Interference Cancellation Technique with Orderings in Rayleigh Fading Channel for MIMO Systems

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DECLARATION

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This thesis does not, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

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Abstract

MIMO systems, which use multiple antennas at the transmitter and receiver, are a key technology to meet the growing demand for high data rate wireless systems.

We tend to discuss a method to enhance the performance of the MIMO systems by interference cancellation technique. We tend to apply it for MIMO spatial multiplexing channels with in the Rayleigh fading environment. During this we tend to introduce MIMO systems, followed by system model, and planned interference cancellation strategy, then transient discussion regarding results and conclusion. We tend to do interference cancellation on each parallel branch of the receiver that already prepared with distinct orderings pattern, by which different branches gives distinctive symbol approximate vector, so at the end of the branches, detector achieves higher detection diversity to pick the best performed branch with selection rules, during this we tend to use choice rule MMSE because it performs higher and it has low complexness. Our simulation results show that our detector approaches performance of the best optimal detector and complexness is low.

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LIST OF ABBREVIATION

FDMA	Frequency division multiple access
TDMA	Time division multiple access
CDMA	Code division multiple access
W-CDMA	Wideband Code Division Multiple Access
FDD	Frequency Division Duplex
TDD	Time Division Duplex
QPSK	Quadrature Phase Shift Keying
FDM	Frequency Division Multiplexing
ISI	Inter symbol Interference
SI	Side information
AWGN	Additive White Gaussian Noise
MIMO	Multiple Input Multiple Output
QAM	Quadrature Amplitude Modulation
ML	Maximum Likelihood
MMSE	Minimum Mean Square Error
SISO	Single Input Single output
SIMO	Single Input multiple output
MISO	Multiple Input Single Output

CHAPTER 1

INTRODUCTION

1. Introduction

Recently, it has been recognized that the deployment of multiple transmit and receive antennas significantly improves wireless link performance in communication systems. The degrees of freedom afford by the multiple antennas can offer dramatic multiplexing and diversity gains. The multiplexing gains enable high spectral efficiencies, whereas the diversity gains make the links more reliable and allow low error rates over wireless fading channels. In these multiple input multiple output (MIMO) systems, the transmitter and the receiver should be appropriately designed in order to exploit the structure of the propagation channels.

In a spatial multiplexing configuration, the system can obtain substantial gains in data rate. These capacity gains grow linearly with the minimum number of transmit and receive antennas, and the transmission of individual data streams from the transmitter to the receiver. In order to separate these streams, the designer may resort to several detection techniques, which are similar to multiuser detection methods. The optimal maximum likelihood (ML) detector can be implemented using the sphere decoding algorithm. However, the complexity of this algorithm can be polynomial or exponential depending on the signal-to-noise ratio (SNR) and the signal constellation. This has motivated the development of various alternative low-complexity strategies [1]. A promising transmission system, called diagonal Bell Laboratories Layered Space- Time (D-BLAST) proposed by Foschini, is the first BLAST architecture. Owing to the large computational complexity required for the scheme, a simplified version, called the Vertical BLAST (V-BLAST) has been proposed. The V-BLAST can be seen as an ordered SIC, on the other hand, there is equivalence between the V-BLAST receiver and the generalized decision feedback equalizer (GDFE). A number of other strategies are also investigated to achieve the capacity gain of MIMO systems including the linear and the decision feedback (DF) detector and the parallel interference cancellation (PIC) [2].

Multiple-input multiple-output, or MIMO, is a radio communications technology or RF technology that is being mentioned and used in many new technologies these days. Wi-Fi, LTE (Long Term Evolution), and many other radio, wireless and RF technologies are using the new MIMO wireless technology to provide increased link capacity and spectral efficiency combined with improved link reliability using what were previously seen as interference paths [3].

Even now there are many MIMO wireless routers on the market, and as this RF technology is becoming more widespread, more MIMO routers and other items of wireless MIMO equipment will be seen. As the technology is complex many engineers are asking what is MIMO and how does it work.

1.1 MIMO development and history

MIMO technology has been developed over many years. Not only did the basic MIMO concepts need to be formulated, but in addition to this, new technologies needed to be developed to enable MIMO to be fully implemented. New levels of processing were needed to allow some of the features of spatial multiplexing as well as to utilize some of the gains of spatial diversity.

Up until the 1990s, spatial diversity was often limited to systems that switched between two antennas or combined the signals to provide the best signal. Also various forms of beam switching were implemented, but in view of the levels of processing involved and the degrees of processing available, the systems were generally relatively limited. However with the additional levels of processing power that started to become available, it was possible to utilize both spatial diversity and full spatial multiplexing.

The initial work on MIMO systems focused on basic spatial diversity - here the MIMO system was used to limit the degradation caused by multipath propagation. However this was only the first step as system then started to utilize the multipath propagation to advantage, turning the additional signal paths into what might effectively be considered as additional channels to carry additional data.

Two researchers: Arogyaswami Paulraj and Thomas Kailath were first to propose the use of spatial multiplexing using MIMO in 1993[4] and in the following year their US patent was granted. However it fell to Bell Labs to be the first to demonstrate a laboratory prototype of spatial multiplexing in 1998.

1.1.1 MIMO -Multiple Input Multiple Output basics

A channel may be affected by fading and this will impact the signal to noise ratio. In turn this will impact the error rate, assuming digital data is being transmitted. The principle of diversity is to provide the receiver with multiple versions of the same signal. If these can be made to be affected in different ways by the signal path, the probability that they will all be affected at the same time is considerably reduced. Accordingly, diversity helps to stabilize a link and improves performance, reducing error rate. Several different diversity modes are available and provide a number of advantages.

- Time diversity: Using time diversity, a message may be transmitted at different times, e.g. using different timeslots and channel coding.
- Frequency diversity: This form of diversity uses different frequencies. It may be in the form of using different channels, or technologies such as spread spectrum / OFDM.
- Space diversity: Space diversity used in the broadest sense of the definition is used as the basis for MIMO. It uses antennas located in different positions to take advantage of the different radio paths that exist in a typical terrestrial environment.

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used [5].

1.1.2 General Outline of MIMO system

One of the core ideas behind MIMO wireless systems space-time signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas, i.e. the use of multiple antennas located at different points. Accordingly MIMO wireless systems can be viewed as a logical extension to the smart antennas that have been used for many years to improve wireless.

It is found between a transmitter and a receiver, the signal can take many paths. Additionally by moving the antennas even a small distance the paths used will change. The variety of paths available occurs as a result of the number of objects that appear to the side or even in the direct path between the transmitter and receiver. Previously these multiple paths only served to introduce interference. By using MIMO, these additional paths can be used to advantage. They can be used to provide additional robustness to the radio link by improving the signal to noise ratio, or by increasing the link data capacity.

The two main formats for MIMO are given below

- Spatial diversity: Spatial diversity used in this narrower sense often refers to transmit and receive diversity. These two methodologies are used to provide improvements in the signal to noise ratio and they are characterized by improving the reliability of the system with respect to the various forms of fading.

- Spatial multiplexing: This form of MIMO is used to provide additional data capacity by utilizing the different paths to carry additional traffic, i.e. increasing the data throughput capability.

As a result of the use multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel while still obeying Shannon's law. By increasing the number of receive and transmit antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. This makes MIMO wireless technology one of the most important wireless techniques to be employed in recent years. As spectral bandwidth is becoming an ever more valuable commodity for radio communications systems, techniques are needed to use the available bandwidth more effectively. MIMO wireless technology is one of these techniques.

There is a number of different MIMO configurations or formats that can be used. These are termed SISO, SIMO, MISO and MIMO. These different MIMO formats offer different advantages and disadvantages - these can be balanced to provide the optimum solution for any given application.

The different MIMO formats - SISO, SIMO, MISO and MIMO require different numbers of antennas as well as having different levels of complexity. Also dependent upon the format, processing may be needed at one end of the link or the other - this can have an impact on any decisions made.

1.2 Terminology

The different forms of antenna technology refer to single or multiple inputs and outputs. These are related to the radio link. In this way the input is the transmitter as it transmits into the link or signal path, and the output is the receiver. It is at the output of the wireless link. Therefore the different forms of single / multiple antenna links are defined as below:

- SISO - Single Input Single Output
- SIMO - Single Input Multiple output
- MISO - Multiple Input Single Output
- MIMO - Multiple Input multiple Output

The term MU-MIMO is also used for a multiple user version of MIMO as described below.

1.2.1 MIMO – SISO

The simplest form of radio link can be defined in MIMO terms as SISO - Single Input Single Output. This is effectively a standard radio channel - this transmitter operates with one Antenna as does the receiver. There is no diversity and no additional processing required.

SISO - Single Input Single Output

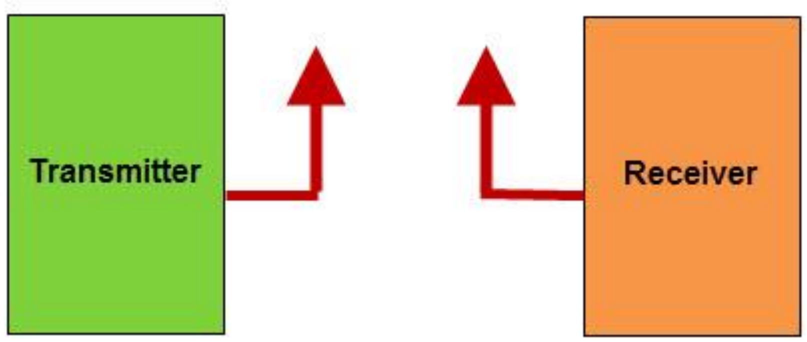

Figure 1: Single Input Single Output transmission system.

The advantage of a SISO system is its simplicity. SISO requires no processing in terms of the various forms of diversity that may be used. However the SISO channel is limited in its performance. Interference and fading will impact the system more than a MIMO system using some form of diversity, and the channel bandwidth is limited by Shannon's law - the throughput being dependent upon the channel bandwidth and the signal to noise ratio.

1.2.2 MIMO– SIMO

The SIMO or Single Input Multiple Output version of MIMO occurs where the transmitter has a single antenna and the receiver has multiple antennas. This is also known as receive diversity. It is often used to enable a receiver system that receives signals from a number of independent sources to combat the effects of fading. It has been used for many years with short wave listening / receiving stations to combat the effects of ionosphere fading and interference.

