CAPACITY AUGMENTATION OF MIMO COMMUNICATION LINK WITH PARTIAL CSI

Synopsis

Of

Ph.D. Thesis

Submitted by

RAVI KUMAR
(Enrollment Number: 07P01001G)

Under the Guidance of

Prof. Rajiv Saxena

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING,
JAYPEE UNIVERSITY OF ENGINEERING & TECHNOLOGY,
GUNA-473 226, M.P. (INDIA)

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PREFACE

Wireless communication devices such as Mobile phones are being used primarily for voice communications, but the main attention is now diverting to devices capable of many more capabilities like data communications as well. Data communications mainly involve the transfer of data in any form, pictures, streaming video etc. The requirement of data rates are of supreme importance in mobile applications for streaming audio and video. The evolution of third-generation cell phone systems promised to transform the speech-and-message handset into an exciting multimedia device. It was a challenge largely unfulfilled, mainly because bandwidths had been limited to certain levels between 384 kbps and 2 mbps maximum. But the engineers and the network operators at the International Telecommunication Union are looking quite far ahead aiming to achieve the high data rates with next-generation (4G) technology which will be all-packet services and will integrate voice and data transmitted at high speeds and capacities with recommended targets of 100 Mbps point-to-point download transmission speed when riding in a vehicle and 1 Gbps when walking. Hence, the development of 4G standards is at high priority nowadays.

The recent successful and viable solution to achieve high data rates is the use of multiple antennas i.e. antenna arrays at the transmitter or receiver end, which are generally termed as multiple antenna systems. Multiple antennas can be arranged in any form such as linear, circular, or planar configurations and can be installed at both the base station and the mobile station. The prime focus of the Scientists and Engineers is on the combination of these multiple antennas with their smart steering properties utilizing the Digital signal processing which is termed as Smart Antennas.

The primary ideas in this field was first given by A.R. Kaye and D.A. George (1970), Branderburg and Wyner (1974) and W. Van Etten (1975, 1976). Jack Winters and Jack Salz at Bell Laboratories published several papers on beamforming and capacity related applications in 1984 and 1986. In 1996, Greg Raleigh and Gerard J. Foschini refined new approaches to MIMO technology, considering a configuration where multiple transmit antennas are co-located at one transmitter to improve the link throughput effectively. MIMO is a data transmission scheme in which different data streams are sent over the same channel using multiple transmitters and received at the receiver antennas. MIMO achieves high data rates by exploiting a drawback in some fundamental speed limits of information theory, which were first shown by Claude Shannon. These speed limits govern the maximum possible amount of data that can be handled between two transmit and receive antennas. MIMO systems Multiple-input multiple-output (MIMO) techniques for wireless communication have recently emerged and offer a powerful archetype for meeting these challenges. This new extended system of smart antenna type utilizes multipath propagation, which typically been considered as a pitfall in wireless transmission, into a benefit
for the user. A key idea in MIMO systems is space-time signal processing in which time (the natural dimension of digital communication data) is combined with the spatial dimension inherent in the use of multiple spatially distributed antennas which exploits the spatial dimension by increasing the number of unique spatial channels between the transmitter and the receiver. MIMO system requires a multipath rich environment to make convenient to manipulate the channel matrix inversion process.

MIMO exploits random fading with different environmental conditions and utilizes different technologies, and multipath delay spread, for increasing transfer rates. Since parallel transmission of data streams is the main contribution of this system, there is a linear increase in throughput with every pair of antennas added to the system without increasing the requirement of bandwidth. The possibility of several orders of magnitude improvement in wireless communication performance without the need for extra spectrum is one of the biggest reasons for the success of MIMO as a topic for new research.

The underlying mathematical nature of MIMO, where data is transmitted over a matrix rather than a vector channel, creates new and enormous opportunities beyond just the added diversity or array gain benefits. This was illustrated in [Foschini (1996)], where the author shows how one may under certain conditions transmit independent data streams simultaneously over the eigenmodes of a matrix based channels created by transmitting and receiving antennas. In particular, MIMO systems constitute a unified way of modeling a wide range of multiple communication channels, which can be handled with a compact vector-matrix notation.

Nevertheless, the general stochastic robust designs usually lead to solutions that clearly describe system structures, and thus provide direct information on how impairments such as erroneous channel estimation and channel correlation affect system performance. The results from the general designs are also helpful in identifying key channel parameters that should be quantized and transferred back to the transmitter, as well as in assessing the performance of limited-feedback designs. Therefore, it is of great importance to study MIMO system designs with uncertain CSI modeled statistically.

