MULTIPLE ANTENNA SYSTEM AND CHANNEL ESTIMATION FOR MULTIBAND ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING IN ULTRA-WIDEBAND SYSTEMS

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To my beloved parents, my lovely wife and son,
for their understanding and support through the years

ABSTRACT

Multiband Orthogonal Frequency Division Multiplexing (OFDM) has been deployed for practical implementation of low cost and low power Ultra-Wideband (UWB) devices due to its ability to mitigate the narrowband interference and multipath fading effects. In order to achieve high data rates, the deployment of multiple antenna techniques into a UWB system has gained considerable research interest. In a UWB system, both the spatial and multipath diversities exist in UWB system can be exploited via the use of Multiple-Input Multiple-Output (MIMO) antenna system and Space-Time Codes (STC) by leveraging Alamouti scheme. This work shows that MIMO system outperforms Alamouti technique in providing a power combining gain in the receiver. Given that channel estimation for time-frequency multiplexed such as a multiband OFDM system is unexplored largely, this thesis also addresses this issue. In literature, most of the conventional Channel Frequency Response (CFR) estimations require either pre-storing a large matrix or performing real-time matrix inversion. In general, these requirements are prohibitive for practical implementation of UWB devices. In this thesis, the implementation issues of STC-based on Alamouti scheme are investigated for the multiband OFDM system. The research quantifies and analyses existing channel estimation in frequency domain such as Least-Square (LS) and Minimum Mean Square Error (MMSE) techniques. Consequently, low-complexity channel estimation based on Singular Value Decomposition (SVD) technique is developed for multiband OFDM system evaluates under modified Saleh-Valuenzela (S-V) channel modelling represents the realistic wireless indoor environment. This work implies that the SVD technique gives an improvement of 3-5 dB compared to LS technique. Even though SVD performs similarly to MMSE, it managed to reduce significantly the complexity by or to 57.8%.

ABSTRAK

Peranti Jalur-Lebar Ultra (UWB) telah mengguna-pakai teknik Pemultipleksan Pembahagi Frekuensi Setentang (OFDM) Pelbagai Jalur untuk merealisasikan perlaksanaan peranti berkos dan berkuasa rendah secara praktikal kerana ianya berupaya mengurangkan gangguan isyarat jalur sempit dan kesan hingar jalur berbilang. Penyelidikan terhadap teknik antena berbilang telah memberikan faedah yang besar dalam usaha untuk mencapai kadar kelajuan data yang tinggi. Sistem UWB yang menggunakan teknik OFDM berupaya untuk mengeksploitasi ruang dan jalur berbilang yang wujud dengan menggunakan sistem komunikasi antena input-berbilang output-berbilang (MIMO) dan kod ruang-masa (STC) dengan memanfaatkan skim Alamouti. Penyelidikan ini telah menunjukkan sistem MIMO memberikan prestasi yang lebih baik dari skim Alamouti dengan menyediakan gabungan kuasa di penerima. Disamping itu, aggaran media untuk pemultipleks masa-frekuensi seperti Pelbagai Jalur OFDM belum dikaji sepenuhnya. Kebanyakan anggaran media untuk sambutan frekuensi memerlukan sama ada pra-penyimpanan matriks yang besar atau memerlukan kepada operasi matrik songsang masa nyata. Secara umum, keperluan ini perlu dielakkan untuk peranti UWB yang praktikal. Tesis ini telah mengkaji isu-isu perlaksanaan STC bercirikan skim Alamouti untuk sistem Pelbagai Jalur OFDM. Penyelidikan dan analisis terhadap beberapa jenis anggaran media seperti teknik Persegi Terendah (LS) dan Purata Minimum Ralat Persegi (MMSE). Seterusnya, anggaran media yang kurang kompleks menggunakan teknik Penguraian Nilai Singular (SVD) telah dibangunkan untuk sistem Pelbagai Jalur OFDM dinilai menggunakan persekitaran dalaman sebenar iaitu media Saleh-Valenzuela (S-V). Hasil penyelidikan teknik SVD menunjukkan peningkatan 3-5 dB berbanding teknik LS. Walaupun menunjukkan keupayaan seperti MMSE, SVD menunjukkan pengurangan ketara sebanyak 57.8%.