SIMO - Single Input Multiple Output

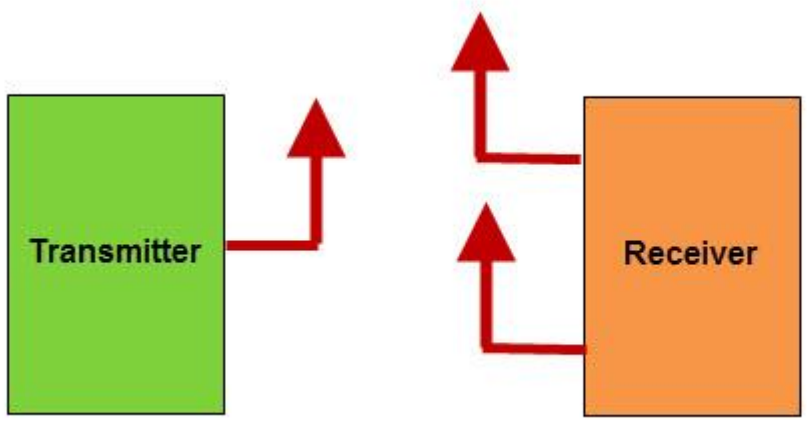

Figure 2: Single Input Multiple Output transmission system.

SIMO has the advantage that it is relatively easy to implement although it does have some disadvantages in that the processing is required in the receiver. The use of SIMO may be quite acceptable in many applications, but where the receiver is located in a mobile device such as a cell phone handset, the levels of processing may be limited by size, cost and battery drain.

There are two forms of SIMO that can be used:

- **Switched diversity SIMO**: This form of SIMO looks for the strongest signal and switches to that antenna.
- **Maximum ratio combining SIMO**: This form of SIMO takes both signals and sums them to give them a combination. In this way, the signals from both antennas contribute to the overall signal [6].

1.2.3 MIMO– MISO

MISO is also termed transmit diversity. In this case, the same data is transmitted redundantly from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to receive extract the required data.

MISO - Multiple Input Single Output

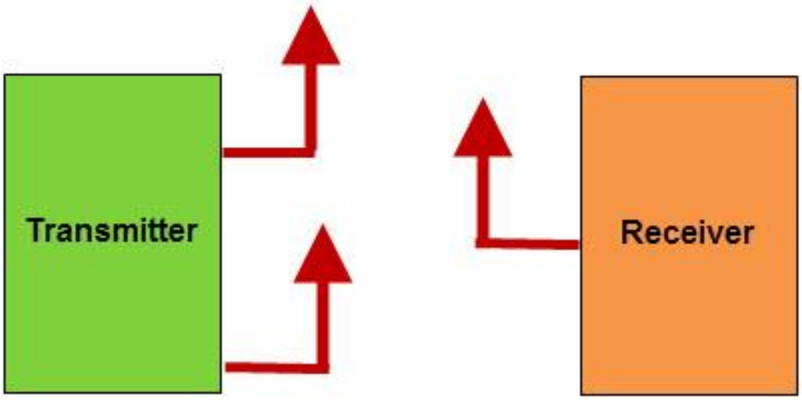

Figure 3:Multiple Input Single Output transmission system.

The advantage of using MISO is that the multiple antennas and the redundancy coding processing is moved from the receiver to the transmitter. In instances such as cell phone UEs, this can be a significant advantage in terms of space for the antennas and reducing the level of processing required in the receiver for the redundancy coding. This has a positive impact on size, cost and battery life as the lower level of processing requires less battery consumption.

MIMO

Where there are more than one antenna at either end of the radio link, this is termed MIMO - Multiple Input Multiple

1.2.4 MIMO - Multiple Input Multiple Output

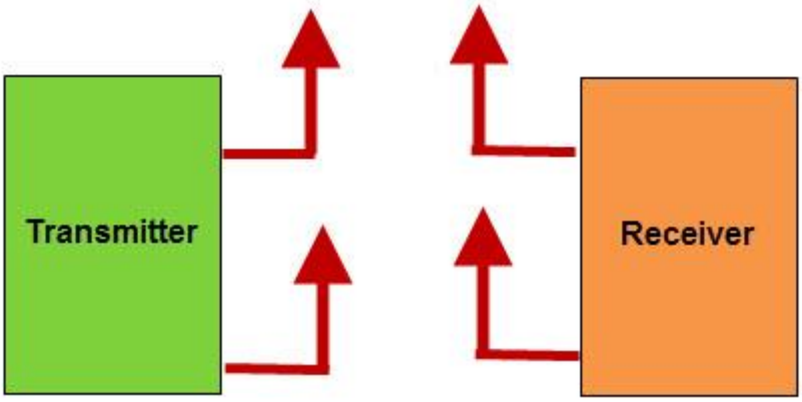

Figure 4: Multiple Input Multiple Output transmission system.

In order to be able to benefit from MIMO fully it is necessary to be able to utilise coding on the channels to separate the data from the different paths. This requires processing, but provides additional channel robustness / data throughput capacity.

There are many formats of MIMO that can be used from SISO, through SIMO and MISO to the full MIMO systems. These are all able to provide significant improvements of performance, but generally at the cost of additional processing and the number of antennas used. Balances of performance against costs, size, processing available and the resulting battery life need to be made when choosing he correct option. One of the key advantages of MIMO spatial multiplexing is the fact that it is able to provide additional data capacity. MIMO spatial multiplexing achieves this by utilizing the multiple paths and effectively using them as additional "channels" to carry data. The maximum amount of data that can be carried by a radio channel is limited by the physical boundaries defined under Shannon's Law.

1.3 Shannon's Law

As with many areas of science, there a theoretical boundaries, beyond which it is not possible to proceed. This is true for the amount of data that can be passed along a specific channel in the presence of noise. The law that governs this is called Shannon's Law, named after the man who formulated it. This is particularly important because MIMO wireless technology provides a method not of breaking the law, but increasing data rates beyond those possible on a single channel without its use.

Shannon's law defines the maximum rate at which error free data can be transmitted over a given bandwidth in the presence of noise. It is usually expressed in the form:

$$C = W \log_2 (1 + {}^{S}\!/_{N}) \tag{1.1}$$

Where C is the channel capacity in bits per second, W is the bandwidth in Hertz, and S/N is the SNR (Signal to Noise Ratio).

From this it can be seen that there is an ultimate limit on the capacity of a channel with a given bandwidth. However before this point is reached, the capacity is also limited by the signal to noise ratio of the received signal [7].

In view of these limits many decisions need to be made about the way in which a transmission is made. The modulation scheme can play a major part in this. The channel capacity can be increased by using higher order modulation schemes, but these require a better signal to noise ratio than the lower order modulation schemes. Thus a balance exists between the data rate and the allowable error rate, signal to noise ratio and power that can be transmitted.

While some improvements can be made in terms of optimizing the modulation scheme and improving the signal to noise ratio, these improvements are not always easy or cheap and they are invariably a compromise, balancing the various factors involved. It is therefore necessary to look at other ways of improving the data throughput for individual channels. MIMO is one way in which wireless communications can be improved and as a result it is receiving a considerable degree of interest.

1.4 MIMO spatial multiplexing

To take advantage of the additional throughput capability, MIMO utilizes several sets of antennas. In many MIMO systems, just two are used, but there is no reason why further antennas cannot be employed and this increases the throughput. In any case for MIMO spatial multiplexing the number of receive antennas must be equal to or greater than the number of transmit antennas.

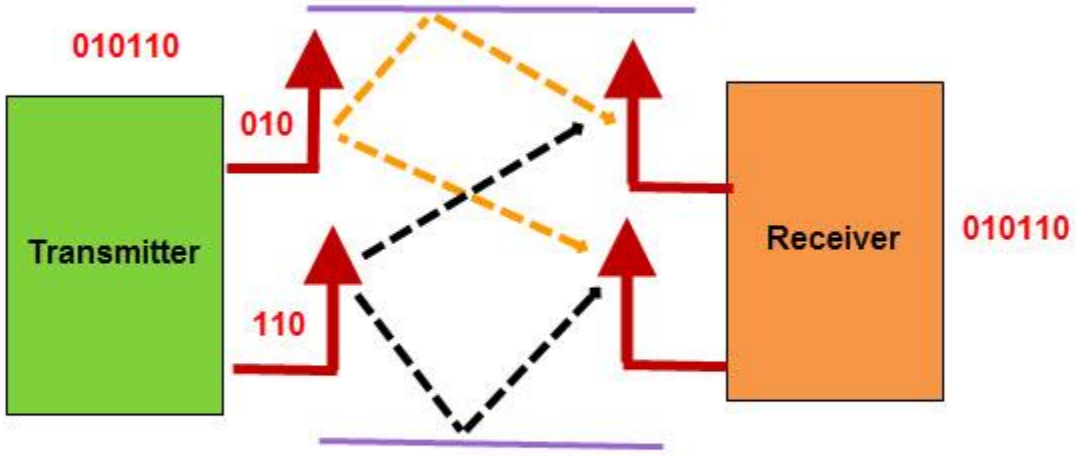

Figure 5: Multiple Input Multiple Output Spatial Multiplexing transmission system.

To take advantage of the additional throughput offered, MIMO wireless systems utilize a matrix mathematical approach. Data streams $t_1,\ldots,t_n$ can be transmitted from antennas 1, 2…, n. Then there are a variety of paths that can be used with each path having different channel properties. To enable the receiver to be able to differentiate between the different data streams it is necessary to use. These can be represented by the properties h_{12}, travelling from transmit antenna one to receive antenna 2 and so forth. In this way for a three transmit, three receive antenna system a matrix can be set up:

$$r_1 = h_{11}t_1 + h_{21}t_2 + h_{31}t_3$$

$$r_2 = h_{12}t_1 + h_{22}t_2 + h_{32}t_3$$

$$r_3 = h_{13}t_1 + h_{23}t_2 + h_{33}t_3 \qquad (1.2)$$

Where r_1 = signal received at antenna r_1, r_2 is the signal received at antenna 2 and so forth.

In matrix format this can be represented as:

$$[R] = [H] \times [T] \qquad (1.3)$$

To recover the transmitted data-stream at the receiver it is necessary to perform a considerable amount of signal processing. First the MIMO system decoder must estimate the individual channel transfer characteristic h_{ij} to determine the channel transfer matrix. Once all of this has been estimated, then the matrix [H] has been produced and the transmitted data streams can be reconstructed by multiplying the received vector with the inverse of the transfer matrix.

$$[T] = [H]^{-1} \times [R] \qquad (1.4)$$

This process can be likened to the solving of a set of N linear simultaneous equations to reveal the values of N variables.

In reality the situation is a little more difficult than this as propagation is never quite this straightforward, and in addition to this each variable consists of an ongoing data stream, this nevertheless demonstrates the basic principle behind MIMO wireless systems. In order that MIMO spatial multiplexing can be utilized, it is necessary to add coding to the different channels so that the receiver can detect the correct data.

There are various forms of terminology used including Space-Time Block Code - STBC, MIMO pre-coding, MIMO coding, and Alamouti codes [8].

1.5 Space time block codes

Space-time block codes are used for MIMO systems to enable the transmission of multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. Space-time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.

