ANTENNA AND FREQUENCY DIVERSITY IMPROVEMENT IN MIMO WIMAX TECHNOLOGY

MOHAMMED ABOUD KADHIM

UNIVERSITI SAINS MALAYSIA

2011

ANTENNA AND FREQUENCY DIVERSITY IMPROVEMENT IN MIMO WIMAX TECHNOLOGY

by

MOHAMMED ABOUD KADHIM

Thesis submitted in fulfillment of the requirements for the degree of

Doctor of Philosophy

August 2011

DEDICATION

To

My Father and Sister in memory........

Who offered me encouragement to continue my studies.

ACKNOWLEDGMENT

First of all, I am thankful to ALMIGHTY ALLAH, who is the creator of the whole universe, most merciful, the most beneficent, and who gave me strength, guidance and ability to complete this thesis. I would like to express my sincere thanks to my supervisors, Dr Widad Ismail, for the invaluable guidance, encouragement, generosity, patience, advice and comments throughout my research work. I greatly appreciate all their support. I would also like to express my warm and sincere thanks Dr. Mohd Fadzli Mohd Salleh for his valuable suggestions and encouragement during the course of my PhD study. I would like to thank the staffs of the Auto-ID Laboratory (AIDL) and communication Laboratory, who were very friendly and cooperative. I express my gratitude to the wonderful Malaysian people who gave their kindly help to me during my stay in Malaysia. Finally, I would like to thank my family, for their patience, understanding, support and love.

TABLE OF CONTENTS

CHAPTER 2

LITERATURE REVIEW

CHAPTER 3

DESIGN OF ANTENNA ARRAY WITH DIVERSITY IMPROVEMENT

CHAPTER 4

SIGNAL PROCESSING METHODS FOR FREQUENCY DIVERSITY IMPROVEMENT

CHAPTER 5

RESULTS AND ANALYSIS FOR DIVERSITY IMPROVEMENT

CHAPTER 6

CONCLUSION AND FUTURE WORK

APPENDIX

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAS	Adaptive Antenna System
AOA	Angles of Arrival
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase-Shift Keying
BWA	Broadband Wireless Access
CC	Convolutional Codes
CCI	Co-Channel Interference
CCS	Code Composer Studio
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CIR	Channel Impulse Response
CMFBs	Cosine Modulated Filter Banks
CP	Cyclic Prefix
CSI	Channel State Information
CST	Computer Simulation Technology
dB	Decibel
DF	Degradation Factor
DL	Down Link
DMWT	Discrete Multiwavelet Transform
DRAM	Dynamic Random Access Memory
DS	Direct Sequence
DSL	Digital Subscriber Line
DSP	Digital signal processor

DWT	Discrete Wavelet Transform
DWMT	Discrete Wavelet Multi-tone
EGC	Equal Gain Combining
Eq	Equation
ETSI	European Telecommunications Standards Institute
FCH	Frame Control Header
FDD	Frequency Division Duplexing
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FPGA	Field-Programmable Gate Array
4G	Fourth Generation
GF	Galois Field
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICI	Inter-Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IDMWT	Inverse Discrete Multiwavelet Transform
IDWT	Inverse Discrete Wavelet Transform
IEEE	Institute of Electrical and Electronics Engineers
IFA	Inverted-F Antenna
IFFT	Inverse Fast Fourier Transform
Iid	Independent and Identically Distributed
ILA	Inverted-L Antenna

IP	Internet Protocol
ISI	Inter-Symbol Interference
LTE	Long Term Evolution
ITU	International Telecommunications Union
LOS	Line of Sight
LS	Least Squares
MAC	Media Access Control Layer
MAN	Metropolitan Area Networks
MC	Multi-Carrier
MCM	Multi-Carrier Modulation
MEG	Mean Effective Gain
MISO	Multiple Input Single Output
MIMO	Multiple Input Multiple Output
ML	Maximum Likelihood Detector
MRC	Maximal Ratio Combining
MRRC	Maximal-Ratio Receiver Combining
NLOS	Non-Line-of-Sight
NMHA	Normal Mode Helix Antenna
OFDM	Orthogonal Frequency Division Multiplexing
OSTBC	Orthogonal Space Time Block Code
PCB	Printed Circuit Board
PCS	Personal Communication Services
PDA	Personal Digital Assistant
PDC	Personal Digital Communications
PIFA	Planar Inverted-F Antenna

PH	Average Horizontal Power
PHY	Physical Layer
PMP	Point-to-Multi-Point
PSAM	Symbol Assistant Modulation
PV	Average Horizontal Power
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QSTBC	Quasi-Orthogonal Space-Time Block Codes
RF	Radio-Frequency
RS	Reed-Solomon
RTW	Real-Time Workshop
Rx	Receiver
SC	Selection Combiner
SDR	Software Defined Radio
SDRAM	Synchronous Dynamic Random Access Memory
SFF	Small Form Factor
SIMO	Single Input Multiple Output
SISO	Single Input Single Output
SM	Spatial Multiplexing
SNR	Signal-to-Noise Power Ratio
SS	Spread Spectrum
STBC	Space Time Block Code
STC	Space Time Code
STTC	Space Time Trellis Code
TDD	Time Division Duplexing

TI	Texas Instruments
TLC	Target Language Compiler
Tx	Transmitter
UL	Up Link
ULA	Uniform Linear Array
UMTS	Universal Mobile Telecommunication System
UTRA	UTMS Terrestrial Radio Access
WCDMA	Wide-band Code Division Multiple Access
WiBro	Wireless Broadband
Wi-Fi	Wireless-Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
XPR	Cross-Polar Ratio

