise. These benefits are due to the fact that the Power Spectral Density (PSD) of DCO WOFDM signal is more compatible with the channel frequency response in contrast to the PSD of DCO OFDM signal.

ABSTRAK

Pemultipleksan Pembahagian Frekuensi Ortogon (OFDM) adalah teknik Pemodulatan Pembawa Berbilang (MCM) yang telah dikenalpasti sebagai langkah untuk mengatasi masalah Gangguan Antara Simbol (ISI) yang disebabkan oleh penyerakan cahaya dalam saluran optik. Oleh sebab itu, saluran optik OFDM telah dicadangkan dekad ini dengan bertujuan untuk mengurangkan serakan modal dan kromatik dalam sistem komunikasi optik. Objektif projek ini adalah untuk menganalisis dan membandingkan prestasi system Pemultipleksan Pembahagian Frekuensi Ortogon Optik dipincang DC (DCO OFDM) dan Riak Optik dipincang DC berdasarkan Pemultipleksan Pembahagian Frekuensi Ortogon (DCO WOFDM) dalam Gentian Berbilang Mod (MMF) optik. Pemodulat Mach Zehnder (MZM) telah digunakan sebagai pemodulasi optik. Simulasi dijalankan dengan menggunakan perisian Optisystem. Kadar Ralat Bit (BER) melawan jarak penghantaran serta Nisbah Hingar kepada Isyarat Optik (OSNR) melawan jarak penghantaran digunakan sebagai kriteria untuk menilai prestasi sistem tersebut. Keputusan simulasi menunjukkan bahawa sistem DCO WOFDM menawarkan peningkatan yang cukup besar dalam prestasi BER berbanding dengan sistem DCO OFDM. Didapati bahawa jarak penghantaran bebas ralat untuk DCO OFDM dan DCO WOFDM berlaku masing-masing pada 330 m dan 360 m. BER yang dicapai oleh sistem DCO WOFDM pada jarak 375 m adalah 23 kali lebih kecil daripada BER yang dicapai oleh DCO OFDM pada jarak yang sama. Walaupun, lebar jalur isyarat DCO WOFDM adalah dua kali lebar jalur isyarat DCO OFDM, kepekaan isyarat DCO WOFDM terhadap hingar lebih baik sedikit daripada kepekaan isyarat DCO OFDM. Manfaat yang diperolehi ini berikutan fakta bahawa Ketumpatan Spektral Kuasa (PSD) dari isyarat DCO WOFDM lebih serasi dengan respon frekuensi saluran berbanding dengan PSD isyarat DCO OFDM.

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LIST OF ABBREVIATIONS

ACO OFDM	-	Asymmetrically Clipped Optical OFDM
ADC	-	Analog to Digital Converter
BER	-	Bit Error Ratio
CATV	-	Cable Access TV
CO OFDM	-	Coherent detection Optical OFDM
COFDM	-	Coded OFDM
CP	-	Cyclic Prefix
CWT	-	Continuous Wavelet Transform
DAC	-	Digital to Analog Converter
DCO OFDM	-	Direct Current biased Optical OFDM
DDO OFDM	-	Direct Detection Optical OFDM
DFT	-	Discrete Fourier Transform
DMT	-	Discrete Multi Tone
DSL	-	Digital Subscriber Loop
DWT OFDM	-	Discrete Wavelet Transform based OFDM
DWT	-	Discrete Wavelet Transnsform
EDFA	-	Erbium Doped Fiber Amplifier
FEC	-	Forward Error Correction
FFT	-	Fast Fourier Transform
FIR	-	Finite Impulse Response
FSO	-	Free Space Optics
GI	-	Guard Interval
HPF	-	High Pass Filter
ICI	-	Inter Carrier Interference
IDFT	-	Inverse Discrete Fourier Transform
IDWT	-	Inverse Discrete Wavelet Transnsform
IFFT	-	Inverse Fast Fourier Transform
ISI	-	Inter Symbol Interference

IWPT	-	Inverse Wavelet Packet Transform
LPF	-	Low Pass Filter
LS	-	Least Square
MCM	-	Multi Carrier Modulation
MIMO	-	Multiple Input Multiple Output
ML	-	Maximum Likelihood
MMF	-	Multi Mode Fiber
MMSE	-	Minimum Mean Square Error
MZM	-	Mach Zehnder Modulator
OFDM	-	Orthogonal Frequency Division Multiplexing
P/S	-	Parallel to Serial
PAPR	-	Peak to Average Power Ratio
PSD	-	Power Spectral Density
QAM	-	Quadrature Amplitude Modulation
S/P	-	Serial to Parallel
SMF	-	Single Mode Fiber
SSB OFDM	-	Single Sideband OFDM
SSMF	-	Standard Single Mode Fiber
WLAN	-	Wireless Local Area Network
WOFDM	-	Wavelet based OFDM
WPM	-	Wavelet Packet Modulation
WPT OFDM	-	Wavelet Packet Transform based OFDM
WPT	-	Wavelet Packet Transform

LIST OF SYMBOLS

$\Im$	-	Fourier transform
a	-	Transmitted information symbol
a'	-	Received information symbol
C	-	Channel frequency response
c	-	Transmitted information symbol
C'	-	Estimated channel
c'	-	Received information symbol
E	-	Mathematical expectation
G	-	Wavelet filter (Analysis)
$\hat{G}$	-	Wavelet filter (Synthesis)
g	-	Wavelet filter coefficients (HPF)
H	-	Scaling filter (Analysis)
$\hat{H}$	-	Scaling filter (Synthesis)
h	-	Scaling filter coefficients (LPF)
k	-	Continues scale
l	-	Level in the wavelet packet tree
N	-	Number of subcarriers
r	-	Received signal
R	-	Received WOFDM symbol
s	-	Transmitted signal
S	-	Transmitted WOFDM symbol
T_{cp}	-	Duration of the CP
T_s	-	Duration of OFDM symbol
V_π	-	Half wave switching voltage
x	-	Continues translation
α	-	Discrete scale Index
β	-	Discrete translation Index
θ	-	Phase error