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LIST OF ABBREVIATIONS

AWGN	-	Additive White Gaussian Noise
BER	-	Bit-Error Rate
CFR	-	Channel Frequency Response
CIR	-	Channel Impulse Response
CM	-	Channel Model
CP	-	Cyclic Prefix
CSI	-	Channel State Information
DFT	-	Discrete Fourier Transform
DS-UWB	-	Direct Sequence Pulse UWB
ECMA	-	European Computer Manufacturer Association
EM	-	Expectation-Maximization
FCC	-	Federal Communications Commission
FFT	-	Fast Fourier Transform
GPS	-	Global Positioning System
HDTV	-	High Definition TV
IEEE	-	Institute of Electrical and Electronics Engineers
ICI	-	Inter-Carrier Interference
IDFT	-	Inverse Discrete Fourier Transform
ISI	-	Inter-Symbol Interference
LS	-	Least-Square

LLR	-	Log-Likelihood Ratio
LOS	-	Line-of-Sight
MAC	-	Medium Access Control Layer
MBOA	-	Multiband Orthogonal Frequency Division Multiplexing Alliance
MIMO	-	Multiple-Input Multiple-Output
MMSE	-	Minimum Mean Square Error
MRC	-	Maximal Ratio Combining
OFDM	-	Orthogonal Frequency Division Multiplexing
OLA	-	Overlap-Add
OSIC	-	Ordered Successive Interference Cancellation
PDF	-	Probability Density Functions
PHY	-	Physical Layer
PSD	-	Power Spectral Density
QPSK	-	Quadrature Phase Shift Keying
RF	-	Radio Frequency
RMS	-	Root Mean Square
RX	-	Receiver
SFTS	-	Space-Frequency Transmit selection
SISO	-	Single-Input Single-Output
SNR	-	Signal-to-Noise Ratio
STC	-	Space-Time Codes
STF	-	Space-Time-Frequency Codes
SVD	-	Singular Value Decomposition
S-V	-	Saleh-Valenzuela
TFC	-	Time-Frequency Code
TX	-	Transmitter

USB	-	Universal Serial Bus
UWB	-	Ultra-Wideband
WiMAX	-	Worldwide Interoperability for Microwave Access
WPAN	-	Wireless Personal Area Network
ZP	-	Zero Padded
Pdf	-	Probability Distribution Function

CHAPTER 1

INTRODUCTION

Fervent engineering activities devoted by researchers and scientist around the world to incorporate the function of Wireless Personal Area Network (WPAN) features into portable devices such as mobile and Smartphones, digital cameras and printing devices, to name a few [1]. Soon, consumer will demand for media exchange between these devices interconnecting one another centred on personal workspace. Nevertheless, today's wireless technologies cannot meet the needs of tomorrow's consumer electronic devices. Both spectrum capacity and usability requirement are due to the demand of high-rate, low-cost and low power for these devices [2]. Hence, the emergence of ultra wideband (UWB) technology is widely expected to offer a compelling solution. UWB enables wireless connectivity to support multiple high data rate connection, low power consumption and small size of next generation consumer electronic devices.

This chapter briefs on the history and interesting features of emerging UWB technologies for WPAN communications. UWB devices are expected to provide a low-cost solution that can satisfy high data rate as well as low power consumer market demands. In addition, this chapter will explain in detail about the problems experienced by the system and suggest several alternatives that lead to the purpose of this thesis.

1.1 Ultra Wideband System Overview

UWB is a radio technology pioneered by Robert A. Scholtz that used at a low energy level for short-range communications using a large portion of the radio spectrum. In late 1990, much work in the UWB field becomes commercialized and the development of UWB technology has greatly proliferated. In 1998, a substantial change in the history of UWB when the Federal Communications Commission (FCC) has agreed to release a spectrum range from 3.1 to 10.6 GHz for UWB radio to operate legally on an unlicensed basis [3]. The First Report and Order that appeared on February 2002 authorized the operation of UWB devices under stringent power spectral density emission at -41.3 dBm/MHz. The UWB transmission system has been defined by FCC in terms of the signal bandwidth emission is more than 20% of its centre frequency, in other words it is more than 500 MHz [1].