LIST OF SYMBOLS

Γ	Mean SNR
γ	Instantaneous SNR
$P\ (\gamma < \gamma_s\ )$	Probability of SNR
γ_s	Threshold
B	Phase Constant
N	Number of Branches
ρ_c	Complex Correlation
ρ_e	Envelope Correlation
E	Electric Far Field
P_{min}	Power with the Lower Power
P_{max}	Power with the Higher Power
P_{rec}	Average Power Received
$G_\theta\ \ G_\phi$	Spherical Power Gain (θ, ϕ)
$P_\phi(\theta, \phi)$	Angular Density Functions of the Vertical Plane
$P_\theta(\theta, \phi)$	Angular Density Functions of the Horizontal Plane
$P_\theta(\phi), P_\phi(\phi)$	Angular Density Functions in Azimuth
$P_\theta(\theta)\ , P_\phi(\theta)$	Angular Density Functions in Elevation
A_θ	Constant
A_ϕ	Constant
m_v	Mean Elevation Angles of Vertical Polarized Wave Distribution

m_H	Mean Elevation Angles of Horizontal Polarized Wave Distribution
σ_H	Standard Deviations of the Horizontal Polarized Wave Distribution
σ_V	Standard Deviations of the Vertical Polarized Wave Distribution
t	Time Domain
τ	Time Delay
$h(t, \tau)$	Fading Channel Impulse Response
N_p	Number of Fading Paths
δ	Impulse Function
τ_{max}	Maximum Delay Spread in the Selective Fading Channel
$H(f, t)$	Channel Transfer Function
v	Terminal Station Speed
f_c	Carrier Frequency
f_d	Doppler Frequency
c	Speed of Light
N_{OFDM}	Number of Transmitted OFDM Symbols in One Frame
N_{data}	Number of Used Data Subcarriers
N_{rows}	Number of Rows in Interleaving Matrix
N_{tcb}	Total Number of Coded Bits
N_{cpc}	Number of Transmitted Bits Per Symbol
N_{cbps}	Number of Coded Bits Per the Specified Allocation
$N_{tx-data}$	Number of Transmitted Data Symbols

$N_{ISI,single-carrier}$	Number of Interfered Symbols in Single-Carrier Modulation
$N_{ISI,multi-carrier}$	Number of Interfered Symbols in Multi-Carrier Modulation
T_d	Bit duration
N_c	Number of Sub-Carriers
F_s	Sub-Carrier Spacing
T_s	Symbol Duration
$X(t)$	Complex Envelope of OFDM Symbol
S_n	Parallel Modulated Source Symbol
n	Index for Sub-Carrier Frequencies
T_g	Guard Interval Time
T_b	Useful Symbol Time
$n(t)$	Noise Signal
$y(t)$	Received Signal
$P_t(t)$	Transmitted Pilot Carriers
$P_r(t)$	Received Pilot Carriers
h_k	Channel Coefficient for th k-th Subcarrier
p_k	Training Symbol
n_k	Noise Symbol
y_k	Received Signal on the k-th Subcarrier
X	Cartesian Coordinate
y	Cartesian Coordinate
Z	Cartesian Coordinate
W	Transformation Matrix
$(\Delta f)_c$	Coherence Bandwidth

$\Psi(t)$	Scalar Wavelet
$\Phi(t)$	Multiscaling Function
$PALL$	Frequency Domain Sequence
P_{even}	Frequency Domain Sequence for Long Training Symbols
P_{odd}	Frequency Domain Sequence for Long Training Symbols in STC
P_{short}	Frequency Domain Sequence for Short Training Symbols
$p(x)$	Primitive Polynomial
$g(x)$	Generator Polynomial
T_{sym}	OFDM Symbol Time
G	Ratio of CP Time to Useful Symbol Time
W_k	Output of PRBS Generator
C	Capacity
α	Roll-Off Factor
BW	Nominal Channel Bandwidth
B_{coh}	Coherence bandwidth
I	Identity matrix
$+$	Conjugate transpose
$det\ (.)$	Determinant

PENINGKATAN KEPELBAGAIAN ANTENA DAN FREKUENSI DALAM TEKNOLOGI MIMO WIMAX

ABSTRAK

Kepelbagaian ialah teknik komunikasi berpengaruh yang mengatasi kekaburan dengan memanfaatkan sifat rawak saluran tanpa wayar dan mengesan laluan isyarat bebas antara pemancar dengan penerima. Dalam lapisan fizikal WiMAX (PHY) teknik kepelbagaian seperti kepelbagaian masa, kepelbagaian frekuensi dan kepelbagaian antena digunakan untuk meningkatkan prestasi. Tujuan utama tesis ini ialah meningkatkan prestasi kepelbagaian WiMAX PHY. Langkah pertama ialah mengubahsuai reka bentuk sedia ada dan melaksanakan tatasusunan Antena Satah Tersongsang-F (PIFA) untuk aplikasi telefon mudah alih, dengan memanfaatkan kepelbagaian antena dalam aplikasi mudah alih MIMO WiMAX. Langkah kedua ialah reka bentuk dan pelaksanaan penghantar-terima jalur dasar gelombang kecil dan gelombang kecil berbilang berasaskan MIMO WiMAX (IEEE802.16.d) OSTBC-OFDM yang diterapkan pada sebuah platform perisian-tertakrif berbilang-teras untuk peningkatan kepelbagaian frekuensi. Sebuah reka bentuk PIFA yang diubah suai dan tatasusunannya dicadangkan dan dikaji pada 3.5 GHz. PIFA tunggal itu, dengan satah bumi bersaiz kecil, membentuk satu struktur bina-sendiri dan mengurangkan hubungan terputus ketika hubungan dengan satah bumi dan plat atas dibuat. Satah bumi dan plat atas dibuat daripada plat tembaga yang sama, yang dibentuk dalam dimensi tertentu. Satah bumi, yang saiznya sekecil saiz antena, diletakkan di antara PIFA dengan PCB sehingga PCB tidak lagi berfungsi sebagai satah bumi untuk PIFA. Dua modul PIFA dan empat modul PIFA yang dipasangkan pada PCB tidak berkongsi satah bumi yang sama. Sebagai akibatnya, prestasi pemencilan antara antena PIFA yang diubahsuai meningkat secara signifikan dan mencapai kepelbagaian yang baik, sambil mengekalkan korelasi rendah. Selain itu, reka bentuk ini memberikan tahap kuasa sederhana antara elemen antena dalam dua modul PIFA dan empat modul PIFA dengan cara yang hampir sama seperti ia memberikan peningkatan prestasi pada telefon mudah alih kecil MIMO WiMAX. Ciri-ciri dan prestasi kepelbagaian dua dan empat antena unsur PIFA pada jalur frekuensi 3.5GHz dinilai. Blok OSTBC-OFDM telah dikaji secara menyeluruh, dan struktur baru untuk OSTBC-OFDM dicadangkan berdasarkan gelombang kecil dan gelombang kecil berbilang. Ia mempunyai satu, dua, atau lebih penapis laluan-rendah dan laluan-tinggi. Tujuan sistem ini ialah mencapai tahap ralat bit rendah dan kemampuan untuk menyesuaikan kualiti pada kadar bit yang dikehendaki, meningkatkan nisbah kuasa isyarat-ke-bunyi (SNR), dan menyokong kecekapan spektrum yang jauh lebih tinggi. Transformasi reka bentuk baru gelombang kecil dan gelombang kecil berbilang berasaskan OFDM ini boleh digunakan sebagai alternatif untuk MIMO WiMAX OSTBC-OFDM konvensional. Sistem OFDM yang dicadangkan ini dimodelkan dan diuji, dan prestasinya didapati sesuai dengan model-model saluran Pertubuhan Telekomunikasi Antarabangsa yang dipilih untuk saluran wayarles dalam proses simulasi ini. Hasil prestasi sistem SISO, MISO, dan MIMO yang disimulasikan juga dibandingkan.