Space time block coding uses both spatial and temporal diversity and in this way enables significant gains to be made. Space-time coding involves the transmission of multiple copies of the data. This helps to compensate for the channel problems such as fading and thermal noise. Although there is redundancy in the data some copies may arrive less corrupted at the receiver. When using space-time block coding, the data stream is encoded in blocks prior to transmission. These data blocks are then distributed among the multiple antennas (which are spaced apart to de-correlate the transmission paths) and the data is also spaced across time. A space time block code is usually represented by a matrix. Each row represents a time slot and each column represents one antenna's transmissions over time. Within this matrix, S_{ij} is the modulated symbol to be transmitted in time slot i from antenna j. There are to be T time slots and N_T transmit antennas as well as N_R receive antennas. This block is usually considered to be of 'length' T [9].

1.5.1 MIMO Alamouti coding

A particularly elegant scheme for MIMO coding was developed by Alamouti. The associated codes are often called MIMO Alamouti codes or just Alamouti codes. The MIMO Alamouti scheme is an ingenious transmit diversity scheme for two transmit antennas that does not require transmit channel knowledge. The MIMO Alamouti code is a simple space time block code that he developed in 1998.

1.5.2 Differential space time block code

Differential space time block coding is a form of space time block coding that does not need to know the channel impairments in order for the signal to be decoded. The differential space time block codes are normally based upon the more standard space-time block codes. One block-code is transmitted from a set in response to a change in the input signal. This enables the system to work because the differences among the blocks in the set are designed to allow the receiver to extract the data with good reliability.

The MIMO antenna technologies used are key to the overall MIMO performance. Additionally MIMO beam forming is an option that is coming to the fore [10]. As various forms of technology improve the MIMO antenna technology can be pushed further allowing techniques like MIMO beam forming to be considered.

1.6 MIMO antenna & MIMO beam forming development

For many years antenna technology has been used to improve the performance of systems. Directive antennas have been used for very many years to improve signal levels and reduce interference. Directive antenna systems have, for example, been used to improve the capacity of cellular telecommunications systems. By splitting a cell site into sector where each antenna illuminates 60° or 120° the capacity can be greatly increased - tripled when using 120° antennas. With the development of more adaptive systems and greater levels of processing power, it is possible to utilize antenna beam forming techniques with systems such as MIMO.

1.6.1 MIMO beam forming smart antennas

Beam forming techniques can be used with any antenna system - not just on MIMO systems. They are used to create a certain required antenna directive pattern to give the required performance under the given conditions. Smart antennas are normally used - these are antennas that can be controlled automatically according the required performance and the prevailing conditions.

Smart antennas can be divided into two groups:

- **Phased array systems*:*** Phased array systems are switched and have a number of pre-defined patterns - the required one being switched according to the direction required.
- **Adaptive array systems (AAS):** This type of antenna uses what is termed adaptive beam forming and it has an infinite number of patterns and can be adjusted to the requirements in real time [11].

MIMO beam forming using phased array systems requires the overall system to determine the direction of arrival of the incoming signal and then switch in the most appropriate beam. This is something of a compromise because the fixed beam is unlikely to exactly match the required direction.

Adaptive array systems are able to direct the beam in the exact direction needed, and also move the beam in real time - this is a particular advantage for moving systems - a factor that often happens with mobile telecommunications. However the cost is the considerable extra complexity required. Multi-user MIMO or MU-MIMO is an enhanced form of MIMO technology that is gaining acceptance. MU-MIMO, Multi-user MIMO enables multiple independent radio terminals to access a system enhancing the communication capabilities of each individual terminal.MU-MIMO exploits the maximum system capacity by scheduling multiple users to be able to simultaneously access the same channel using the spatial degrees of freedom offered by MIMO. To enable MU-MIMO to be used there are several approaches that can be adopted, and a number of applications / versions that are available.

1.7 MU-MIMO Basics

MU-MIMO provides a methodology whereby spatial sharing of channels can be achieved. This can be achieved at the cost of additional hardware - filters and antennas - but the incorporation does not come at the expense of additional bandwidth as is the case when technologies such as FDMA, TDMA or CDMA are used. When using spatial multiplexing, MU-MIMO, the interference between the different users on the same channel is accommodated by the use of additional antennas, and additional processing when enable the spatial separation of the different users. There are two scenarios associated with MU-MIMO, Multi-user MIMO:

- **Uplink - Multiple Access Channel, MAC*:*** The development of the MIMO-MAC is based on the known single user MIMO concepts broadened out to account for multiple users.
- **Downlink - Broadcast Channel, BC *:*** The MIMO-BC is the more challenging scenario. The optimum strategy involves pre-interference cancellation techniques known as "Dirty Paper Coding", DPC - see below. This is complemented by implicit user scheduling and a power loading algorithm

1.7.1 MU-MIMO Multi-User MIMO advantages

MU-MIMO, Multi-user MIMO offers some significant advantages over other techniques:

- MU-MIMO systems enable a level of direct gain to be obtained in a multiple access capacity arising from the multi-user multiplexing schemes. This is proportional to the number of base station antennas employed.
- MU-MIMO appears to be affected less by some propagation issues that affect single user MIMO systems. These include channel rank loss and antenna correlation - although channel correlation still affects diversity on a per user basis, it is not a major issue for multi-user diversity.
- MU-MIMO allows spatial multiplexing gain to be achieved at the base station without the need for multiple antennas at the UE. This allows for the production of cheap remote terminals - the intelligence and cost is included within the base station.

The advantages of using multi-user MIMO, MU-MIMO come at a cost of additional hardware - antennas and processing - and also obtaining the channel state information which requires the use of the available bandwidth.

1.7.2 MIMO-MAC

This form of MU-MIMO is used for a multiple access channel - hence MIMO and it is used in uplink scenarios. For the MIMO-MAC the receiver performs much of the processing - here the receiver needs to know the channel state and uses Channel Sate Information at the Receiver, CSIR. Determining CSIR is generally easier than determining CSIT, but it requires significant levels of uplink capacity to transmit the dedicated pilots from each user. However MIMO MAC systems outperform point-to-point MIMO particularly if the number of receiver antennas is greater than the number of transmit antennas at each user.

1.7.3 MIMO-BC

This form of MU-MIMO is used for the MIMO broadcast channels, i.e. the downlink. Of the two channels, BC and MAC, it is the broadcast channel that is the more challenging within MU-MIMO. Transmit processing is required for this and it is typically in the form of pre-coding and SDMA, Space Division Multiple Access based downlink user scheduling. For this the transmitter has to know the Channel State Information at the Transmitter, CSIT. This enables significant throughput improvements over that of ordinary point to point MIMO systems, especially when the number of transmit antennas exceeds that of the antennas at each receiver.

CHAPTER - 2

REVIEW OF LITERATURE

2.1 Literature Review

G. J. Foschini and M. J. Gans, **et al,** In mid 90(s) researches of A. PaulrajS. Kailath t al, E. Telatar and the historical research of G. FoschiniJ. Gansld quo On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas .He investigated a new era in the modern wireless communication. The research of G. Foschini J.Gans led to what became defined as Space Time (ST) premise. Their study depicted mathematical models for optimizing spatial sharing of the physical link (channel capacity) through use of multi-element antenna MEA (space dimension). Use of space dimension opened new avenues to produce efficient coding and modulation techniques by exploring various combinations between spatial and the established time frequency techniques. It has become a part of today's WCT necessities, that wireless designers acquire a profound understanding of this premise. This paper reviews the capacity limits in MEA channel, as expressed by G. FoschiniJ. Gans and E. Telatar and the impact of their findings on succeeding developments in WCT field. The paper includes a brief description of two selected ST schemes; Multi-Input-Multi-Output with Orthogonal-Frequency-Division-Multiplexing (MIMO-OFDM) and a method to exploit the location diversity of Multiple Antenna Sites (MAS) for spatial multiplexing SFN-MAP-TDD-MIMO- OFDM technique. Finally, paper predicts and discusses the next probable development roots in WCT [1][2][3][4].

I. E. Telatar, et al, we investigate the problem of maximizing the capacity of multi-antenna Gaussian channels when one has the freedom of moving the transmit/receive antennas so as to modify individual singular values of the transfer matrix (subject to an overall energy conservation constraint). We solve this maximization problem and make some interesting observations. Namely that with n transmit and n receive antennas, when the signal-to-noise ratio is sufficiently large, the optimal solution corresponds to creating n parallel channels, all of which have the same strength. On the other extreme, when the signal-to-noise ratio is sufficiently small, the optimal solution boils down to creating a single channel. This is done by using the transmit and receive antennas to create focused beams. Perhaps the most interesting lesson is that beam forming is optimal only in the low signal-to-noise regime[5]

G. J. Foschini, et al,For the single-user communications pragmatic yet powerful methods known as layered space-time (LST) architectures provide means to increase the user data rate of a multiple-input multiple-output (MIMO) antenna system dramatically. To achieve better error rate performance, the LST transmission can be further accompanied with forward error correction coding. Future wireless communication systems, however, require high data rates also in multiuser environments. For broadband multiuser wireless communications, multicarrier code-division multiple-access (MC-CDMA) has emerged as an attractive technique due to its low equalization complexity and robust performance in multipath fading channels. Utilizing strong channel coding and LST architectures with MC-CDMA, high spectral efficiency and good error rate performance can be obtained in diverse environments. In this paper, single and multi-antenna turbo coded downlink MC-CDMA is combined with the concept of LST architectures. Due to the inevitable complexity restrictions, a suboptimal receiver interface for the underlying system is designed and its performance is evaluated in fading channels. The results demonstrate that significant improvement in both error rate performance and the system throughput can be achieved also with multiuser communications by using these MIMO techniques[6][7][8].

G. D. Golden, C. J. Foschini, R. A. Valenzuela and P. W. Wolniansky, et al, The signal detection algorithm of the vertical BLAST (Bell Laboratories Layered Space-Time) wireless communications architecture is briefly described. Using this joint space-time approach, spectral efficiencies ranging from 20-40 bit/s/Hz have been demonstrated in the laboratory under flat fading conditions at indoor fading rates. Early results are presented[9][10]

P.W. Wolniansky, G.J. Foschini, G.D. Golden and R.A. Valenzuela, et al, Information theory research has shown that the rich-scattering wirelesschannel is capable of enormous theoretical capacities if the multipath is properly exploited. In this paper, we describe a wireless communication architecture known as vertical BLAST (Bell Laboratories Layered Space-Time) or V-BLAST, which has been implemented in real-time in the laboratory. Using our laboratory prototype, we have demonstrated spectral efficiencies of 20-40 bps/Hz in an indoor propagation environment at realistic SNRs and error rates. To the best of our knowledge, wireless spectral efficiencies of this magnitude are unprecedented and are furthermore unattainable using traditional techniques[11][12][13]

S. Alamouti, et al,This paper presents a simple two-branch transmit diversity scheme. Using two transmit antennas and one receive antenna the scheme provides the same diversity order as maximal-ratio receiver combining (MRRC) with one transmit antenna, and two receive antennas. It is also shown that the scheme may easily be generalized to two transmit antennas and receive antennas to provide a diversity order of 2. The new scheme does not require any bandwidth expansion any feedback from the receiver to the transmitter and its computation complexity is similar to MRRC. Papers by Gerard J. Foschini and Michael J. Gans, Foschini and EmreTelatar have shown that the channel capacity (a theoretical upper bound on system throughput) for a MIMO system is increased as the number of antennas is increased, proportional to the smaller of the number of transmit antennas and the number of receive antennas. This is known as the multiplexing gain and this basic finding in information theory is what led to a spurt of research in this area. Despite the simple propagation models used in the aforementioned seminal works, the multiplexing gain is a fundamental property that can be proved under almost any physical channel propagation model and with practical hardware that is prone to transceiver impairments[14][15][16].