**OBJECTIVE OF THE STUDY**

In general, channel state information is always subject to ambiguous and, hence, the assumption of perfect CSI does not hold true which consequences in failing the assumption of perfect CSI predicted by the algorithm because the transmitted signal suffers from the mismatch between the CSI at the transmitter and the channel. Considering the existence of these ambiguities between the real and the estimated channel, a reasonable question in this practical context is: How sensitive are the transmitters to the uncertainty in the channel knowledge?

To answer this question, a new signal processing technique i.e. Adaptive pilot assisted semiblind channel estimation scheme (APASBCE) has been proposed in this thesis inspired by the time and
frequency component, utilizing the pilot symbol bunching in frequency component before transmitting through the MIMO antenna systems i.e. MIMO antenna systems with multiple users simultaneously transmitting and overlapping in both time and frequency. Also the precoder and decoder have been modified with minimized Mean Squared Error (MSE) for a MIMO communication system over a frequency-selective fading channel. The main motivation of this research is to propose powerful signal processing techniques to improve the performance of MIMO communication systems. Comparison of perfect channel state information has been done with the semiblind Channel state information to evaluate the performance of the proposed system.

This effect of the channel uncertainty in the performance of the MIMO communication scheme motivates the main objectives of this thesis:

- To study and design robust algorithms for the pilot scheme to estimate the Semi-blind channel or channel with partial CSI with increased robustness, considering all the possible channel uncertainty when designing the transmitter schemes with minimizing the Mean Square Error of the proposed scheme.

- To modify the basic transmission blocks of the systems for increasing the robustness of the proposed algorithm for making it feasible that could provide a robust channel state information with the newly proposed pilot assistance system at the transmitter and maximizing the mutual information of the MIMO system with Transmitter knowing the Partial channel information with allocation of equal power level to maximum subchannels.

- To improve the capacity and BER of the system for sending more information with the requirement of less bandwidth in the semiblind channel using Space Time Block Coding (STBC) techniques considering different fading correlation effects and to increase the SNR levels at the lower bound conditions with the MIMO system having the partial channel state information.

- To reduce the cost function using Expectation Maximization and to implement the modified MIMO system using different modified modules of the proposed schemes with Orthogonal Frequency Division Multiplexing (OFDM) and see the effect with the existing results available in the literature.

These four objectives have been considered separately in three independent part i.e., the design of the algorithm for the adaptive pilot scheme that increases the weight for the CSI at the transmitter (Chapter 3), the modification in the precoder and decoder section of the system for increasing the robustness of the proposed system (Chapter 4) and the implementation of the high code rate STBCs with the proposed
Training symbols i.e. pilot symbols must be carefully chosen in order to maximize the signal-to-noise ratio during channel estimation. In MIMO systems, it is important to design the system in such a way so that it utilizes very less training symbols for making the channel freely available in terms of bandwidth for transmitting more information symbols through. Due to delay in acquiring transmitted information at the receiver end, the time selective fading wireless channel often induces incomplete or partial CSI. The dynamic CSI model has also been tried consisting channel mean and covariance which leads to the extracting of channel estimates and error covariance. Both parameters indicated the CSI quality since these are the functions of temporal correlation factor, and based on this, the model covers data from perfect to statistical CSI, either partial or full blind. It is found that in the case of partial & imperfect CSI, the capacity depends on the statistical properties of the error in the CSI. Based on the knowledge of statistical distribution of the deviations in CSI knowledge, a new approach which maximizes a capacity of spatial channel model has been tried. The interference then interactively reduced by employing the iterative channel estimation and data detection approach, where by utilizing the detected symbols from the previous iteration, multiuser/MIMO channel estimation and symbol detection is improved. Spatial orthogonality should be preserved in frequency-domain for the different transmit antennas. A new approach has been tried in Chapter 3 utilizing the adaptive pilot symbol based semiblind channel estimation scheme.

It is known that with proper linear precoder-decoder designs, a spatial multiplexing system becomes an expedient structure to improve the capacity, link reliability as well as offer a flexible diversity multiplexing tradeoff for the MIMO communication systems. Various performance measures are required to design the precoder and decoder, e.g., minimum weighted Mean square error (MSE), minimum mean-square error (MMSE), maximized mutual information and minimum bit error rate (BER) for single transmit and receive MIMO systems. Some recent studies related to the motive of the thesis have been found in [Lamahewa et al. (2007) ; Zhiguo et al. (2006) ; Zhiguo and Ward (2005) ; Zijian and Leus (2006)] for which the comparative analysis has been shown in the respective chapter 4. In this chapter, the focus has been taken for minimizing the MSE designs related criteria and balancing the interferences with noise suppression. Earlier research on precoder and decoder designs for spatial channel assumed perfect channel state information at the receiver and only few considered the partial CSI conditions at both transmitter and receiver side which generally had not considered the loss due to the effect of channel estimation error when considered with channel transmit and receive correlation. This is also the reason to work on with the channel with partial channel state information since this has impact on both at transmit
and receive antenna. Further, the mutual information design which is also a MSE related design has been tried to maximize with the help of the high code rate Space time block codes (STBC).