ANTENNA AND FREQUENCY DIVERSITY IMPROVEMENT IN MIMO WIMAX TECHNOLOGY

ABSTRACT

Diversity is an influential communication technique that combats fading by exploiting the random nature of the wireless channel and finding independent signal paths between the transmitter and the receiver. In WiMAX PHY, diversity techniques such as time diversity, frequency diversity and antenna diversity are used to improve performance. The main objectives of this thesis are to improve diversity performance in WiMAX PHY. The first step is to modify the existing design and implement the PIFA antenna arrays for mobile handset application, exploiting antenna diversity in MIMO WiMAX mobile applications. The second step is the design and implementation of MIMO WiMAX (IEEE802.16.d) OSTBC-OFDM based wavelet and multiwavelet baseband transceiver applied to a multi-core software-defined radio platform for improved frequency diversity. A modified PIFA (Planar Inverted-F Antenna) design and its array were proposed and studied at 3.5 GHz. The unique PIFA with a small-size ground plane forms a self-composed structure and there are no connection losses when connecting to the ground plane and the top plate. The ground and top plates are made from the same copper plate, twisted in the specified dimensions. The ground plane, as small as the antenna, is situated between the PIFA and the PCB so that the PCB is no longer acting as a ground plane for the PIFA. The two PIFA modules and the four PIFA modules fixed on the PCB do not share the same ground plane. Consequently, the isolation performances between the modified PIFA antennas are significantly improved and

achieve a good diversity gain, while maintaining a low correlation. Moreover, the design gives mean power levels between the antenna elements in the two PIFA modules and four PIFA modules in almost the same way as it gives improved performance on a small MIMO WiMAX mobile handset. The characteristics and diversity performance of two and four element PIFA antennas in the 3.5GHz frequency bands are evaluated. The OSTBC-OFDM block has been studied extensively, and a new structure for the OSTBC-OFDM is proposed based on wavelet and multiwavelet. It has one, two, or more low-pass and high-pass filters. The purpose of the system is to achieve low bit error rates and the ability to adapt the quality to the required bit rate, increase signal-to-noise power ratio (SNR), and support a much higher spectrum efficiency. The new design of the OFDM based wavelet and multiwavelet transformation can be used as an alternative to the conventional MIMO WiMAX OSTBC-OFDM. The proposed OFDM system was modeled and tested, and its performance was found to comply with International Telecommunications Union channel models that were elected for the wireless channel in the simulation process. The presentation results of the simulated SISO, MISO, and MIMO systems were also compared.

CHAPTER 1

INTRODUCTION

1.1 Preface

Developments in the proficiency of digital networks have led to requirements for higher-capacity designs for new communication networks. The telecommunication industry is also changing, gaining a need for a wider range of services, such as video conferences, or applications with multimedia contents. Increased dependence on computer networking and the internet has resulted in a greater necessity for connectivity to be provided "anywhere, any time," leading to an increase in the requirements for higher capacity and higher reliability broadband wireless telecommunication systems. Broadband accessibility brings high presentation connectivity to over a billion users' worldwide, thus developing new wireless broadband standards and technologies that will rapidly span wireless coverage. Wireless digital communications are a growing field that has experienced a spectacular expansion through the last several years. Furthermore, the enormous assimilation rate of mobile phone technology, WLAN (Wireless Local Area Network) and the exponential development of internet have resulted in an increased requirement for new methods of obtaining high capacity wireless networks. Worldwide Interoperability for Microwave Access (WiMAX) is the general name associated with the IEEE 802.16a/R E V d/e standards. WiMAX is called the next generation broadband wireless technology which offers high speed, secure, sophisticated, and last mile broadband services along with a cellular backhaul and Wi-Fi hotspots. The evolution of WiMAX began a few years ago when scientists and engineers needed wireless internet access and other broadband services which would work well everywhere, especially in rural areas or in those areas where it is hard or economically infeasible to establish wired infrastructure. These standards are issued by the IEEE 802.16 subgroup that initially covered the Wireless Local Loop technologies with a radio spectrum from 10 to 66 GHz and after that added physical layer support from 2 to 11GHz. WiMAX is also defined as WMAN2, a type of enormous hot-spot that provides interoperable broadband wireless connectivity to portable, nomadic and fixed users. Other techniques used presently to improve the performance of wireless communications systems are based on multiple antennas on the transmitter and or on the receiver. These forms increase the capacity of a wireless link leading to higher data rates. Diversity: a method for improving the reliability of a message signal by using multiple communications channels. With MIMO, WiMAX systems are able to achieve three type of diversity: antenna diversity, frequency diversity through the use of multicarrier modulation OFDM, and time diversity, which can be accomplished by using an outer Reed-Solomon code concatenated with an inner convolutional code into its physical layer. In MIMO systems, antennas are planted in small confined volumes, such as in mobile phones, which causes high coupling between them. This results in high correlation as well as low efficiency, which leads to bad diversity gain and high return loss. Antenna diversity is one of the most significant characteristics of a MIMO antenna. Good antenna diversity means that radio signals can be transmitted or received in any direction with any polarization and correlation of the received signal is low; therefore the channel capacity is increased. Good frequency diversity by way of OFDM of MIMO is also an influential and effective method of increasing data transmission and BER performance of MIMO WiMAX technology. This thesis purposed to study and improve diversity performance, including antenna diversity and frequency diversity, in MIMO WiMAX technology.