Papers by Fernando Rosas and Christian Oberli have shown that the entire MIMO SVD link can be approximated by the average of the SER of Nakagami-m channels. This leads to characterize the eigen channels of N × N MIMO channels with N larger than 14, showing that the smallest eigen channel distributes as a Rayleigh channel, the next four eigen channels closely distributes as Nakagami-m channels with m = 4, 9, 25 and 36, and the N - 5 remaining eigen channels have statistics similar to an additive white Gaussian noise (AWGN) channel within 1 dB signal-to-noise ratio. It is also shown that 75% of the total mean power gain of the MIMO SVD channel goes to the top third of all the eigen channels.

A textbook by A. Paulraj, R. Nabar and D. Gore has published an introduction to this area. There are many other principal textbooks available as well. Mobile Experts has published a research report which predicts the use of MIMO technology in 500 million PCs, tablets, and smart phones by 2016[17][18][19].

CHAPTER - 3

RATIONABLE AND SCOPE OF THE STUDY

In radio, multiple-input and multiple-output, or MIMO (pronounced my-moh by some and me-moh by others), is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) and/or to achieve a diversity gain that improves the link reliability (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+.

3.1 First concepts

The earliest ideas in this field go back to work by AR Kaye and DA George (1970), Branderburg and Wyner (1974) and W. van Etten (1975, 1976). Jack Winters and Jack Salz at Bell Laboratories published several papers on beam forming related applications in 1984 and 1986.

3.1.1 Principle

The multi-user MIMO concept of space-division multiple access (SDMA) was proposed by Richard Roy and BjörnOttersten, researchers at Array Comm, in 1991. Their US patent (No. 5515378 issued in 1996) emphasizes "an array of receiving antennas at the base station" and "plurality of remote users". Arogyaswami Paulraj and Thomas Kailath proposed the concept of spatial multiplexing (SM) using MIMO in 1993. Their US patent (No. 5,345,599 issued in 1994) emphasized "wireless broadcast communications" applications and splitting a high-rate signal "into several low-rate signals".

In 1996, Greg Raleigh, Gerard J. Foschini, and EmreTelatar 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. Bell Labs was the first to demonstrate a laboratory prototype of spatial multiplexing in 1998, where spatial multiplexing is a principal technology to improve the performance of MIMO communication systems.

Wireless standards

In the commercial area, Iospan Wireless Inc. developed the first commercial system in 2001 that used MIMO with orthogonal frequency-division multiple access technology (MIMO-OFDMA). Iospan technology supported both diversity coding and spatial multiplexing. In 2005, Airgo Networks had developed an IEEE 802.11n precursor implementation based on their patents on MIMO. Following that in 2006, several companies (including at least Broadcom, Intel, and Marvell) fielded a MIMO-OFDM solution based on a pre-standard for 802.11n Wi-Fi standard. Also in 2006, several companies (Beceem Communications, Samsung, Runcom Technologies, etc.) had developed MIMO-OFDMA based solutions for IEEE 802.16eWiMAX broadband mobile standard. All upcoming 4G systems will also employ MIMO technology. Several research groups have demonstrated over 1 Gbit/s prototypes.

3.1.2 Functions of MIMO

MIMO can be sub-divided into three main categories, precoding, spatial multiplexing or SM, and diversity coding.

Precoding is multi-stream beamforming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-stream) beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input. The benefits of beamforming are to increase the received signal gain, by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect. In line-of-sight propagation, beamforming results in a well defined directional pattern. However, conventional beams are not a good analogy in cellular networks, which are mainly characterized by multipath propagation. When the receiver has multiple antennas, the transmit beamforming cannot simultaneously maximize the signal level at all of the receive antennas, and precoding with multiple streams is often beneficial. Note that precoding requires knowledge of channel state information (CSI) at the transmitter and the receiver.

Spatial multiplexing requires MIMO antenna configuration. In spatial multiplexing, a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures and the receiver has accurate CSI, it can separate these streams into (almost) parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. Spatial multiplexing can be used without CSI at the transmitter, but can be combined with precoding if CSI is available. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access or multi-user MIMO, in which case CSI is required at the transmitter .The scheduling of receivers with different spatial signatures allows good seperability.

Diversity Coding techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beamforming or array gain from diversity coding. Diversity coding can be combined with spatial multiplexing when some channel knowledge is available at the transmitter.

3.1.3 Forms of MIMO

Multi-antenna types

Multi-antenna MIMO (or Single user MIMO) technology has been developed and implemented in some standards, e.g., 802.11n products.

- SISO/SIMO/MISO are special cases of MIMO
    - Multiple-input and single-output (MISO) is a special case when the receiver has a single antenna.
    - Single-input and multiple-output (SIMO) is a special case when the transmitter has a single antenna.
    - single-input single-output (SISO) is a conventional radio system where neither the transmitter nor receiver have multiple antenna.
- Principal single-user MIMO techniques
    - Bell Laboratories Layered Space-Time (BLAST), Gerard. J. Foschini (1996)
    - Per Antenna Rate Control (PARC), Varanasi, Guess (1998), Chung, Huang, Lozano (2001)
    - Selective Per Antenna Rate Control (SPARC), Ericsson (2004)

- Some limitations
    - The physical antenna spacing is selected to be large; multiple wavelengths at the base station. The antenna separation at the receiver is heavily space constrained in hand sets, though advanced antenna design and algorithm techniques are under discussion.

Multi-user types

Recently, results of research on multi-user MIMO technology have been emerging. While full multi-user MIMO (or network MIMO) can have a higher potential, practically, the research on (partial) multi-user MIMO (or multi-user and multi-antenna MIMO) technology is more active.

- Multi-user MIMO (MU-MIMO)
    - In recent 3GPP and WiMAX standards, MU-MIMO is being treated as one of the candidate technologies adoptable in the specification by a number of companies, including Samsung, Intel, Qualcomm, Ericsson, TI, Huawei, Philips, Alcatel-Lucent, and Free scale. For these and other firms active in the mobile hardware market, MU-MIMO is more feasible for low complexity cell phones with a small number of reception antennas, whereas single-user SU-MIMO's higher per-user throughput is better suited to more complex user devices with more antennas.
    - PURC allows the network to allocate each antenna to a different user instead of allocating only a single user as in single-user MIMO scheduling. The network can transmit user data through a codebook-based spatial beam or a virtual antenna. Efficient user scheduling, such as pairing spatially distinguishable users with codebook based spatial beams, is additionally discussed for the simplification of wireless networks in terms of additional wireless resource requirements and complex protocol modification. Recently, PURC is included in the system description documentation (SDD) of IEEE 802.16m (WiMAX evolution to meet the ITU-R's IMT-Advance requirements).
    - Enhanced multiuser MIMO: 1) Employs advanced decoding techniques, 2) Employs advanced precoding techniques
    - SDMA represents either space-division multiple access or super-division multiple access where super emphasises that orthogonal division such as

    - frequency and time division is not used but non-orthogonal approaches such as superposition coding are used.
- Cooperative MIMO (CO-MIMO)
    - Uses distributed antennas which belong to other users.
- Macro diversity MIMO
    - A form of space diversity scheme which uses multiple transmit or receive base stations for communicating coherently with single or multiple users which are possibly distributed in the coverage area, in the same time and frequency resource.
    - The transmitters are far apart in contrast to traditional micro diversity MIMO schemes such as single-user MIMO. In multi-user macro diversity MIMO scenario, users may also be far apart. Therefore, every constituent link in the virtual MIMO link has distinct average link SNR. This difference is mainly due to the different long-term channel impairments such as path loss and shadow fading which are experienced by different links.
    - Macro diversity MIMO schemes pose unprecedented theoretical and practical challenges.
- MIMO Routing
    - Routing a cluster by a cluster in each hop, where the number of nodes in each cluster is larger or equal to one. MIMO routing is different from conventional (SISO) routing since conventional routing protocols route node by node in each hop.

3.1.4 Applications of MIMO

Spatial multiplexing techniques make the receivers very complex, and therefore they are typically combined with Orthogonal frequency-division multiplexing (OFDM) or with Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by a multi-path channel are handled efficiently. The IEEE 802.16e standard incorporates MIMO-OFDMA. The IEEE 802.11n standard, released in October 2009, recommends MIMO-OFDM. MIMO is also planned to be used in Mobile radio telephone standards such as recent 3GPP and 3GPP2. In 3GPP, High-Speed Packet Access plus (HSPA+) and Long Term Evolution (LTE) standards take MIMO into account. Moreover, to fully support cellular environments, MIMO research consortia including IST-MASCOT propose to develop advanced MIMO techniques, e.g., multi-user MIMO (MU-MIMO).

MIMO technology can be used in non-wireless communications systems. One example is the home networking standard ITU-TG.9963, which defines a powerline communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