θ_0	-	Constant phase error
λ, γ	-	DWT coefficients
φ	-	Scaling function
ψ	-	Wavelet function
$\Pi(t)$	-	Pulse shaping function

CHAPTER 1

INTRODUCTION

1.1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a Multi Carrier Modulation (MCM) technique in which data is simultaneously carried over many low rates subcarriers. Two of the main advantages of OFDM are its robustness against channel dispersion and its ease of phase and channel estimation in dispersive environments.

1.2 Problem statement

Dispersion is one of the most important constraints in optical communication systems, which reduces the data rate and respectively the useful bandwidth of the optical channels. Recently researchers have shown that OFDM is an effective tool to overcome dispersion in optical communication systems considering the robustness properties of OFDM against Inter Symbol Interference (ISI) caused by a dispersive channel [1-20].

In the optical domain, the OFDM signal can be represented either by the intensity of the light, called intensity modulation, or by the optical field, called linear filed modulation. In the optical OFDM systems which are based on linear field modulation, the demodulation of the optical OFDM signal can be realized by means of direct detection or coherent detection. Direct Detection Optical OFDM (DDO

OFDM) and Coherent detection Optical OFDM (CO OFDM) have been utilized to compensate chromatic dispersion in single mode fibers [1-10]. In the optical wireless and multi mode fiber systems, intensity modulation should be used to produce optical OFDM signals. Direct Current biased Optical OFDM (DCO OFDM) and Asymmetrically Clipped Optical OFDM (ACO OFDM) have been proposed to combat modal dispersion in multimode fibers and wireless optical links [11-20].

The utilized transform coding technique in the electrical part of conventional OFDM systems is the Discrete Fourier Transform (DFT). Wavelet Transform is a relatively new transform compared to the Fourier transform. It provides the time frequency representation of signals, whereas Fourier transform gives only the frequency representation. Additionally wavelet transform offers better orthogonality than the Fourier transform. Strong advantages of wavelet transform over Fourier transform have caused the replacement of the Fourier transform with wavelet transform in the most recent digital communication systems. One of such replacements has taken place in the conventional OFDM, which is known as Wavelet based OFDM (WOFDM) [21].

Conventional OFDM signals only overlap in the frequency domain while the WOFDM signals overlap in both time and frequency. This overlapping feature increases the WOFDM symbol duration hence higher channel dispersion tolerance is obtained in comparison with conventional OFDM. In addition, since the duration of WOFDM symbol is long enough, WOFDM cannot gain advantage of Cyclic Prefix (CP). Lack of CP increases the spectral efficiency of WOFDM, CP contains only redundant data. Also, due to the time overlap, WOFDM has significantly lower side lobes than conventional OFDM hence higher immunity to Inter Carrier Interference (ICI) as well as higher immunity to ISI is achieved. In other words, WOFDM offers greater robustness against channel dispersion/fading and higher spectral efficiency than conventional OFDM [22-24]. Furthermore it has been proven that WOFDM is resilience to impulse noise [25] and to the Doppler spread introduced by the time variant channels [26]. Other advantages of WOFDM over conventional OFDM are as such: easier implementation, lower circuit cost as fewer carriers than in conventional

OFDM, lower complexity and higher flexibility [21-30]. These several advantages make WOFDM a candidate for future of OFDM in optical communication systems.

1.3 Objectives

The general objective of this thesis is to compare the transmission performances of DCO OFDM and DCO WOFDM signals over multi mode fiber optical links. For this aim, computer simulation, i.e. Optisystem software, was utilized.

Specific objectives are:

- To simulate DCO OFDM system, using Optisystem software. The electrical OFDM transmitter and receiver are implemented using Matlab software.

- To replace Fourier transform with discrete wavelet transform, using haar wavelet family, in the simulated DCO OFDM system.

- To evaluate the simulated systems in terms of Bit Error Rate (BER) and Optical Signal to Noise Ratio (OSNR) as two functions of transmission distance.

- To discuss on the optimal bias point of Mach Zehnder Modulator (MZM) in intensity modulation applications.

1.4 Organization of the Thesis

This thesis consists of six chapters. Chapter one briefly introduces this project by explaining the project background, objectives and overview of this thesis.

Chapter two was written based on the literature review carried out. It provides an introduction to OFDM principles including, a historical perspective of OFDM, its basic mathematical formulation, DFT implementation of OFDM, cyclic prefix, channel estimation in OFDM, Peak to Average Power Ratio (PAPR) property and OFDM sensitivity to the frequency offset and phase noise. At last a complete description of optical OFDM is given by this chapter. A brief discussion on linearity between optical domain and electrical domain, and various types of optical OFDM are the issues which are elaborated in the last part of this chapter.

In chapter three, WOFDM is studied. This chapter provides an introduction to WOFDM fundamentals including, a historical perspective, basic idea for wavelet transform, implementation of discrete wavelet transform with digital filter banks, wavelet packet transform, wavelet basis functions, and architecture and design of various types of WOFDM.

Chapter four includes the simulation models of DCO OFDM and DCO WOFDM systems. All simulation parameters which were used in these OFDM simulations are explained in this chapter.

The simulation results and their analyses are presented in chapter five along with conclusions.

The thesis is concluded with chapter six describing the conclusions and suggestion for further work.

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