1.2 Problem Statement

Wireless communication systems have traditionally used a single antenna for transmission and a single antenna for reception. These systems are known as single input single output or SISO systems. In recent years however, important progress has been made in the area of development systems that use multiple antennas at the transmitter and receiver to achieve better performance. In 1948, Shannon worked on the primary capacity limit of this system (CE Shannon, 2001), demonstrating that the maximum capacity *C* of the SISO system is dependent on channel bandwidth (*BW*) and signal-to-noise ratio (*SNR*) over this bandwidth. Notice from the Eq (1.1) that the channel capacity can only be increased by an increase in bandwidth or signal power. On one hand, it is very expensive to occupy additional spectrum, and on the other hand, the signal power cannot be readily increased as the communication system is interference-limited.

$$C = BW log_2(1 + SNR) \quad \frac{bits}{s} \tag{1.1}$$

MIMO works on the principle of multiple antennas at the transmitter and receiver to send and receive signals, and certain algorithms are used to send out the data in different paths, which are then reassembled after arriving at the receiving antenna. For a while, most of the studies on MIMO technology focused on signal processing algorithms and channel characteristics. But recently, the antenna's effect on MIMO system has been investigated by assuming the antennas are ideal half wavelength dipoles which radiate omni-directionally in the azimuth plane (M. Gans et al., 2002, D. Chizhik et al., 2002, P. Kyritsi et al., 2000, P.Kyritsi, 2001). However, when two or more dipoles/monopoles are placed closely to each other on a mobile handset, the radiation pattern of each dipole/monopole is no longer omni-directional, because of the coupling between them. Furthermore, it is very impractical and unrealistic to implement a number of dipoles/monopoles on a mobile handset, so in order to predict the true spectral efficiencies of MIMO systems in a real environment whereby realistic mobile handset are used, there is a need to design an appropriate and realistic antenna array on a mobile handset for MIMO systems.

The main problem related to the design of MIMO antennas in MIMO WiMAX mobile handsets is size; generally the antenna must be as small as possible, but still able to meet the performance requirements. Increasingly, the ability to adapt the antenna shape to fit into consumer-acceptable casing is also important. Another problem involves the mutual coupling effects and diversity performance for multiple antennas on a mobile handset, which are essential considerations. The main challenge in designing two or more antennas on a mobile handset is that, in order to provide the highest antenna diversity gain, there must be a low correlation between the signals received in the branches of the diversity system. The power levels of the signals supplied by the antennas in the diversity system should not vary significantly from each other, and thus it is difficult to achieve a high isolation between the antennas with the existing handset design.

This thesis presents a modified PIFA antenna structure at 3.5 GHz in MIMO Mobile WiMAX application, less connection losses and studies the performance analysis of the multiple-input-multiple-output antenna diversity array for MIMO mobile handsets in WiMAX applications. Mobile WiMAX is a next-generation wireless communication technology that allows higher data throughput and better mobility compared to a wireless local area network (WLAN). To examine the effect of changing antenna arrangements on antenna performance, modified PIFA antenna structures were employed. MIMO ideas have been under development for many years for both wireless and wire-line systems. The MIMO scheme can increase not only the channel capacity, but as well the reliability (Quality of Service) of the wireless system by exploiting the various typical coding scheme techniques, e.g. space time coding, spatial multiplexing or the combination of both schemes.

The use of multiple antennas permits independent channels to be created in space, and is one of the most interesting and promising areas of recent innovation in wireless communications. The MIMO WiMAX OSTBC-OFDM systems are able to attain frequency diversity through the use of orthogonal frequency division multiplexing (OFDM) and are able to attain time diversity using an outer Reed-Solomon code concatenated with an inner convolutional code. In addition, spatial diversity can be created without using the additional bandwidth that time and frequency diversity both require (J.G.Andrews et al., 2007). In addition to providing spatial diversity, antenna arrays can be used to focus orthogonal space time coding, as in the OSTBC-OFDM technique, when multiple antennas are used at both the transmitter and the receiver. Transmit diversity is the most popular processing scheme, known as space-time coding, in which a code known at the receiver is applied at the transmitter. Of the many space-time codes advised, space-time block code (STBC) methods are supported in WiMAX systems and easily implemented (Space-time trellis codes can provide better performance, but have a considerably higher complexity) (J.G.Andrews et al., 2007). In specific, the Alamouti code is an orthogonal STBC that is both easily implemented and provides optimal diversity order; however, it is limited to certain combinations of antenna numbers. Dissimilar MRC, STBC schemes provide diversity gain but not array gain.