3.1.5 Mathematical description

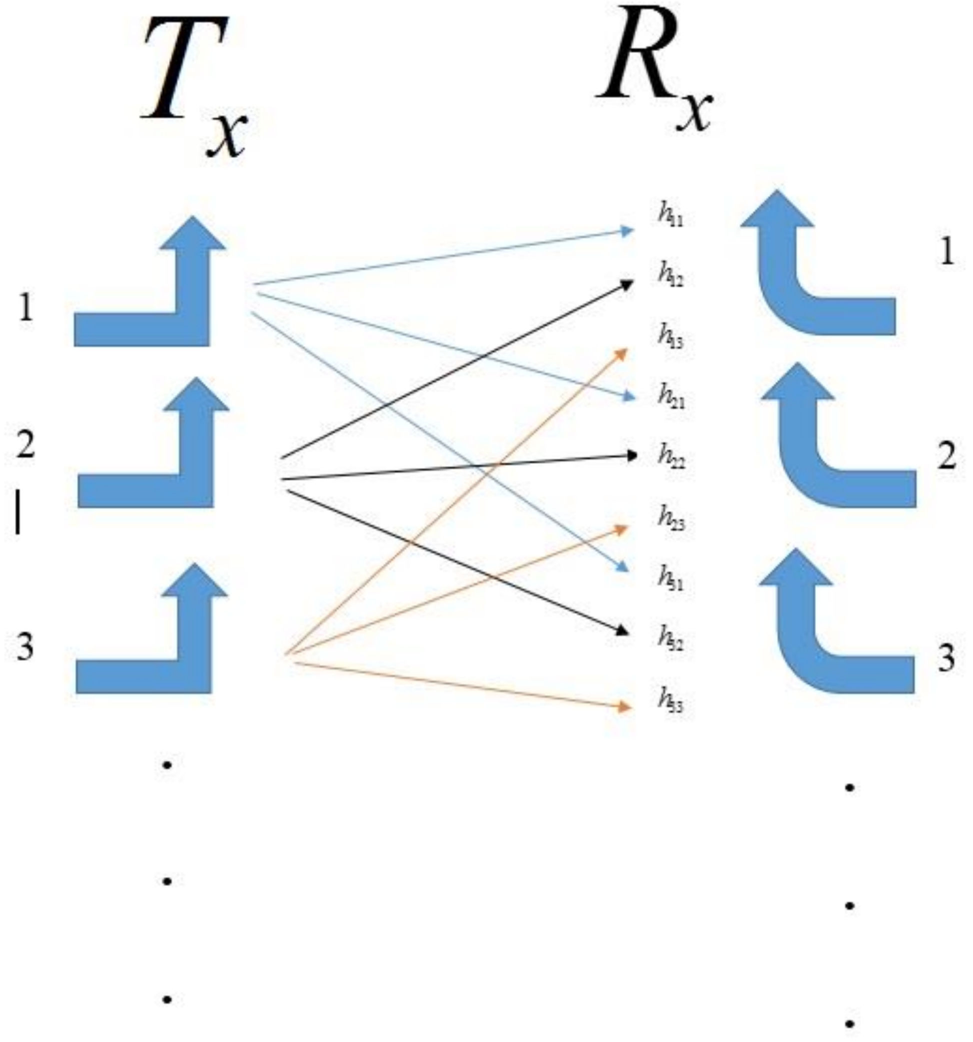

Figure 6: MIMO Channel Model.

In MIMO systems, a transmitter sends multiple streams by multiple transmit antennas. The transmit streams go through a matrix channel which consists of all $N_t N_r$ paths between the N_t transmit antennas at the transmitter and N_r receive antennas at the receiver. Then, the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information. A narrowband flat fading MIMO system is modeled as

$$Y = HX + N \tag{3.1}$$

where Y and X are the receive and transmit vectors, respectively, and H and N are the channel matrix and the noise vector, respectively.

3.2 MIMO Testing

MIMO signal testing focuses first on the transmitter/receiver system. The random phases of the sub-carrier signals can produce instantaneous power levels that cause the amplifier to compress, momentarily causing distortion and ultimately symbol errors. Signals with a high PAR (peak-to-average ratio) can cause amplifiers to compress unpredictably during transmission. OFDM signals are very dynamic and compression problems can be hard to detect because of their noise-like nature. Knowing the quality of the signal channel is also critical. A channel emulator can simulate how a device performs at the cell edge, can add noise or can simulate what the channel looks like at speed. To fully qualify the performance of a receiver, a calibrated transmitter, such as a vector signal generator (VSG), and channel emulator can be used to test the receiver under a variety of different conditions. Conversely, the transmitter's performance under a number of different conditions can be verified using a channel emulator and a calibrated receiver, such as a vector signal analyzer (VSA). Understanding the channel allows for manipulation of the phase and amplitude of each transmitter in order to form a beam. To correctly form a beam, the transmitter needs to understand the characteristics of the channel. This process is called channel sounding or channel estimation. A known signal is sent to the mobile device that enables it to build a picture of the channel environment. The mobile device sends back the channel characteristics to the transmitter. The transmitter can then apply the correct phase and amplitude adjustments to form a beam directed at the mobile device. This is called a closed-loop MIMO system. For beam forming, it is required to adjust the phases and amplitude of each transmitter. In a beam former optimized for spatial diversity or spatial multiplexing, each antenna element simultaneously transmits a weighted combination of two data symbols.

MIMO Foundation

Papers by Gerard J. Foschini and Michael J. Gans, Foschini and EmreTelatar have shown that the channel capacity (a theoretical upper bound on system throughput) for a

MIMO system is increased as the number of antennas is increased, proportional to the smaller of the number of transmit antennas and the number of receive antennas. This is known as the multiplexing gain and this basic finding in information theory is what led to a spurt of research in this area. Despite the simple propagation models used in the aforementioned seminal works, the multiplexing gain is a fundamental property that can be proved under almost any physical channel propagation model and with practical hardware that is prone to transceiver impairments.

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3.2.1 Diversity-multiplexing trade off (DMT)

There exists a fundamental tradeoff between transmit diversity and spatial multiplexing gains in a MIMO system (Zheng and Tse, 2003). In particular, achieving high spatial multiplexing gains is of profound importance in modern wireless systems.

3.2.2 Other Applications

Given the nature of MIMO, it is not limited to wireless communication. It can be used for wire line communication as well. For example, a new type of DSL technology (gigabit DSL) has been proposed based on binder MIMO channels.

3.3 Sampling Theory In MIMO Systems

An important question which attracts the attention of engineers and mathematicians is how to use the multi-output signals at the receiver to recover the multi-input signals at the transmitter. In Shang, Sun and Zhou (2007), sufficient and necessary conditions are established to guarantee the complete recovery of the multi-input signals.

3.3.1 Minimum Mean Square Error

In statistics and signal processing, a minimum mean square error (MMSE) estimator is an estimation method which minimizes the mean square error (MSE) of the fitted values of a dependent variable, which is a common measure of estimator quality.

The term MMSE more specifically refers to estimation in a Bayesian setting with quadratic cost function. The basic idea behind the Bayesian approach to estimation stems from practical situations where we often have some prior information about the parameter to be estimated. For instance, we may have prior information about the range that the parameter can assume; or we may have an old estimate of the parameter that we want to modify when a new observation is made available. This is in contrast to the non-Bayesian approach like minimum-variance unbiased estimator (MVUE) where absolutely nothing is assumed to be known about the parameter in advance and which does not account for such situations. In the Bayesian approach, such prior information is captured by the prior probability density function of the parameters; and based directly on Bayes theorem, it allows us to make better posterior estimates as more observations become available. Thus unlike non-Bayesian approach where parameters of interest are assumed to be deterministic, but unknown constants, the Bayesian estimator seeks to estimate a parameter that is itself a random variable. Furthermore, Bayesian estimation can also deal with situations where the sequence of observations are not necessarily independent. Thus Bayesian estimation provides yet another alternative to the MVUE. This is useful when the MVUE does not exist or cannot be found.

Definition

Let x be $a^n X1$ unknown (hidden) random vector variable, and let y be $a^m X1$ known random vector variable (the measurement or observation), both of them not necessarily of the same dimension. An estimator $\hat{x}(y)$ of x is any function of the measurement y. The estimation error vector is given by $e = \hat{x} - x$ and its mean squared error (MSE) is given by the trace of error covariance matrix

$$MSE = tr[E[(\hat{x}-x)(\hat{x}-x)^T]], \qquad (3.2)$$

where the expectation is taken over both x and y. When x is a scalar variable, then MSE expression simplifies to $E[[\hat{x}-x]^2]$.

3.3.2 Maximum Likelihood

In statistics, maximum-likelihood estimation (MLE) is a method of estimating the parameters of a statistical model. When applied to a data set and given a statistical model, maximum-likelihood estimation provides estimates for the model's parameters.

The method of maximum likelihood corresponds to many well-known estimation methods in statistics. For example, one may be interested in the heights of adult female penguins, but be unable to measure the height of every single penguin in a population due to cost or time constraints. Assuming that the heights are normally (Gaussian) distributed with some unknown mean and variance, the mean and variance can be estimated with MLE while only knowing the heights of some sample of the overall population. MLE would accomplish this by taking the mean and variance as parameters and finding particular parametric values that make the observed results the most probable (given the model).

In general, for a fixed set of data and underlying statistical model, the method of maximum likelihood selects the set of values of the model parameters that maximizes the likelihood function. Intuitively, this maximizes the "agreement" of the selected model with the observed data, and for discrete random variables it indeed maximizes the probability of the observed data under the resulting distribution. Maximum-likelihood estimation gives a unified approach to estimation, which is well-defined in the case of the normal distribution and many other problems. However, in some complicated problems, difficulties do occur: in such problems, maximum-likelihood estimators are unsuitable or do not exist.

Principles

Suppose there is a sample $x_1, \ldots, x_n$ of n independent and identically distributed observations, coming from a distribution with an unknown probability density function $f_0(.)$.

To use the method of maximum likelihood, one first specifies the joint density function for all observations. For an independent and identically distributed sample, this joint density function is

$$f(x_1, \ldots, x_n / \theta) = f(x_1/\theta) \times f(x_2/\theta) \times \ldots \times f(x_n/\theta). \tag{3.3}$$

Now we look at this function from a different perspective by considering the observed values $x_1, \ldots, x_n$ to be fixed "parameters" of this function, where as θ will be the function's variable and allowed to vary freely,this function will be called the likelihood:

$$L(\theta / x_1, \ldots, x_n) = f(x_1, \ldots, x_n / \theta) \tag{3.4}$$

Note that the vertical bar in $L(\theta/x_1,\ldots,x_n)$ does not mean "condition" or "given" in probability theory. Instead, the vertical denotes a separation between the two input arguments and θ the vector-valued input $x_1,\ldots,x_n$.

A maximum likelihood estimator coincides with the most probable Bayesian estimator given a uniform prior distribution on the parameters. Indeed, the maximum a posteriori estimate is the parameter θ that maximizes the probability of θ given the data, given by Bayes' theorem:

$$p(\theta/x_1,\ldots,x_n)=\frac{f(x_1,\ldots,x_n/\theta)\,p(\theta)}{p(x_1,\ldots,x_n)} \tag{3.5}$$

Where $p(\theta)$ is the prior distribution for the parameter θ and where $p(x_1,\ldots,x_n)$ is the probability of the data averaged over all parameters. Since the denominator is independent of θ, the Bayesian estimator is obtained by maximizing $f(x_1,\ldots,x_n/\theta)p(\theta)$ with respect to θ. If we further assume that the prior $p(\theta)$ is a uniform distribution, the Bayesian estimator obtained by maximizing the likelihood function $f(x_1,\ldots,x_n/\theta)$. Thus the Bayesian estimator coincides with the maximum-likelihood estimator for a uniform prior distribution $p(\theta)$.

Iterative Procedures

Consider problems where both states x_i and parameters such as σ^2 require to be estimated. Iterative procedures such as Expectation-maximization algorithms may be used to solve joint state-parameter estimation problems. For example, suppose that n samples of state estimates $\hat{x}_i$ together with a sample mean $\overline{x}$ have been calculated by either a minimum-variance Kalman filter or a minimum-variance smoother using a previous variance estimate $\hat{\sigma}^2$. Then the next variance iterate may be obtained from the maximum likelihood estimate calculation

$$\hat{\sigma}^2=\frac{1}{n}\sum_{i=1}^{n}(\hat{x}_i-\overline{x})^2 \tag{3.6}$$

Applications

Maximum likelihood estimation is used for a wide range of statistical models, including:

- linear models and generalized linear models;
- exploratory and confirmatory factor analysis;
- structural equation modeling;

- many situations in the context of hypothesis testing and confidence interval formation;
- discrete choice models;
- Curve fitting.