In this study, the spatial multiplexing channel has been analyzed with the proposed adaptive semiblind channel estimation scheme to optimize using the MSE related design criteria in which both transmit and receive antenna correlation has been considered to be known at both the ends with the partial channel state information utilizing the Rayleigh fading channels in the MIMO communication systems.

**SUMMARY OF THE THESIS**

This thesis consists of seven chapters including the first chapter of introduction and the remaining chapters contain detailed theoretical aspects, analysis and simulation of APASBCE scheme, modified precoder and decoder applications, STBC design and application for conventional & higher code rates and applications of the proposed scheme with some conventional estimation schemes and OFDM system with their comparison, discussions and conclusions.

**Chapter- 1:**

This chapter provides an overview of the history, evolution and basic details about MIMO antenna systems. The basic ideas about the Smart Antenna system, MIMO techniques, channel capacity, MIMO system with CSI conditions has been discussed in this chapter. The Motivation for the study, thesis organization and thesis findings has also been discussed in this chapter.

This chapter basically shows that the MIMO systems are being utilized in multiuser environment such as wireless Local Area Network (LAN), cellular Communication etc. nowadays, where a multi-antenna base station (BS) simultaneously communicates with several multi-antenna mobile stations (MS). More flexibility and robustness in communication has been achieved in a multiuser environment by the use of multiple antennas and providing high data rate, besides providing spatial multiplexing and diversity gains. Similar to the single-user case, there is a tradeoff among the capabilities of spatial multiplexing, diversity and interference management in multiuser MIMO systems. Thus, MIMO systems have been established as a promising transmission structure to achieve the goal of future wireless systems.

**Chapter- 2:**

This chapter provides an overview of the history and recent development on wireless channel model, basic MIMO techniques, correlation of MIMO systems, channel capacity, channel uncertainty and transmit precoding designs. The purpose of this section is to review the literature on channel capacity and uncertainty, focusing the attention on the design of robust algorithms that mitigate the influence of channel knowledge either with perfect channel state information or with partial channel state information.
This chapter shows about the recent research results found with the MIMO system as a potential candidate to play a major role in future wireless communication system. Early work on multi-antenna systems involves the use of antenna arrays at the receiver to provide spatial diversity against the random destructive effect of fading. Recent rich literature on employing multiple antennas at the transmitter and achieving diversity through space-time coding when there is no channel state information at the transmitter (CSIT) has been shown in [Alamouti (1998) ; Jafarkhani (2001) ; Tarokh \textit{et al.} (1999a), (1999b) ; Tarokh \textit{et al.} (1998)]. Clearly, a MIMO system can be designed to fully exploit transmit and receive spatial diversity provided by the channel.

High performance reliability returns from using MIMO systems largely based on the assumption of perfect coherent reception, i.e., Channel state information (CSI) which can be interpreted both on transmitter and receiver side as perfect channel state information at the transmitter (CSIT) and perfect channel state information at transmitter (CSIT). In general, however, perfect coherent reception (perfect CSI) is not able to fully attain both at the transmitter and receiver side due to channel estimation errors. Consequently, it is necessary to design a system robust to imperfect CSIR.

Practical situations indicate that some forms of partial CSI can be available both at the transmitter and receiver side. For example, partial CSIT can be acquired by transferring the CSIR to the transmitter via a feedback link which is not an uncommon feature and it is present in most wireless systems, e.g., the power control channel in Code Division Multiple Access (CDMA) systems. If a system operates in the time-division duplex (TDD) mode, the transmitter can infer the CSI by measuring its received signal based on the reciprocity of wireless channels. CSIT obtained this way is usually imperfect due to channel estimation errors, erroneous CSIR, and/or limitation of the feedback link. However incomplete CSIT, if efficiently used, can yield considerable performance gain in both space-time coded and spatially multiplexed systems, as opposed to the case of no CSIT.