The OFDM used in WiMAX technology today is based on FFT (WiMAX Forum, 2009) . In wireless communication reception, the credibility of orthogonal frequency division multiplexing (based OFDM FFT) is limited because of the time-varying nature of the channel, OFDM- FFT only gives frequency resolution but no time resolution as results does not gives good information if the frequency components of the signal varies with time, and this causes inter-symbol interference (ISI) and inter-carrier interference (ICI) and increases inaccuracies in channel tracking. These difficulties can effectively be avoided at the cost of power loss and bandwidth distention by inserting a cyclic prefix guard interval (CP) before each block of parallel data symbols. This guard interval decreases the spectral efficiency, signal to noise ratio (SNR) and the number of symbol per second that are transmitted per Hz of bandwidth of the WiMAX OFDM as the corresponding amount also the transmitted energy will increase proportional with the length of cyclic prefix. To solve this problem and to eliminate the need for using cyclic prefix guard interval (CP), a new OFDM structure is utilized in WiMAX technology, namely wavelet OFDM and multiwavelet OFDM. Wavelet and multiwavelet transform gives both the frequency and time resolution. Wavelet OFDM has excellent orthogonality between subcarriers and wonderful spectral containment, hence wavelet OFDM is better for combatting narrowband interference and is more robust with respect to ISI and ICI than Fourier OFDM. Other advantages are possible, such as transform flexibility, lower sensitivity to channel distortion and interference, and improve utilization of spectrum. Multiwavelets also have several advantages compared to single wavelets: a single wavelet cannot possess all the properties of orthogonality, symmetry, compact support, and vanishing moments at the same time, but a multiwavelet can.

In this thesis, a new technique is presented for improving frequency diversity in MIMO WiMAX (IEEE802.16d), by way of OSTBC-OFDM based wavelet and multiwavelet OFDM. This new approach can be used as an alternative to the conventional MIMO WiMAX OSTBC-OFDM. The proposed design has another promising advantage, in that it can support a low-resolution transmission from the original stream, and has the ability to adapt the quality to the required bit rate. These benefits are also desirable for internet transmission.

1.3 Thesis Objectives:

Severe channel conditions have placed a major obstruction upon designing efficient transmission systems over wireless environments in MIMO WiMAX technology. The important objectives for improving diversity performance in MIMO WiMAX technology are as follows:

1- To improve antenna diversity through modified PIFA antennas, at 3.5 GHz, with the aim to achieve a good diversity gain , low correlation and mean power levels between the antenna elements with developed two and four element antennas diversity for MIMO WiMAX mobile handset.

2- To improve frequency diversity by way of a new design of IEEE802.16d wavelet and multiwavelet transform based OSTBC-OFDM , which can be used as an alternative to the conventional IEEE802.16d OSTBC-OFDM that use FFT; these new WiMAX structures can give lower bit error rates, increase signal-to-noise power ratio (SNR), and support higher spectrum efficiency.

1.4 Thesis Contributions

The thesis is original and innovative in the following aspects:

- For a while, most of the studies on MIMO technology have focused on signal processing algorithms and channel characteristics. The focus of this thesis is on diversity and MIMO techniques for WiMAX technology. One main advantage of spatial diversity relative to time diversity is that no additional bandwidth or power is needed to take advantage of spatial diversity. Another focus was to improve the communication reliability by decreasing the sensitivity to fading. When multiple antennas are present at the receiver, two forms of gain are available, diversity gain and array gain. Diversity gain results from the creation of multiple independent channels between the transmitter and the receiver and is a product of the statistical affluence of those channels. Array gain, on the other hand, does not rely on statistical diversity between the channels and instead attains its performance improvement by coherently combining the energy received by each of the antennas. The first part of the diversity techniques in this thesis is on antenna diversity, which in practice has been implemented at base stations for current mobile communications to mitigate the fading effects of a multipath environment. It has also been implemented at mobile handsets. Therefore, the design of an antenna diversity array for a mobile handset is carried out in this thesis, for the purpose of improving the antenna diversity of MIMO WiMAX mobile handsets. In order to achieve a good diversity performance, the antennas have to meet two criteria: low correlation, and mean power levels between the antennas. It is a very challenging task to satisfy both criteria given the small dimensions of a mobile handset. In this thesis, an antenna diversity array was designed consisting of two and four modified PIFA antenna elements on a MIMO WiMAX Mobile handset. Thus the use of a modified PIFA antenna at 3.5 GHZ, having good diversity gain, low correlation and mean power levels between the antenna elements, was proposed and investigated.

- A new technique to improve the frequency diversity in IEEE802.16d OSTBC-OFDM structure based wavelet and multiwavelet was proposed and tested. These tests were carried out to verify successful operation and the possibility of implementation. The performance comparisons of bit error probability with the conventional IEEE802.16d OSTBC-OFDM based FFT structures, applied to SFF SDR (a Multi-Core Software-Defined Radio Platform), was presented. Simulation results were provided to demonstrate that significant gains could be achieved with system users increasing, by combining the DWT and DMWT in OSTBC-OFDM techniques (SISO, MISO and MIMO). As a result, these new structures achieve much lower bit error rates, assuming a reasonable choice of the basis function and method of computation. The results obtained show that S/N measures can be successfully increased using the proposed multiwavelet designed method within a desired multiwavelet basis function. Thus multiwavelet and wavelet-based OFDM outperforms the conventional design. Thus, significant contribution is made to IEEE802.16d OSTBC-OFDM as a wavelet and multiwavelet structures.

1.5 Research Scope and Limitations

WiMAX is the next-generation of wireless technology designed to allow pervasive, high-speed mobile internet access to the widest array of devices. Like the fourth generation (4G) of wireless technology, WiMAX promises low-cost, open networks and is the first all IP mobile internet solution enabling powerful and scalable networks for data, video, and voice. Because diversity performance is a major driver in the support and development of MIMO WiMAX technology, this thesis proposed two ways of improving diversity performance: antenna diversity and frequency diversity in mobile and fixed MIMO WiMAX technology. Improved antenna diversity was achieved by a modified PIFA antenna with good diversity gain, low correlation and mean power levels between the antenna elements running in a MIMO WiMAX mobile handset; and improved frequency diversity was achieved by the proposed DWT-OFDM and DMWT OFDM in MIMO WiMAX IEEE802.16d OSTBC-OFDM, solving the problems caused by using FFT-OFDM, due to the time-varying nature of the channel and the limitation of using CP. Research limitations are as follows; simulated models have been used to calculate the diversity gain of the MIMO WiMAX Mobile handset due to a deficiency of facilities in conducting 3-D radiation pattern measurements in an anechoic chamber. And unavailability of MIMO facility with Lyrtech Multi-Core SSF SDR platform in the laboratory of which only provide SISO platform. In addition, the RF implementation of the SFF SDR Development Platform is basically designed for indoor environment; hence the proposed implementation confined to SFF SDR Development Platform DSP Board. DSP Board can simulate the environment channels and thus prove that the models proposed for the DWT-OFDM and DMWT-OFDM works well in all environmental conditions for WiMAX IEEE802.16d OSTBC-OFDM technology. These models are proposed so that the specialized companies and researchers can benefit and apply this work within the WiMAX IEEE802.16d OSTBC-OFDM standard service.