UWB co-exists with other existing system such as Global Positioning System (GPS), microwave ovens and IEEE 802.11 series including out-of-band IEEE 802.11b/g system [4]. Figure 1.1 illustrates the UWB spectrum frequency allocation that coexists with other services. Conservative FCC's regulations required a low emitted power over a wide spectrum of UWB devices to optimize spectrum used and refrained interference to existing services. The long-term vision of UWB technology is to realize high data-rate over short-range communication replacing cables [5]. It enables wide variety user device application including wireless monitor, highly efficient data transfer in between camcorder and HDTV, wireless printing capability and etcetera. Since then, several technology proposals have been presented to utilize a higher bandwidth over a larger signal-to-noise ratio.

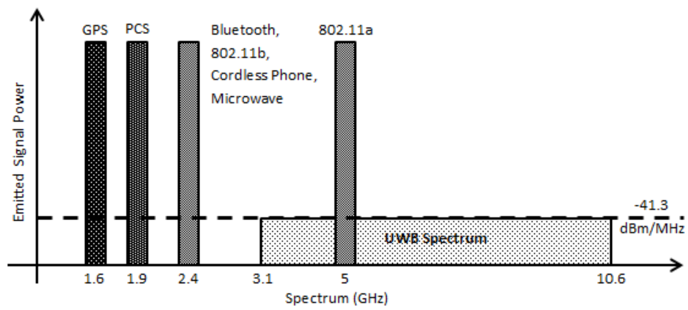

Figure 1.1 UWB Spectrum Allocations [1]

There were two proposals to attempt to provide a high-speed communication over UWB platform exploiting the unlicensed bandwidth; namely direct sequence pulse based design (DS-UWB) and multi band based UWB system [2]. Backed by Multiband Orthogonal Frequency Division Multiplexing Alliance (MBOA), the latter has more favours to enable short-range and high-rate communication over UWB platform. MBOA is a non-profit industrial consortium; part of WiMedia Alliance aimed to enable wireless connectivity for multimedia applications and promotes UWB worldwide interoperability. Complementary WPAN technologies that shared common UWB platform include Wireless USB, Wireless 1394 and Bluetooth 3.0 that operate at different payload capabilities. In December 2005, European Computer Manufacturer Association (ECMA) International released two ISO-based specifications, namely ECMA-368 and ECMA 369, based on WiMedia multiband UWB technology [6].

The emerging of UWB technology offers a wide bandwidth capable of transmitting high data rates over 480 Mbps up to 1 Gbps for a short range communication. UWB offers a compelling solution for WPAN to interconnect devices in close proximity of around 20 meters. UWB devices must not only be optimized to provide higher rate data link, but it must be cost effective, low in power consumption and capable of supporting multiple data-rates in order to be integrated with future wireless technology such as mobile WiMAX and 4G devices. UWB technology can be used to replace cables providing wireless connectivity solutions for high quality video streaming, digital TV, DVDs, camcorders in additions for fast media exchange between portable devices.

1.2 Research Motivations

The deployment of multiple antenna techniques into UWB has gained considerable research interest recently to achieve high data rates up to several Gigabits per second [7]-[10]. Scattering scenarios in such a way that WPAN can be exploited through both space and time diversity offered by multiple antenna technology. However, numerous challenges need to be considered in the receiver's design particularly in low-complexity deployment to achieve substantial spectral efficiency and accuracy at a relatively low-cost. In multiband OFDM system, the transmit diversity can be distributed as space-time block codes over successive OFDM symbols as conventional as the coded OFDM system shown in Alamouti scheme [11]. Furthermore, both the spatial and multipath diversities exist in UWB system can be exploited via the use of multiple-input multiple-output (MIMO) antenna system and space-time codes (STC) by leveraging Alamouti scheme. In this thesis, the implementation issues of STC based on Alamouti scheme is investigated for the multiband OFDM UWB system. Furthermore, low complexity single-tap frequency domain equalization is taken into consideration to deploy the MIMO multiband OFDM system.