These uses arise across applications in widespread set of fields, including:

- communication systems;
- psychometrics;
- econometrics;
- time-delay of arrival (TDOA) in acoustic or electromagnetic detection;
- data modeling in nuclear and particle physics;
- magnetic resonance imaging;
- computational phylogenetic;
- origin/destination and path-choice modeling in transport networks;
- geographical satellite-image classification.

3.4 Bell Laboratories Layered Space-Time

Bell Laboratories Layered Space-Time (BLAST) is a transceiver architecture for offering spatial multiplexing over multiple-antenna wireless communication systems. Such systems have multiple antennas at both the transmitter and the receiver in an effort to exploit the many different paths between the two in a highly-scattering wireless environment. BLAST was developed by Gerard Foschini at Lucent Technologies' Bell Laboratories (now Alcatel-Lucent Bell Labs). By careful allocation of the data to be transmitted to the transmitting antennas, multiple data streams can be transmitted simultaneously within a single frequency band — the data capacity of the system then grows directly in line with the number of antennas (subject to certain assumptions). This represents a significant advance on current, single-antenna systems.

3.4.1 V-BLAST

V-BLAST(Vertical-Bell Laboratories Layered Space-Time) is a detection algorithm to the receipt of multi-antenna MIMO systems. Available for the first time in 1996 at Bell Laboratories in New Jersey in the United States by Gerard J. Foschini. He proceeded simply to eliminate interference caused successively issuers.

Its principle is quite simple: to make a first detection of the most powerful signal. It regenerates the received signal from this user from this decision. Then, the signal is regenerated subtracted from the received signal and, with this new signal, it proceeds to the detection of the second user's most powerful, since it has already cleared the first and so forth. What gives a vector containing received less interference.

The complete detection algorithm can be summarized as recursive as follows:

Initialize:

$$\begin{aligned} & i \leftarrow 1 \\ & r_1 = r \\ & G_1 = (H^H H + \sigma^2 I_{N_r})^{-1} H^H \\ & k_1 = \arg\min \left\| (G_1)_j \right\|^2 \end{aligned} \tag{3.7}$$

Recursive:

$$\begin{aligned} & w_k = (G_i)_k \\ & y_k = w_k^T \times r_i \\ & \hat{s}_k = sign(y_k) \\ & r_{i+1} = r_i - \hat{s}_k (H)_{ki} \\ & G_{I+1} = ((H_i^H H_i) + \sigma^2 I_{N_r})^{-1} H_i^H \\ & k_{i+1} = \arg\min \left\| (G_{i+1}) \right\|^2 \\ & i \leftarrow i+1 \end{aligned} \tag{3.8}$$

3.5 Interference

Interference is a phenomenon in which two waves superpose to form a resultant wave of greater or lower amplitude. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Interference effects can be observed with all types of waves, for example, light, radio, acoustic and surface water waves.

3.5.1 Mechanism

The principle of superposition of waves states that when two or more propagating waves of same type are incident on the same point, the total displacement at that point is equal to the vector sum of the displacements of the individual waves. If a crest of a wave meets a crest of another wave of the same frequency at the same point, then the magnitude of the displacement is the sum of the individual magnitudes – this is constructive interference. If a crest of one wave meets a trough of another wave then the magnitude of the displacements is equal to the difference in the individual magnitudes – this is known as destructive interference.

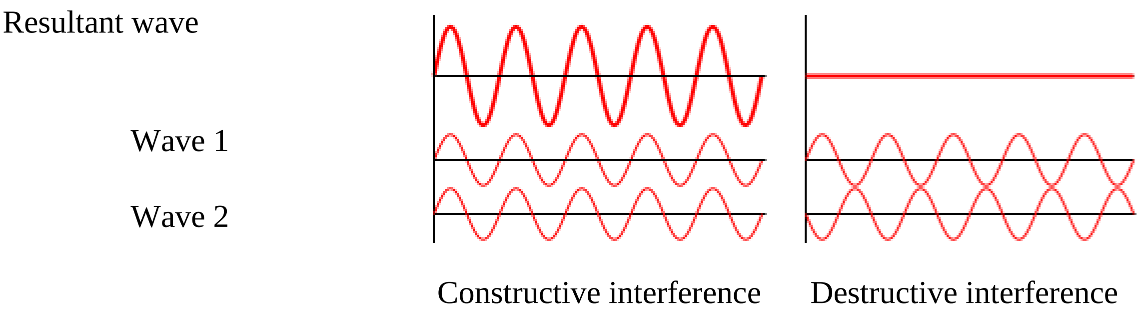

Figure 7: Interference of waves.

Constructive interference occurs when the phase difference between the waves is a multiple of 2π, whereas destructive interference occurs when the difference is an odd multiple of π. If the difference between the phases is intermediate between these two extremes, then the magnitude of the displacement of the summed waves lies between the minimum and maximum values.

Consider, for example, what happens when two identical stones are dropped into a still pool of water at different locations. Each stone generates a circular wave propagating outwards from the point where the stone was dropped. When the two waves overlap, the net displacement at a particular point is the sum of the displacements of the individual waves. At some points, these will be in phase, and will produce a maximum displacement. In other places, the waves will be in anti-phase, and there will be no net displacement at these points. Thus, parts of the surface will be stationary—these are seen in the figure above and to the right as stationary blue-green lines radiating from the center.

Between Two Plane Waves

A simple form of interference pattern is obtained if two plane waves of the same frequency intersect at an angle. Interference is essentially an energy redistribution process. The energy which is lost at the destructive interference is regained at the constructive interference. One wave is travelling horizontally, and the other is travelling downwards at an angle θ to the first wave. Assuming that the two waves are in phase at the point **B**, then the relative phase changes along the *x*-axis. The phase difference at the point **A** is given by

$$\Delta\varphi = \frac{2\pi d}{\lambda} = \frac{2\pi \sin\theta}{\lambda} \tag{3.9}$$

It can be seen that the two waves are in phase when

$$\frac{x \sin\theta}{\lambda} = 0, \pm 1, \pm 2, ... \ , \tag{3.10}$$

and are half a cycle out of phase when

$$\frac{x \sin\theta}{\lambda} = 0, \pm\frac{1}{2}, \pm\frac{3}{2}, ... \tag{3.11}$$

Constructive interference occurs when the waves are in phase, and destructive interference when they are half a cycle out of phase. Thus, an interference fringe pattern is produced, where the separation of the maxima is

$$d_f = \frac{\lambda}{\sin\theta} \tag{3.12}$$

An d_f is known as the fringe spacing. The fringe spacing increases with increase in wavelength, and with decreasing angle θ .The fringes are observed wherever the two waves overlap and the fringe spacing is uniform throughout.

Between Two Spherical Waves

A point source produces a spherical wave. If the light from two point sources overlaps, the interference pattern maps out the way in which the phase difference between the two waves varies in space. This depends on the wavelength and on the separation of the point sources. The figure to the right shows interference between two spherical waves. The wavelength increases from top to bottom, and the distance between the sources increases from left to right.

When the plane of observation is far enough away, the fringe pattern will be a series of almost straight lines, since the waves will then be almost planar.

Multiple Beams

Interference occurs when several waves are added together provided that the phase differences between them remain constant over the observation time.

It is sometimes desirable for several waves of the same frequency and amplitude to sum to zero (that is, interfere destructively, cancel). This is the principle behind, for example, 3-phase power and the diffraction grating. In both of these cases, the result is achieved by uniform spacing of the phases.

It is easy to see that a set of waves will cancel if they have the same amplitude and their phases are spaced equally in angle. Using phasors , each wave can be represented as $Ae^{i\varphi_n}$ for N waves from $n=0$ to $n=N-1$, where

$$\varphi_n - \varphi_{n-1} = \frac{2\pi}{N} . \tag{3.13}$$

To show that

$$\sum_{n=0}^{N-1} Ae^{i\varphi_n} = 0 \tag{3.14}$$

one merely assumes the converse, then multiplies both sides by $e^{i\frac{2\pi}{N}}$.The Fabry–Pérot interferometer uses interference between multiple reflections.

A diffraction grating can be considered to be a multiple-beam interferometer, since the peaks which it produces are generated by interference between the light transmitted by each of the elements in the grating. Feynman suggests that when there are only a few sources, say two, we call it "interference", as in Young's double slit experiment, but with a large number of sources, the process is labeled "diffraction".

3.5.2 Radio Interferometry

In 1946, a technique called astronomical interferometry was developed. Astronomical radio interferometers usually consist either of arrays of parabolic dishes or two-dimensional arrays of Omni-directional antennas. All of the telescopes in the array are widely separated and are usually connected together using coaxial cable, waveguide, optical fiber, or other type of transmission line. Interferometry increases the total signal collected, but its primary purpose is to vastly increase the resolution through a process called Aperture synthesis. This technique works by superposing (interfering) the signal waves from the different telescopes on the principle that waves that coincide with the same phase will add to each other while two waves that have opposite phases will cancel each other out. This creates a combined telescope that is equivalent in resolution (though not in sensitivity) to a single antenna whose diameter is equal to the spacing of the antennas furthest apart in the array.

CHAPTER 4

METHODOLOGY

4.1 Scope of the Project

In a spatial multiplexing configuration, the system can obtain substantial gains in data rate. These capacity gains grow linearly with the minimum number of transmit and receive antennas, and the transmission of individual data streams from the transmitter to the receiver. In order to separate these streams, the designer may resort to several detection techniques, which are similar to multiuser detection methods. The optimal maximum likelihood (ML) detector can be implemented using the sphere decoding algorithm .However, the complexity of this algorithm can be polynomial or exponential depending on the signal-to-noise ratio (SNR)and the signal constellation. This has motivated the development of various alternative low-complexity strategies.

A promising transmission system, called diagonal Bell Laboratories Layered Space-Time (D-BLAST) proposed by Foschini, is the first BLAST architecture. Owing to the large computational complexity required for the scheme, a simplified version, called the Vertical BLAST (V-BLAST) has been proposed. The V-BLAST can be seen as an ordered SIC, on the other hand, there is equivalence between the V-BLAST receiver and the generalized decision feedback equalizer (GDFE). A number of other strategies are also investigated to achieve the capacity gain of MIMO systems including the linear and the decision feedback (DF) detector and the parallel interference cancellation (PIC).

In this work, we propose a novel SIC strategy for MIMO spatial multiplexing systems based on multiple processing branches. The proposed detection structure is equipped with SICs on several parallel branches which employ different ordering patterns. Namely, each branch produces a symbol estimate vector by exploiting a certain ordering pattern. Thus ,there is a group of symbol estimate vectors at the end of the multi-branch (MB) structure. Based on different application requirements, different criteria, such as ML, MMSE and constant modulus (CM), can be used as selection rules to select the branch with the best performance.