Therefore, intelligent MIMO systems designs must exploit the available CSI. The uncertainty in CSI can be modeled and dealt with in two different ways. One way is to model the estimation in channel knowledge as unknown estimate but deterministic and bounded in a certain region. To make statistical CSI available at the transmitter, feedback is required, even though it’s random behavior in slow-fading channels.

After analyzing different viewpoints to design those robust algorithms, the chapter motivates the development of robust algorithms based on Adaptive Pilot assisted channel estimation to increase the mutual information between transmit and receive MIMO antenna systems. The second part of the chapter presents about the time varying channel models which is the basic requirement of the current research scenarios. Section 3 and 4 of this chapter gives the detailed literature review over the adaptive algorithms.
for antenna selection in time varying channel and some more different conditions. Section 5 of the chapter further moves toward the detailed literature review and the state-of-the-art on transmit precoding designs classifying those algorithms as a function of the channel state information at the transmitter for both perfect and partial channel state conditions. Section 6 deals with the literature review and analysis for the STBC codes and shown that how the requirement of these codes are correlated with the improvement of mutual information of the system.

**Chapter- 3:**

This chapter covers the design of a feasible channel estimation scheme with partial channel state information utilizing the adaptive pilot insertion utilizing both the time and frequency component of the transmitted signal and allows tracking time varying channels. After introducing the new pilot scheme which is sent in the form of bunches in the frequency component of the transmitting symbols from the transmitting antenna and adaptively reduces with the increase in the number of iterations, under the assumption of imperfect CSI at both ends. The MMSE design is formulated as a non-convex optimization problem subject to a total transmit power constraint. To resolve the optimization problem, further the precoder and decoder modification algorithms have been developed in next chapter.

The chapter also reviews some basics related pilot aided channel estimation, channel uncertainty in the MIMO communication system and some blind channel estimation scheme using the absolute and higher order moments following the bounds given by Cramer Rao bounds. Further the capacity analysis and comparison has been shown for the proposed estimation scheme. Among the main results we found the minimum amount of pilot symbols used with the adaptive iteration method resulting increase in the capacity of the MIMO system with the effect of the correlation coefficient of the antennas at the higher SNR levels. The comparative Mean Square Error (MSE) study has been done between the LS based channel estimation approach in [Feng, Zhu, et al. (2008)], nulling based channel estimation approach given by [Feng, Wei-Ping, et al. (2008)], whitening rotation based algorithm proposed by [Jagannatham and Rao (2006)] and the proposed scheme [Kumar and Saxena (2012b)] for the Least Square approach based estimation method which shows that the proposed scheme is giving better results than the said one and the quantified values are shown in the work. Similarly the power amplification of the pilot symbols contributing to the channel estimation has been compared with the closed form semiblind channel estimation (CFSB) proposed in [Murthy et al. (2006)] which also shows the improvement. At the last the BER analysis has been compared with BER given by [Cui and Tellambura (2007) ; Feng, Zhu, et al. (2008) ; Murthy et al. (2006)] and found the improved results which has been shown in this work.
Chapter- 4:

This chapter extends the study of the chapter 3 and focused with the modifications in the precoder and decoder designs for robust power allocation algorithms in partial channel state information conditions. The chapter discussed about two design conditions: the minimization of the MSE and the maximization of the mutual information of the system with simultaneous improvement in the BER of the system. The basic novelty with respect to previous works that consider the same strategies of design is the modification of precoder and decoder designs to minimize the MSE. The uplink and downlink minimum average sum MSE transceiver optimization problems have been formulated with the partial CSI conditions.

The improvement has been observed by improving the previous Karush Kuhn Tucker (KKT)-conditions-based algorithms which has reduced the complexity of the system for estimating the channel under the partial CSI conditions. It is known that it is very difficult to determine the exact capacity expression under the partial CSI conditions. But the tight upper and lower bound conditions following the Cramer Rao bounds [Cramér (1945) ; Kay (1998)] have been considered for the design purpose in which the focus has been done basically on the lower bound conditions. With the help of these lower bound conditions, the closed-form optimum transmit covariance matrix has to be determined, subject to a total transmit power constraint.

This helps us in designing and increasing the maximum mutual information with the partial CSI conditions. We relate this problem to that of minimizing the log determinant of the MSE matrix, which is a non-convex problem which has been used in deriving the structure of the optimum transmit covariance matrix. By implementing this algorithm with proposed APASBCE scheme for the partial channel state information in multiple iterations, the tightness of the ergodic capacity bounds and the effects of channel estimation error and channel correlation have been seen in this chapter. By comparing the numerical results, in terms of coded BER, all the algorithms proposed in this thesis shown that, as expected, the algorithm that maximizes the cut-off rate outperforms the others.