1.4 Thesis Outline

This thesis is focused on the improvement of diversity performance in MIMO WiMAX technology. Following the introduction Chapter 1, Chapter 2 gives a survey of WiMAX technology development and also a review and background of diversity and MIMO techniques, and explains wavelet and multiwavelet transforms on an OFDM system. Chapter 3 explains the modified design of the PIFA (Planar Inverted-F Antenna) and its array. Then Chapter 4 briefly describes the new designs proposed for MIMO WiMAX IEEE 802.16d OSTBC- OFDM based on wavelet and multiwavelet transforms. Results for the proposed models are discussed in Chapter 5, including topics such as return loss, isolation, and radiation pattern of the two and four -element diversity PIFAs, and analyses using simulation data to evaluate the diversity performance of a two and four-element PIFA array. The performance of the proposed systems of MIMO WiMAX IEEE802.16d OSTBC-OFDM based on wavelet and multiwavelet is demonstrated, by way of analyses and comparisons with the conventional OFDM based FFT. Finally, Chapter 6 presents the conclusions, and some thoughts for future work. Figure 1.1 explains of the interrelation and flow of the chapters.

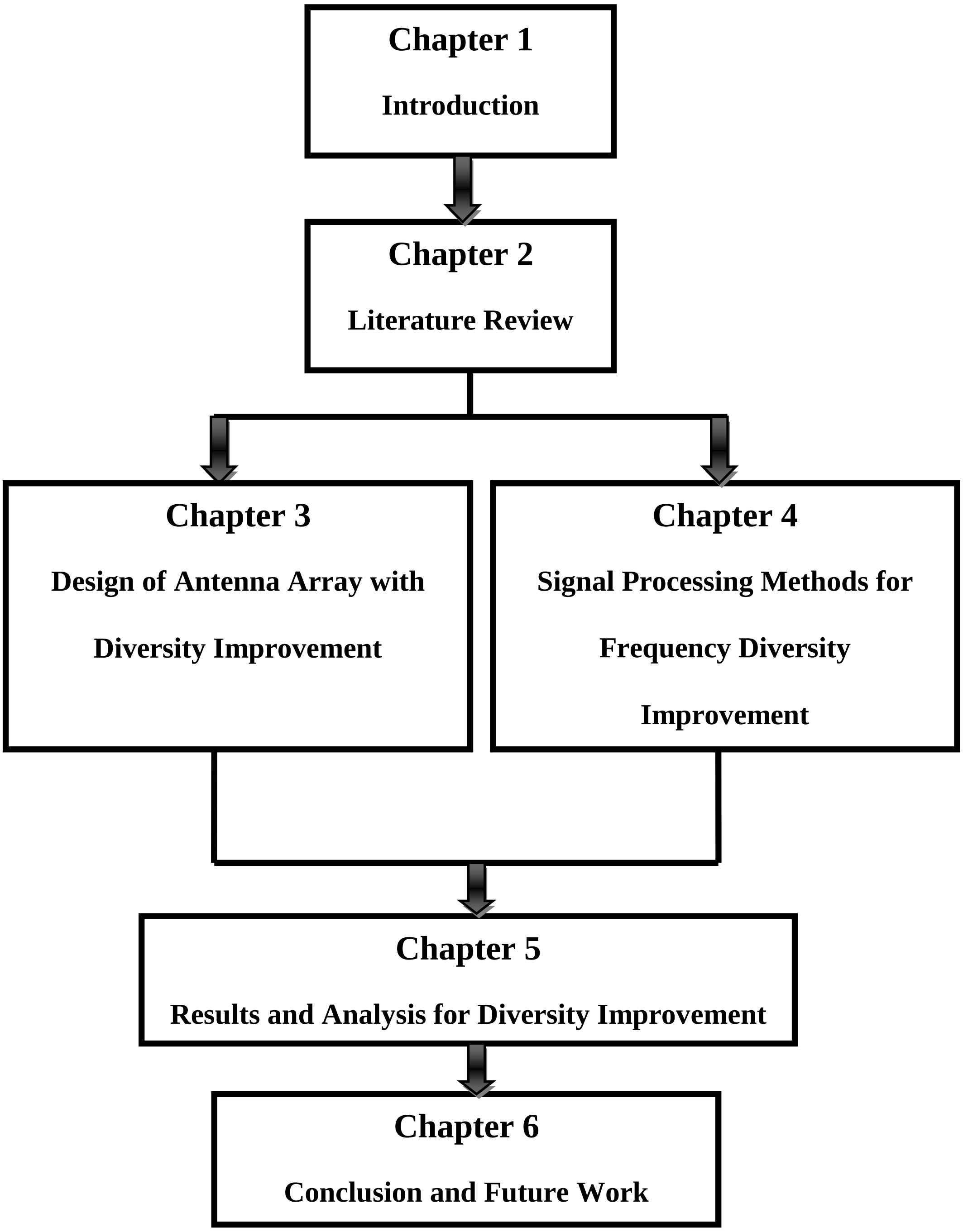

Figure1.1 Illustration of the flow of the chapters

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an extensive review of previous works related to diversity and MIMO techniques. A survey of WiMAX technology development is introduced in section 2.2, and a review and background of diversity and MIMO techniques is presented in section 2.3. Wavelet and multiwavelet based OFDM systems are discussed in section 2.4; meanwhile, in section 2.5, the related work in this thesis is explained and compared; then, section 2.6 summaries the chapter.

