PERFORMANCE OF MIMO SPACE-TIME CODED SYSTEM AND TRAINING BASED CHANNEL ESTIMATION FOR MIMO-OFDM SYSTEM

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To my beloved mother and father

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ABSTRACT

Multiple-input-multiple-output (MIMO) antenna architecture has the ability to increase capacity and reliability of a wireless communication system. Orthogonal frequency division multiplexing (OFDM) is another popular technique in wireless communication which is famous for the efficient high speed transmission and robustness to frequency selective channels. Therefore, the integration of the two technologies probably has the potential to meet the ever growing demands of future communication systems. Because of aforementioned merits of these two techniques, this thesis was about MIMO and MIMO-OFDM system, and it addressed two different issues. Firstly it has investigated the performance of MIMO-STBC system and surveyed the effect of imperfect channel estimation on performance of MIMO-OFDM system. Secondly, it has focused on training based channel estimation algorithm for MIMO-OFDM system. In the first part, BER of space-time block coded system (STBC) was calculated for different antenna configuration using simulation software. The results proved that the reliability of the wireless link increases as the number of transmits and received antenna increase. At the next stage of the project, the effect of channel estimation algorithm on performance of MIMO-OFDM system was investigated. The simulation results shown that imperfect channel estimation degrade the performance of the system significantly. At the final part of the research, channel estimation in MIMO-OFDM system has been discussed. The mathematical model of the system in frequency selective fading channel has been developed. Then the comparison analysis in terms of performance efficiency and computational complexity has been made for two different channel estimations algorithm namely LS (Least Square) and QR decomposition. It should be mentioned that reduction of computational complexity of the channel estimation and data detection algorithm is a major challenge for receiver design in MIMO-OFDM system, and complication of receiver design is mostly due to these algorithms. Therefore in this part QR decomposition algorithm has been investigated as a solution. For doing so, the performance analysis between QR decomposition and LS algorithm in terms of MSE (Mean Square Error) and BER (Bit Error Rate) has been done using simulations software. A complexity comparison between two algorithms has been made in terms of number of mathematical operation. The results have shown that the performance efficiency of these two algorithms are exactly the same as it expected while the computational complexity of the QRD is much less than LS algorithm. Finally it can be concluded that the application of QR decomposition can greatly reduces the complexity of channel estimation in MIMO-OFDM system.

ABSTRAK

Senibina antena berbilang masukan berbilang keluaran (MIMO) mempunyai keupayaan untuk meningkatkan kapasiti dan keboleharapan sistem perhubungan wayerles. Pemultipleksan pembahagi frekuensi ortogon (OFDM) terkenal dengan kecekapan penghantaran berkelajuan tinggi dan ketahanan terhadap saluran frekuensi memilih. Dengan ini, penggabungan dua teknologi ini berpotensi untuk mencapai apa jua pertumbuhan permintaan sistem komunikasi di masa akan datang. Berdasarkan merit kedua-dua teknik di atas, tesis ini adalah berkenaan sistem MIMO dan MIMO-OFDM. Ianya membincangkan dua isu yang berlainan, yang pertama ialah kajian terhadap prestasi sistem MIMO-STBC dan kesan ketidaksempurnaan penganggaran saluran terhadap prestasi system MIMO-OFDM. Kedua, ia tertumpu kepada algoritma penganggaran saluran untuk sistem MIMO-OFDM yang berasaskan latihan. Dalam bahagian pertama, BER sistem kod blok ruang masa (STBC) telah dikira menggunakan perisian simulasi untuk konfigurasi antena yang berbeza. Keputusan membuktikan bahawa keboleharapan rangkaian wayerles meningkat apabila bilangan antena penerima dan penghantar meningkat. Pada tahap seterusnya dalam projek ini, kepentingan algoritma penganggaran saluran terhadap prestasi sistem MIMO-OFDM telah dikaji. Keputusan simulasi menunjukkan bahawa ketidaksempurnaan penganggaran saluran mengurangkan prestasi sistem pada tahap yang nyata. Pada bahagian akhir kajian, penganggaran saluran bagi sistem MIMO-OFDM dibincangkan. Model matematik bagi system di dalam saluran memilih frekuensi telah dibangunkan. Seterusnya, analisa perbandingan dari segi kecekapan prestasi dan kesulitan pengiraan telah dilakukan untuk dua algoritma penganggaran saluran yang berlainan yang dikenali sebagai LS (Kuasa dua terkecil) dan penguraian QR. Ianya perlu dinyatakan bahawa pengurangan kesulitan pengiraan terhadap penganggaran saluran dan algoritma pengesanan data ialah cabaran utama di dalam merekabentuk sistem MIMO-OFDM. Kesulitan merekabentuk penerima adalah sebahagian besarnya berpunca daripada algoritma ini. Oleh itu dalam bahagian ini, algoritma penguraian QR dikaji sebagai kaedah penyelesaian. Untuk tujuan itu, analisa prestasi di antara penguraian QR dan algoritma LS dari segi MSE (ralat min kuasa dua) dan BER (kadar ralat bit) telah dilakukan menggunakan perisian simulasi. Perbandingan kesulitan di antara dua algoritma telah dilakukan dari sudut operasi matematik. Keputusan menunjukkan bahawa kecekapan prestasi kedua-dua algoritma ini adalah sama seperti yang dijangkakan manakala kesulitan pengiraan bagi QRD adalah kurang berbanding algoritma LS. Akhirnya, ianya dapat disimpulkan bahawa penggunaan penguraian QR boleh mengurangkan dengan banyaknya kesulitan penganggaran saluran dalam sistem MIMO-OFDM.