The performance analysis has been done to evaluate the Symbol Error Rate, BER and Capacity at the last of the analysis of the precoder and decoder based analysis. The proposed scheme in this chapter has been developed on the basis of KKT conditions [Kumar and Saxena (2012c)] and compared with the [Zhiguo et al. (2006)] which had given better results than the SER developed in [Zhiguo and Ward (2005)] and found that the results developed in [Kumar and Saxena (2012c)] are better than the results developed by [Zhiguo et al. (2006)] which has been shown graphically this chapter. Similarly the BER developed in this chapter is better than the results found in[Lamahewa et al. (2007)] and reaching very near to the BER developed by [Zijian and Leus (2006)] using the Jake’s precoder model. At last the capacity results has
been compared with the capacity results found in [Seo (2012)] for the correlation coefficient of 0.1 & 0.9 and found that the capacity achieved in this chapter is giving better results at the correlation coefficient of 0.5 only.

Chapter- 5:

This chapter implements the study done in previous chapters with the diversity coding techniques using MIMO antenna systems. Different Space Time Block Codes (STBC) schemes have been explored and analyzed [Kumar and Saxena (2013)] with the high code rate greater than 1. STBC with higher code rates have been simulated and implemented with the modified schemes shown in chapter 3 and chapter 4 [Kumar and Saxena (2012d)]. The high code rate STBCs are capable of sending more information with requirement of less bandwidth at the transmitter end. All the methods have been simulated and compared in the semiblind channel environment which shows the improvement even in highly correlated antenna arrays, and is found very close to the condition when channel state information (CSI) is known to the channel. The proposed scheme when implemented with the Alamouti’s scheme for 3x3 antenna configurations using QPSK and 16-QAM modulation schemes has been shown with the improved results for the partial CSI conditions. Also, the mitigation has been performed and shown in this chapter by rotating the constellation angle of the modulating signal for maintaining the high code rates for different code rate values for different Space time block codes in both 16-QAM and QPSK modulation schemes. Similarly the simulations have been performed over 3x3 and 4x4 antenna systems using QPSK and 16-QAM modulation schemes with different code rates of 1/2, 1, 1.3, 1.5 and 2 for the partial Channel state information conditions which have shown remarkable improvement on the basis of the schemes proposed in chapter 3 and chapter 4.

The comparison has been shown using different comparative analysis figures and found that the results are better or at par with the [Basar and Aygolu (2009) ; Choqueuse et al. (2011) ; Loiola et al. (2011) ; Long et al. (2011) ; Yi-Sheng (2010)] in terms of constellation angle, BER and Capacity as shown in [Kumar and Saxena (2012d), (2013)] which has been developed on the basis of the methods and models of the STBCs proposed in [Grau et al. (2008) ; H.Jafarkhani (2005) ; Jafarkhani (2001) ; Tarokh et al. (1999a), (1999b)].

Chapter- 6:

This chapter deals with the application of the proposed schemes and the modifications done in chapter 3 and 4 with the missed data channel estimation schemes and improving the results using forward-backward averaging method and expectation maximization methods based on the filter techniques given in
[Larsson and Jian (2003) ; Li et al. (1998) ; Liu et al. (1998) ; Lopez-Dekker and Mallorqui (2010) ; Shahbazpanahi et al. (2006) ; Stoica et al. (1999) ; Wu et al. (1998) ; Yanwei et al. (2005)]. The improvements have been shown using the comparative graphs for Normalized Root Mean Square Error, BER and Capacity for different schemes using 2x2 and 4x4 antenna applications [Kumar and Saxena (2012a)].

Further, the Orthogonal Frequency Division Multiplexing (OFDM) scheme has been implemented with the proposed schemes and methods in chapter 3, 4 and 5. The comparative analysis has been done between the [Abuthinien et al. (2008)] and the proposed scheme implemented MIMO-OFDM system for the BER and found that the proposed MIMO-OFDM implemented scheme with partial CSI is reaching very close to the perfect CSI conditions. Similarly, [Yu and Lin (2009)], [Zeng et al. (2006)] and [Hsiao-Yun et al. (2010)] has also been compared for the NMSE and shown the improved results for the partial CSI conditions. The application based analysis has been done for both perfect and partial channel state information conditions.

Chapter- 7:

This chapter concludes the thesis, summarizing the main outcomes of this thesis and briefing the different schemes for their performances. Finally, the chapter outlines some ideas and suggests for future research work.

References