2.2 WiMAX Technology Developments

At the end of the last century, many telecommunication equipment manufacturers were starting to progress and offer products for Broadband Wireless Access (BWA). The IEEE Working Group 802.16 is responsible for the development of the 802.16 standard including the air interface for BWA. The effectiveness of this working group were initiated in a meeting in August 1998 (Roger B. Marks, 2003), named by the National Wireless Electronics Systems Test bed (N-WEST) which is a part of U.S. National Institute of Standards and Technology. Primarily the group focused on the development of standards and air interface for the 10-66 GHz band. Later, an improvement project led to the approval of the IEEE 802.16a standard meant for the 2-11 GHz band. The last approval of the 802.16a Air Interface specification came in January 2003 (Roger B. Marks, 2003), an IEEE 802.16 standard which included the specification of Physical (PHY) and Medium Access Control (MAC) layer for BWA. The first appearance of the standard IEEE802.16 2001 (IEEE Std 802.16, 2001) was when it was adopted in December 2001, and it has since undergone many improvements to assimilate new characteristics and functionalities. The current version of the standard IEEE 802.16 2004 (IEEE 802.16, 2004), accepted on September 2004, joins together all the previous versions of the standards. This standard specifies the air interface for fixed BWA systems supporting multimedia services in the licensee and licensed exceptive spectrum (IEEE 802.16, 2004). The Working Group accepted the correction IEEE 802.16e 2005 (IEEE Std 802.16e and 802.16d, 2006) to IEEE802.16 2004 in February 2006. The development of the standard to its current stage is presented here.

2.2.1 IEEE 802.16 2001

This first activity of the standard specifies a set of MAC and PHY layer standards intended to furnish fixed broadband wireless access in a point to point (PTP) or point to multipoint (PMP) topology (IEEE Std 802.16, 2001). The PHY layer uses single carrier modulation in the 10–66GHz frequency range. Transmission times, durations and modulations are allotted by a Base Station (BS) and shared with all nodes in the network in the form of broadcast Uplink and Downlink maps. Subscribers need only to hear the base station to which they are connected and do not need to listen to any other node of the network. Subscriber Stations (SS) have the ability to dicker for bandwidth allocation on a burst to burst basis, providing scheduling flexibility. The standard applies QPSK, 16QAM and 64QAM as modulation schemes. These can be varied from frame to frame and from SS to SS, depending on the robustness of the connection. The standard supports both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) as Duplexing techniques. A significant characteristic of the 802.16 2001 is its capacity to provide differential Quality of Service (QoS) in the MAC Layer, since a Service Flow ID does a QoS check. Service flows are characterized by their QoS parameters, which be able to then be used to specify parameters as maximum latency and admitted fidget (D.Boom, 2004). Service flows can be originated either from BS or SS. The 802.16 2001 standard works only in (Near) Line of Sight (LOS) conditions with outdoor Customer Premises Equipment (CPE).

2.2. 2 IEEE 8020.16a 2003

This version of the standard improves upon IEEE 802.16 2001 by enhancing the medium access control layer to support multiple physical layer specifications and providing additional physical layer specifications. This advancement was acknowledged by the IEEE 802.16 working group in January 2003 (IEEE Std 802.16a, 2003), and added physical layer support for 2-11GHz. Both licensed and license-exceptive bands are included. Non Line of Sight (NLOS) operation becomes easy caused by the inclusion of below 11GHz range, extending the geographical reach of the network. Caused by NLOS operation, however, multipath propagation becomes an issue, and to deal with multipath propagation and interference, alleviation characteristics as advanced power management technique and adaptive antenna arrays were included in the specification (IEEE Std 802.16a, 2003). The choice of applying Orthogonal Frequency Division Multiplexing (OFDM) was included as an alternative to single carrier modulation. In addition, security was modified in this version; many of the privacy layer characteristics became mandatory while in 802.16 2001 they were optional. IEEE 802.16a too adds optional support for mesh topology as well as to PMP.

2.2.3 IEEE 802.16c 2002

In December 2002, the IEEE Standards Board accepted improvement IEEE 802.16c (Roger B. Marks, 2003), in which elaborate system profiles for 10-66GHz were added and several errors and inconsistencies of the first version of the standard were corrected.

2.2.4 IEEE 802.16 2004

The 802.162001, 802.16a 2003 and 802.16c 2002 standards were all combined together and a new standard was made which is famous as 802.16 2004. In the first, it was published as improvement of the standard under the name 802.16 REVd, but the changes were so significant that the standard was re-formed under the name 802.16 2004 in September 2004. In this version, the whole group of previous standards was accepted and approved (IEEE 802.16, 2004).

2.2.5 IEEE 802.16e 2005

This improvement was accumulated in the current applicable version of standard IEEE 802.16 2004 in December 2005, and contains PHY and MAC layer advances to adapt combined fixed and mobile operations in licensed band (IEEE Std 802.16e and 802.16d, 2006). In 2009 in the WiMAX Forum, the continuous use of IEEE802.16 was approved, as shown in Table 2.1 (WiMAX Forum, 2009).

Table 2.1 Comparison of IEEE 802.16 standard for Broadband Wireless Access (BWA) (WiMAX Forum, 2009)

	802.16a	802.16d-2004	802.16e-2005
Status	Completed December 2001	Completed June 2004	Completed December 2005
Application	Fixed LOS	Fixed N LOS	Fixed and mobile N LOS
Frequency band	10GHz-66GHz	2GHz-11GHz	2GHz-11GHz for fixed; 2GHz-6GHz for mobile
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM,	QPSK, 16QAM, 64QAM,
Gross data rate	32Mbps-134.4Mbps	1Mbps-75Mbps	1Mbps-75Mbps
Multiplexing	Burst TDM/TDMA	Burst TDM/TDMA/OFDMA	Burst TDM/TDMA/OFDMA
MAC architecture	Point-to-multipoint, mesh	Point-to-multipoint, mesh	Point-to-multipoint, mesh
Transmission scheme	Single carrier only	Single carrier only,256 OFDM or 2048 OFDM	Single carrier only,256 OFDM or 2048 OFDM or Scalable OFDM with 128,512,1024,2048 sub-carriers
Duplexing	TDD and FDD	TDD and FDD	TDD and FDD
Channel bandwidths	20MHz,25MHz,28MHz	1.75MHz,3.5MHz,7MHz 14MHz,1.25MHz,5MHz 10MHz,15MHz,8.75MHz	1.75MHz,3.5MHz,7MHz 14MHz,1.25MHz,5MHz 10MHz,15MHz,8.75MHz
Air-interface designation	Wireless MAN-SC	Wireless MAN-SCa Wireless MAN-OFDM Introduction to WIMAX Wireless MAN-OFDMA Wireless HUMAN	Wireless MAN-SCa Wireless MAN-OFDM Wireless MAN-OFDMA Wireless HUMAN
WiMAX Implementation	None	256-OFDM as Fixed WiMAX	Scalable OFDMA as Mobile WiMAX