It is well known that time domain channel estimation can achieve better performance than frequency domain channel estimation with a time-multiplexed preamble in the common OFDM system [12]. However, channel estimation for time-frequency multiplexed such as multiband OFDM is unexplored largely. If there is an interference source present, the preamble symbol may be corrupted which will spoil the accuracy of channel estimation [13]. Most of the conventional channel frequency response (CFR) estimation requires either pre-storing a large matrix or performing real-time matrix instruction [14]. In general, this requirement is prohibitive for practical implementation of UWB devices. The research motivation will quantify and analyse several channel frequency domain estimation techniques such as least squares (LS) estimation and minimum mean square error (MMSE) estimation. Consequently, low-complexity CFR estimation based on singular value decomposition (SVD) technique is proposed for Multiband OFDM techniques under realistic UWB wireless indoor environments.

The crucial limitation in UWB system is strictly low power transmission that leads to many challenges in designing the system. Though today's technology makes the high computational algorithm feasible, UWB devices require a low-power and low-cost system implementation. The intuition of this thesis is to demonstrate numerical analysis of MIMO and channel estimation techniques under the UWB channel modelling. The performance and numerical analysis are analysed under realistic Saleh-Valenzuela (S-V) modelling that is adopted by IEEE 802.15.3a standard body as reference to describe indoor propagation environments. In this study, the probability density functions (PDF) and the channel path delays statistics of the S-V channel modelling are derived under several noisy conditions.

1.3 Research Objectives

In this thesis, the research objectives are to quantify and analyse the implementation issues of space-time code (STC), based on Alamouti scheme, for the MIMO multiband OFDM system. The distinctive features of ZP in UWB systems are incorporated in the design of single tap frequency domain equalization to deploy MIMO system. Furthermore, numerical analysis of several existing channel estimation techniques in the frequency domain is observed under the realistic UWB channel modelling. This work also will suggest low-complexity CFR estimation based on SVD techniques for Multiband OFDM techniques under S-V modelling. The main objectives of this work are as follows.

1) To evaluate the S-V mathematical modelling in terms of the probability density functions (PDF) and the channel path delay statistics for UWB system. Note that a modified S-V model will be adopted throughout this thesis according to the IEEE proposal.

2) To investigate the design aspect of Space-Time Codes (STC) for the MIMO multiband OFDM system that is relatively associates to the time-frequency codes (TFC). Hence, the objective is to observe UWB system capacity.

3) To evaluate the comparative performance study of SVD to several existing channel estimation such as Least-Square (LS) and Minimum Mean Square Error (MMSE) algorithm in an UWB environment that extends to multiple antenna scenarios.

1.4 Scope of Research

Multiple-input multiple output (MIMO) is an emerging technology that has gained a lot of attention for its capability to achieve high capacity and link reliability within a given bandwidth. Theoretically, the capacity increases linearly with the number of antennas when the channel exhibits rich scattering and slow variation. This improvement in the capacity is achieved via the parallel sub channels created by dense multipath such as UWB environments; provide that the established transmission path between transmitter and receiver are uncorrelated. This research thesis presents the analysis and implementation of a MIMO system under realistic indoor UWB channel incorporating the distinctive features of the ZP OFDM system.

A challenging problem in UWB system is the channel estimation, since a significant number of channel parameters need to be estimated. Therefore, in order to take the potential advantages of such system, accurate and yet computationally efficient channel estimators are required for low-cost and low-power UWB devices. Channel estimation becomes more important and challenging when the channel is time varying in indoor environments. Motivated by these issues, a part of this research is devoted within the scope to develop high accuracy and low-computational complexity channel frequency estimation methods, which includes LS, MMSE and SVD channel frequency estimation techniques for UWB system.