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LIST OF ABBREVIATIONS

Symbol	Definition
AWGN	additive white Gaussian noise
BER	bit error rate
BLAST	Bell Laboratories layered space-time
CFR	channel frequency response
CIR	channel impulse response
CP	cyclic prefix
CSI	channel state information
EM	expectation maximization
EVD	eigenvalue decomposition
FFT	fast Fourier transform
FLOP	floating point operation
H-QRD	Householder QR decomposition
ICI	Inter channel interference
IFFT	inverse fast Fourier transform
ISI	intersymbol interference
LMS	least mean square
LS	least square
MIMO	multiple input multiple output
ML	maximum likelihood
MMSE	minimum mean square error
MSE	mean square error
OFDM	orthogonal frequency division multiplexing
PDF	probability density function
QAM	quadrature amplitude modulation
QRD	QR decomposition
RLS	recursive least squares
rms	root-mean square
SNR	output signal to noise ratio
SVD	singular value decomposition
STBC	Space-time block coding
V-BLAST	vertical Bell Laboratory layered space time
WLAN	wireless local area networks

CHAPTER 1

INTRODUCTION

I. Introduction

Physical limitations of the wireless medium create a technical challenge for reliable wireless communication. Techniques that improve spectral efficiency and overcome various channel impairments such as signal fading and interference have made an enormous contribution to the growth of wireless communications. Moreover, the need for high-speed wireless Internet has led to the demand for technologies delivering higher capacities and link reliability than achieved by current systems. Multiple -input multiple-output (MIMO) based communication systems are capable accomplishing these objectives.

Multiple input multiple output (MIMO) systems take advantage of spatial diversity obtained through the spatially separated antennas in a dense multipath scattering environment [1]. Spatial diversity can increase the gain diversity consequently increase the reliability of the wireless link. Theoretical studies

indicate that the capacity of MIMO systems grows linearly with the number of transmit antennas used. Many recent works have focused on exploiting the added spatial dimension to increase capacity [2]-[5]. In particular, the revolutionary vertical Bell Laboratory Layered Space Time (V-BLAST) architecture proposed by Foschini achieved the theoretical capacity limits of the MIMO architecture [6].

The multiple antennas configuration exploits the multipath effect to accomplish the additional spatial diversity. However, the multipath effect also causes the negative effect of frequency selectivity of the channel. Orthogonal frequency division multiplexing (OFDM) is a promising multi-carrier modulation scheme that shows high spectral efficiency and robustness to frequency selective channels. In OFDM, a frequency-selective channel is divided into a number of parallel frequency-flat sub channels, thereby reducing the receiver signal processing of the system. The combination of OFDM and MIMO is a promising technique to achieve high bandwidth efficiencies and system performance. In fact, MIMO-OFDM is being considered for the upcoming IEEE 802.11n standard, a developing standard for high data rate WLANs [1].

1.2 Motivation

MIMO-OFDM has the potential to meet the increasing high speed and reliability demands of the future. However, this technology to truly succeed in commercial deployment there are still several technical obstacles that must be tackled. A major impediment in MIMO-OFDM is the complicated receiver signal processing. The simultaneous emission of the signals from the multiple transmit antennas increases the mutual interference imposed on the signals, therefore, much