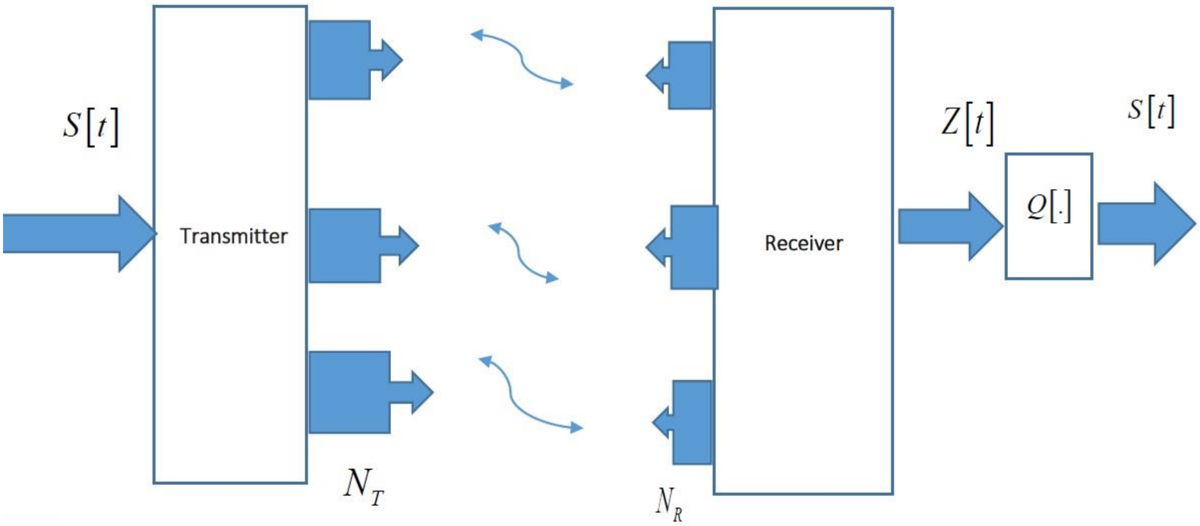

Figure 8 :MIMO Spatial multiplexing model.

MIMO can be sub-divided into three main categories, pre-coding, spatial multiplexing or SM, and diversity coding.

We adopt the MMSE estimator for the design of the proposed MB-SIC structure for MIMO receiver because the MMSE estimator usually has good performance, is mathematically tractable and has relatively simple adaptive implementation. In one word ,the basic principle of the proposed structure is to exploit the orderings of SIC in appropriate ways such that the detector can produce a group of estimate vectors and then higher detection diversity can be obtained by selecting the most likely one based on a certain selection rule. The simulation results reveal that our scheme successfully mitigates the error propagation and approaches the performance of the optimal ML detector.

4.2 MULTI-BRANCH SIC DETECTION

This section is devoted to the description of the proposed multi-branch successive interference cancellation (MB-SIC)detector for MIMO systems. We present the overall principles and structures of the proposed scheme in the first place, and then we introduce the selection rules and ordering schemes which are employed in our proposed detector in the next. Based on different application requirements and system structures, better performance and lower complexity can beachieved by choosing a proper selection rule and ordering scheme.

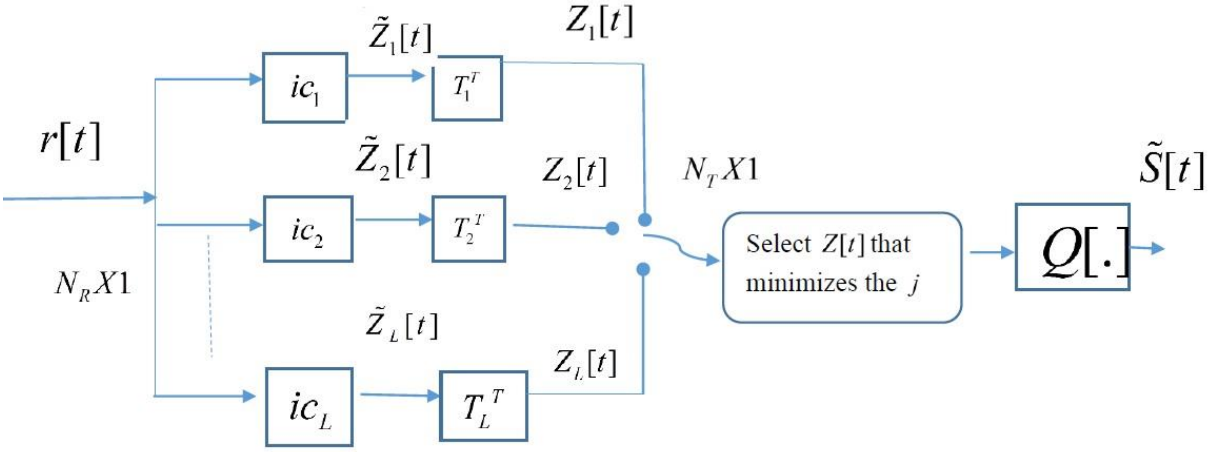

Figure 9: Block diagram of Multi-Branch Interference Cancellation Detector.

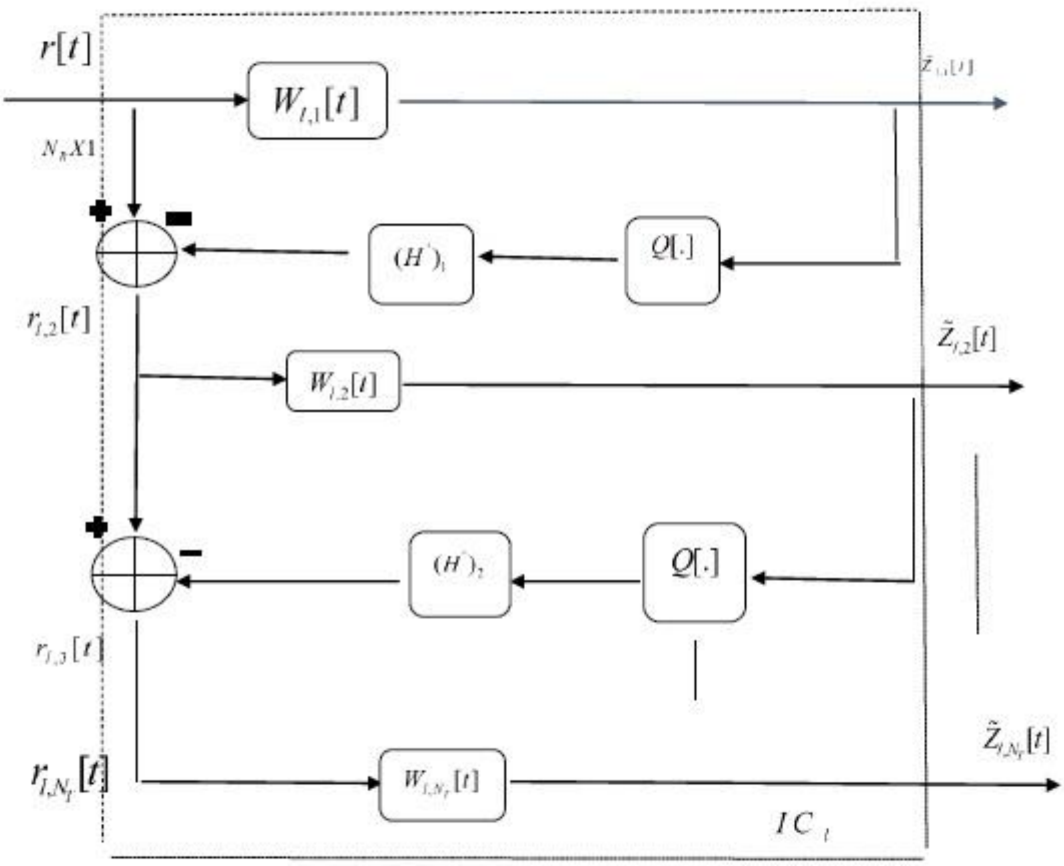

Figure 10: Inner structure of the nth interference cancellater branch.

4.2.1 Proposed Scheme

In this subsection, we detail the principles and structures of the proposed MB-SIC detector for MIMO systems. The proposed detection structure employs SICs on several parallel branches which are equipped with different ordering patterns.

Namely, each branch produces a symbol estimate vector by exploiting a certain ordering pattern. Thus, there is a group of symbol estimate vectors at the end of the multi-branch(MB) structure. We present MMSE-SIC for the design of the proposed multi-branch MIMO receiver because the MMSE estimator usually has good performance, is mathematically tractable and has relatively simple adaptive implementation.

Figure 4 depicts the global block diagram of the proposed detector. In order to detect the transmitted signals using the proposed MB-SIC structure, the detection process for each branch uses linear MMSE nulling and symbol successive cancellation to compute $\tilde{Z}_l[i] = \left[\tilde{Z}_{l,1}[i], \tilde{Z}_{l,2}[i], ...\tilde{Z}_{l,N_T}[i]\right]^T$, which $\tilde{Z}_l[i]$ denotes the $N_T \times 1$ symbol estimate vector detected for the l-th branch by using the ordering transformation matrix T_l. Here, we introduce the ordering transformation matrix $T_l, l = 1, ...L$ which corresponds to the ordering pattern employed in the l-th branch. The process in the l-th SIC branch, shown in Figure 5, is mathematically given as follow

$$\tilde{Z}_{l,n}[i] = \omega_{l,n}^H[i] r_{l,n}[i], \tag{4.1}$$

Where

$$r_{l,n}[i] = r[i], \quad n = 1,$$

$$H_l^{'} = T_l H,$$

$$r_{l,n}[i] = r[i] - \sum_{k=1}^{n-1} \left(H^{'}\right)_k \hat{\tilde{s}}_{l,n}[i], \quad n \geq 2, \tag{4.2}$$

$$\omega_{l,n} = \left(\bar{H}_{l,n}^{'} \bar{H}_{l,n}^{H} + \frac{\sigma_\upsilon^2}{\sigma_s^2} I\right)^{-1} \left(H_l^{'}\right)_n,$$

$$\hat{\tilde{s}}_{l,n}[i] = Q\left(\tilde{Z}_{l,n}[i]\right),$$

Where $H_l^{'}$ is the transformed channel matrix for the l-th branch, $H_{l,n}^{'}$ denotes the n-th column of $H_l^{'}, \bar{H}_{l,n}'$ denotes the matrix obtained by taking columns $n, n+1, ...N_T$ of H'. $r_{l,n}[i]$ denotes the received vector after the cancellation of the previously detected (n-1) symbols, so that $r_{l,1}[i] = r[i]$.Without loss of generality, we assume that the signal stream is detected n=1 first. The interference due to the first stream is then regenerated and subtracted before n=2 is detected. This procedure is repeated successively until all streams are detected. The ordered symbol estimate vector $\tilde{z}_l[i]$ can be arranged in original order by

$$z_l[i] = T_l^T \tilde{z}_l[i] \tag{4.3}$$

In summary, the basic principle of the proposed structure is to exploit the orderings of SIC in appropriate ways such that the detector can produce a group of estimate vectors and then higher detection diversity can be obtained by selecting the most likely one based on a certain selection rule, which will be introduced in the following section. The simulation results reveal that our scheme successfully mitigates the error propagation and approaches the performance of the optimal ML detector.