The intuition of this thesis is to demonstrate the complexity of MIMO system and several existing channel frequency estimation. This work will exploit the diversity scheme to the channel estimation, particularly in the modified S-V channel modelling. Numerical analysis includes the clock cycle count and operational complexity will be analysed under various highly noisy S-V channel conditions. It will be interesting to investigate several existing channel estimation method to implement on multiple antenna system for the case of the multiband OFDM transmission system. Finally, research methodologies in this thesis are as follows while the working flow chart is shown in Figure 1.2

1. Feasibility studies of the Multiband OFDM System and the Ultra Wideband channel modelling
   a) Review and understand the proposed ECMA-368: *High Rate Ultra Wideband PHY and MAC Standard.*
   b) Understand the characteristic of Ultra Wideband channels used for this system such as S-V model.
   c) Derive the probability density functions (PDF) and the statistics of the channel path delays of the S-V model.

2. UWB baseband system development and S-V channel modelling using MATLAB
   a) Develop the Multiband OFDM system that consists of the baseband transmitter and receiver, and then integrate the S-V channel modelling proposed by the IEEE 802.15.3 committee.
   b) Simulate and analyse the performance of Multiband OFDM system under the perfect channel assumption and proposed IEEE channel modelling.

3. Algorithm development studies and integration into the Multiband OFDM system
   a) Research studies on the multiple antenna technique focusing on Multiple Input Multiple Output (MIMO) system. Emphasize on

Alamouti scheme based on the block coding techniques is discussed thoroughly.

b) Review studies on the channel estimation techniques for wireless OFDM system such as the least squares (LS) and minimum mean square error (MMSE) method.

c) Develop and integrate the multiple antenna techniques and the channel estimation method into Multiband OFDM baseband system.

4. Performance studies and data analysis of the algorithm

a) Investigate and analyse the performance of the channel estimation in the Multiband OFDM system simulated under multipath fading scenario and compare with UWB channel.

b) Investigate and analyse the channel capacity and the performance of the multiple antenna technique in the Multiband OFDM system simulated under UWB channel.

c) Performance and results comparison with existing and relevant research to conclude the thesis works.

d) Tabulate the results data and generate a graphical view of the algorithm performance.

Based on the proposed channel modelling in IEEE 802.15.3a standard body, the S-V propagation analysis is evaluated using four different types of channel models for UWB system. The salient feature of ZP approach employs in multiband OFDM is evaluated to prove the low-power requirement for UWB devices. This thesis also investigates the performance of a multiband OFDM UWB system when it operates in conjunction with transmit diversity. More specifically, the analysis of Alamouti scheme based on block coding for the suitability and performance of UWB system is conducted under various S-V channel model condition. Furthermore, the work extends to the case of multiple receives antenna to observe the performance of MIMO system.

1.6 Thesis Organization

This thesis is organized as follows. An introductory overview is given in Chapter 1 that briefs on the issues and problems arise in the conventional UWB system. Motivated by the market needs of low-cost and low-power UWB devices, this thesis envisaged compelling solutions suggesting significant research objectives.

Chapter 2 provides a brief review of the multiband OFDM system, multi carrier technique of the conventional UWB system, and discusses on wireless propagation model and its characteristic of a short-range indoor environment, specifically the S-V channel modelling. A literature survey on multiple antenna based OFDM system as well as channel estimation for single-input single-output (SISO) OFDM system is also provided at the end of Chapter 2.

In Chapter 3, the research methodology of the multiband MIMO-OFDM based on Alamouti space-time coding along with receive diversity techniques is introduced. Based on the developed model, the channel estimation techniques in the frequency domain are integrated with S-V channel modelling.

Then, the analytical and simulation results of the newly developed system model are presented in Chapter 4. Particularly, the effects of ZP-OFDM system performance under richly scattering environment are investigated under all S-V channel conditions. In the framework of the developed channel model, this thesis provides an evaluation of the MIMO system and frequency domain channel estimation techniques under different environmental circumstance as well. Finally, the conclusion and suggestions on the future work are summarized in Chapter 5.

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