more complex detection schemes are required to extract the transmitted signals. For example, the complexity of a maximum likelihood detector increases exponentially with the number of transmit antennas. Spatial equalizers and space-time coding has been proposed to simplify the detection for MIMO-OFDM systems [7]-[8]. Note, coherent detection requires knowledge of the channel; therefore, accurate channel estimation is crucial in realizing the full potential of MIMO-OFDM. Channel estimation for OFDM has been well researched in literature. The extension of the results to MIMO-OFDM channel estimation is substantially more complicated. In a MIMO system, multiple channels have to be estimated simultaneously. The increased number of channel unknowns significantly increases the computational complexity of the channel estimation algorithm. Previous works have investigated the problem of channel estimation in MIMO-OFDM [15]-[18]. The most common approach is training-based estimation, where a known pilot sequence is transmitted and used at the receiver to determine the channel. The least square (LS) approach is the common method for training-based estimation. The LS solution is relative simple compared to other estimation techniques such as blind estimation. However, this solutions still require complex matrix inversions, which are undesirable in real time implementation. In [9], specific training sequences design and pilot placement patterns are used to obtain the channel frequency response (CFR) of the channel in attempt to reduce the estimation complexity. Note that the number of unknowns of the CFR is usually significantly greater than the number of unknowns in the channel impulse response (CIR). In [10], it is proven that computational complexity can be reduced by estimating the CIR as opposed to the CFR. The proposed solution reduces the number of unknowns to be solved, but the solution still requires a matrix inversion. The main objective of this research after performance analysis of MIMO-STBC is investigating QR decomposition algorithm for reducing the complexity of the channel estimation for MIMO-OFDM. As the results have shown, QR decomposition can be good solution for finding the channel unknowns, which eliminates the matrix inversion operation.

The QR decomposition is low in complexity, stable and can be efficiently implemented in hardware.

1.3 Objectives

The project had three objectives. The first one was performance analysis of space-time orthogonal block coded MIMO system. For doing so, OSTBC (Orthogonal Space Time Coded) Transmission was considered in the system. The block code was 2 by 2 complex Alamouti code. The number of transmit and receive antenna was assumed two and M respectively. Second objective of the project was to assess the performance of MIMO system and MIMO-OFDM with imperfect channel estimation. In this part comparison analysis in the system with and without perfect channel knowledge has been made. Third and main objective of the project was comparison analysis between LS and QR-LS channel estimation for MIMO-OFDM system in terms of computational complexity and performance efficiency. The first two objectives were supporting this part technically. For the last objective, structure of the system was assumed MIMO-OFDM with STBC transmission. OFDM system make the MIMO structure robust in frequency selective channel, and also it make the data equalization and channel estimation algorithms simpler.

1.4 Scope of works

The project was based on theoretical results and software modeling. MIMO system had STBC structure with 2 × M Antenna constellation. Channel was assumed Rayleigh flat fading with additive white Gaussian noise with zero mean and variance one. Simulation has been done at baseband. The performance of the system investigated using the BER parameter.

Second phase of the project simulation has been done for two different systems with two different conditions. The first one was MIMO system with flat fading channel condition. This part had the same structure similar to the first phase of the project. Second part of phase two, the system was assumed MIMO-OFDM system. For this part antenna constellation was 2 by 2, Channel was frequency selective with additive white Gaussian noise. Also Channel was assumed quasi-static within two transmission block. Number of sub-carrier and CP (cyclic prefix) has been assumed to 64 and 16 respectively.

In the third phase of the project MIMO-OFDM structure had similar structure to phase two. However LS and QRD channel estimation have been applied to the system separately. It should be mention that the software used for the project is MATLAB. This choice has been made because of provided facilities in MATLAB for engineering programming.

1.5 Thesis outline

In Chapter 2, background information and basic principle in MIMO-STBC is given. Alamouti schemes as a base stone of this theory is clearly interpreted. The simple mathematical formula in matrix form for general structure of Alamouti scheme with antenna configuration of 2×N is developed. Then space-time trellis coding as a perfect space-time coding schemes for high data rate wireless communication is briefly introduced. At the end of the chapter brief introduction about spatial multiplexing or MIMO-BLAST as a mean to increase spectral efficiency or in the other words increasing the data rate of wireless system is given.

In Chapter 3, OFDM system is fundamentally discussed. Firstly an introduction of this system is given then data transmission and reception in OFDM is mathematically expressed. In this chapter the most important feature of this system which is robustness in ISI is explained, and the ability of system to overcome inter carrier interference (ICI) is discussed.

In Chapter 4, MIMO-OFDM system with OSTBC transmission in frequency selective channel is modeled. Mathematical expression in time-domain and frequency domain for data transmission and reception in a very simple and understandable form is developed . This model is used in chapter five to estimate the channel using LS or QRD channel estimation.

In Chapter 5, a literature review of previous works on channel estimation for MIMO-OFDM is presented. Basic estimation theory of classical estimation is discussed. The derivation of the LS is presented. The LS is adapted to the OFDM

and MIMO-OFDM channel estimation. And finally QRD channel estimation as a mean to reduce computational complexity of LS channel estimation is briefly presented.

In Chapter 6, simulation results for MIMO system performance and MIMO-OFDM channel estimation is given. Any simulation section has its own conclusion. In this chapter a performance comparisons using simulation results is made between the LS and QRD for estimating the CIR of MIMO-OFDM systems. The basic principle for relative computational complexity comparison has been given by Katryn in [43] is interpreted. At the end of this chapter, final conclusion of the work is presented, and some possible future works are suggested.

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