2.3 A Review and Background of Diversity and MIMO Techniques

Design of wireless communications system is a major challenge because of the complex, time-varying propagation medium. Due to non-existing line-of-sight transmission, scattering and reflection of radiated energy from objects (trees, hills, buildings, etc), in addition to mobility effects, a signal transmitted in a wireless environment arrives at the receiver via different paths, called multi-paths, which have different delays, angles of arrival, amplitudes and phases. As a result, the received signal varies like a function of frequency, time and space. These signal variations are called the fading effect, and are the reason for signal quality degradation.

Techniques for transmitting signals by different media, to combat fading effects in wireless communications, are known as diversity techniques. Between different types of diversity techniques, spatial diversity using multiple transmit and receive antennas provides a very good performance without increasing bandwidth, delay or transmission power. Information theory results in prior work (G. Foschini and Gans, 1998, I . E. Telatar, 1999) showed that there is an enormous benefit of using such spatial diversity. At the beginning, the receive diversity technique that uses multiple antennas at the receiver was the primary focus for space diversity systems due to the fact that diversity gain can be accomplished by using simple but efficient combination techniques. Also, transmit diversity has been widely studied as a method for combating fading effects and increasing transmission data rate (S.Alamouti, 1998, G. Raleigh and Cioffi, 1998, GJ Foschini and MJGans, 1998, V. Tarokh et al., 1998, J. Guey et al., 1999, V.Tarokh et al., 1999a, V.Tarokh et al., 1999b, VTarokh et al., 1999). A multilayered space-time structural design that uses spatial multiplexing to increase the data rate but not necessarily provides transmit diversity was introduced by Foschini (G Foschini, 1996); the criterion for accomplishing maximum transmit diversity has been derived (J. Guey et al., 1999); and a complete study for maximum diversity goals and coding gains, in addition to the design of space-time trellis codes has been proposed (V. Tarokh et al., 1998). The simple diversity transmission design (S.Alamouti, 1998) and the introduction of space-time orthogonal block coding (V.Tarokh et al., 1999a) opened an attractive research domain in Multi-Input Multi-Output (MIMO) techniques. The combination of transmit and receive diversity techniques, familiar as MIMO technique, not only achieves reliability in wireless communications by way of diversity gain (which is equal to the product of transmit and receive antennas number), but also efficiently increases the channel capacity and the transmission data rate. In this section, the principles and the different types of diversity techniques are presented first, then diversity gain and performance of combination techniques are investigated, followed by the two principal MIMO techniques: Spatial Multiplexing (SM) and Space Time Code (STC). And lastly, the capacity of MIMO channel is discussed.

2.3.1 Diversity Techniques

Diversity is an effective communication receiver technique that provides wireless link enhancement at a relatively low cost. Diversity techniques are used in wireless communications systems mainly to increase performance over a fading radio channel. The theory of diversity techniques is that copies of a transmitted signal are sent via different mediums, such as different time slots, different frequencies, different polarizations, or by way of different antennas, for combating the fading effect. If these copies have independent fades, the possibility that all transmitted signals are at the same time in deep fades is minimized. Consequently, using proper combining techniques, the receiver can reliably decode the transmitted signal and the probability of error will be lower. By sending two or further signal copies in independent fading channels, the transmit diversity can be exploited. The diversity gain G_d is definite as

$$G_d = \lim_{\gamma \to \infty} \frac{log(P_e)}{log(\gamma)} \tag{2.1}$$

where P_e is the error probability of the received signal and is γ the received signal to noise ratio (SNR). Different techniques have been introduced into the physical layer (PHY) for NLOS operation of the WiMAX technology in 2-11GHz, to mitigate the effects of fading and ISI. The next sections give an overview of a number of those techniques. The main types of diversity used by the WiMAX PHY are time diversity, frequency diversity, and antenna diversity (J.G.Andrews et al., 2007), which are discussed below.

2.3.1.1 Time Diversity

Time diversity involves a process by which the same data is transmitted multiple times, or an additional error code is added; by the methods of bit-interleaving, the error bursts are spread in time. The WiMAX system exploit time diversity by incorporating an outer Reed-Solomon code concatenated with an inner convolutional code into its physical layer. Turbo coding has been left as an optional characteristic, which can better the coverage and or capacity of the system, at the price of increased decoding latency and complication. Thus, time diversity is not bandwidth-efficient, because of this underlying redundancy.

In the present work, only an outer Reed-Solomon code concatenated with an inner convolutional code is used. More details of the Reed-Solomon code and the convolutional code used are included in Appendix B.

2.3.1.2 Frequency Diversity

Frequency diversity uses different carrier frequencies to accomplish the diversity transmission (P. Balaban and Salz, 1991). In this technique, copies of the transmitted signal are sent via different carrier frequencies. These carrier frequencies must be spaced by more than the coherence bandwidth of the channel to ensure independent fades. Similar to time diversity, frequency diversity is not bandwidth efficient and the receiver must tune to different carrier frequencies for signal reception. Spread spectrum modulation and orthogonal frequency division multiplexing (OFDM) are considered frequency diversity techniques (T.S Rappaport, 2002, J.G.Andrews et al., 2007). Along with detailing a PHY with a single-carrier modulated air interface