4.2.2 Selection Rules

The proposed MB-SIC detector selects the branch that optimizes the corresponding cost function J according to

$$l_{opt} = \arg \min_{1 \le l \le L} \quad J\left(z_l[i]\right), \tag{4.4}$$

The final detected symbol is

$$\hat{s}_f[i] = Q\left(Z_{l_{opt}}[i]\right) \tag{4.5}$$

Based on different application requirements, different criteria, such as ML, MMSE and CM, can be used as selection rules to select the branch with the best performance.

1) Maximum Likelihood (or Minimum Euclidean Distance) Criterion: The cost function for the ML criterion, which is equivalent to the minimum Euclidean distance criterion, is written as

$$J_{ML} = \left\| r[i] - H\hat{s}[i] \right\|^2 \tag{4.6}$$

The ML criterion can provide the best performance among these candidate criteria while channel information is available. Although the channel estimation would cost extra complexity, the performance improvement by employing the ML criterion is considerable.

2) Minimum Mean Square Error Criterion:

   While channel information is not available, MMSE criterion can be used to select the branch which minimizes the mean square error of transmitted symbols. The cost function is given by

$$J_{MMSE} = \left\| \hat{s}[i] - z[i] \right\|^2 \tag{4.7}$$

   Where $\hat{s}\left[i\right]$ is symbol estimation in the decision directed mode, thus, the MMSE criterion would be greatly impaired by the error propagation.

3) Constant Modulus Criterion:

   The CM algorithm originally proposed by Godard, has widely been applied to the blind detection because of its robustness and easy implementation. In this context, CM criterion attempts to minimize the cost function

$$J_{CM} = E\left[\left|\left(Z_n[i]\right)^2 - 1\right|\right] \tag{4.8}$$

   We will show how these selection rules perform later in the simulation section. Note that for non constant modulus constellations such as QAM, one can replace the cost function with a square contour.

The novel structure for detection exploits different patterns and orderings for the modification of the original V-BLAST architecture and achieves higher detection diversity by selecting the branch which yields the estimates with the best performance .Fig.4(a) depicts the global block diagram of the proposed detector. In order to detect the transmitted signals using the proposed MB-SIC structure, the detection process for each branch uses linear MMSE nulling.

In summary, the basic principle of the proposed structure is to exploit the orderings of SIC in appropriate ways such that the detector can produce a group of estimate vectors and then higher detection diversity can be obtained by selecting the most likely one based on a certain selection rule, which will be introduced in the following section. The simulation results reveal that our scheme successfully mitigates the error propagation and approaches the performance of the optimal ML detector.

4.3. Ordering Schemes

Here, we propose the optimal ordering scheme and three alternative ordering schemes for designing the proposed receiver ,where the common framework is the use of parallel branches with ordering patterns that yield a group of symbol estimate vectors.

We propose three sub-optimal schemes to constrain them to be appropriate structures such that they can be used for low-complexity implementation of the detector. These three schemes are developed based on an assumption that the original detection ordering is the optimal ordering instead of an arbitrary ordering.

1) Pre-Stored Patterns (PSP): The transformation matrix T1 for the first branch is chosen as the identity matrix to keep the optimal ordering as described by T1 . The remaining ordering patterns can be described mathematically .The proposed ordering algorithm shifts the ordering of the antennas according to shifts

$$T_l = \begin{bmatrix} I_S & o_{S,N_{T-s}} \\ o_{N_{T-s,s}} & \phi[I_s] \end{bmatrix}, 2 \le l \le N_T \tag{4.9}$$

2) Frequently Selected Branches (FSB): The basic principle of the proposed FSB algorithm is to build a codebook which contains the ordering patterns for the most likely selected branches. In order to build such codebook, we resort to a simulation approach, where we identify the statistics of each selected branch and construct the codebook with the n most likely selected branches to be encountered.

$$\begin{aligned} &L_{opt} \leftarrow N_T\,! \\ &d_E[l] = \left\| r[i] - H\,s_l[i] \right\| \\ &L_{idx}(n_e) \leftarrow MININDEX\,(d_E) \\ &L_{FSB} \leftarrow SELECT(HIST(L_{idx})) \end{aligned} \tag{4.10}$$

3) Listing Patterns Approach (LPA): Motivated by the factthat we have to do a lot of prior work before the FSB algorithm can be employed, we propose an online codebook updating algorithm, which is called listing patterns approach(LPA). However, this approach is restricted by the number of antennas. We suppose that the channel is block-fading in which a block of symbols are affected by the same fading value. Thus, once the channel changes, we would re-select a list of ordering patterns to update the codebook. In this case ,the LPA algorithm is proposed to fulfil the online updating.

$$\begin{aligned} &L_{LPA} \leftarrow SELECT(d_E) \\ &L_{LPA} \leftarrow LENGTH(L_{LPA}) \end{aligned} \tag{4.11}$$

4.4 Algorithm:

1. Consider the input parameters such as no of transmitters, no of receivers, hermitian operator and signal to noise ratio

2. Defining a MIMO spatial multiplexing system in which we generate communication between transmitters and receiver based on signal to noise ratio range

3. A random data is generated and transmitted in the system in which we are evaluating a channel matrix with respect to complex channel response

4. To approach multi branch successive interference cancellation detector we are defining V-BLAST ordering schemes for this we evaluate the bank of matching filters with a specific stream order

5. Calculate the decor relator and zero forcing estimator for implementing successive interference cancellation

6. Based on that we can implement MMSE successive interference cancellation design for higher detection diversity by selecting the branch which yields the estimates with the best performance

7. To detect the transmitter signal we are using the linear MMSE nulling and symbol successive cancellation for this we use frequently selected branches and listening pattern approach

8. If we detect any interference it’s been cancelled by the nulling and regeneration occurs this process repeats until all the detected interferences are cleared and the respective bit error rate is evaluated

9. Now we introduce Rayleigh fading to reduce the complexity in the selection process.

10. After adopting Rayleigh fading we may increase the transmitter and receiver antennas as per the user requirement and respected bit error rate is also become better.

4.5 Flow chart:

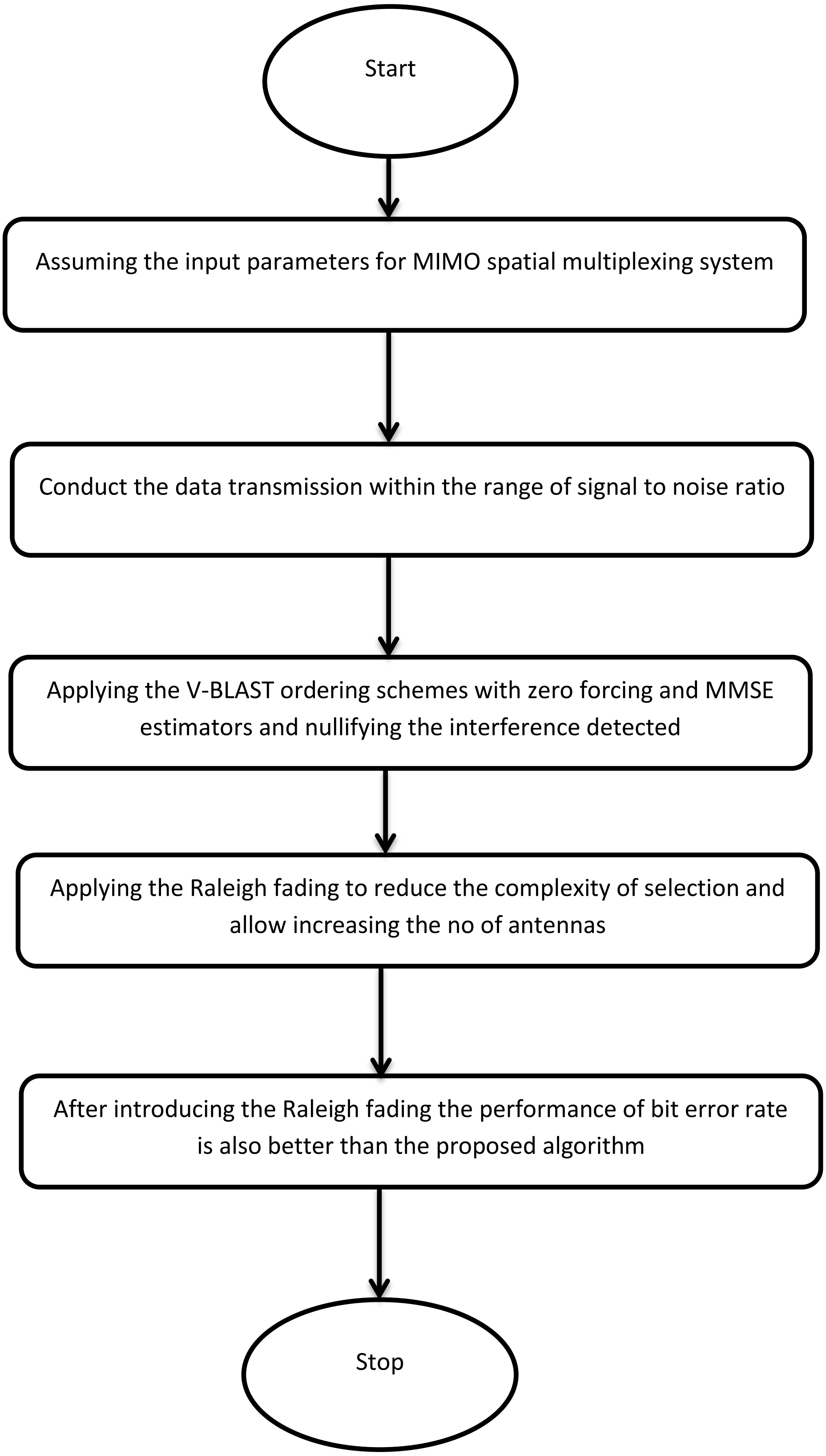

Table 1: Methodology Flow Chart

CHAPTER - 05

RESULTS AND DISCUSSION

In this section, we assess the bit error rate (BER) performance of the proposed scheme and the existing MIMO detection schemes, namely, the ML detector, the linear MMSE detector, the V-BLAST, the parallel interference cancellation(PIC) and the proposed MB-SIC algorithm. Here, we consider two channel models in the simulation: the first one is independent and identically-distributed random fading, whose coefficients are taken from complex Gaussian random variables with zero mean and unit variance, and the second one is the 3GPP spatial model (SCM), which was developed to be a common reference for evaluating different MIMO concepts in outdoor environments at a centre frequency of 2GHz and a system bandwidth of 5MHz.

5.1 Performance evaluations:

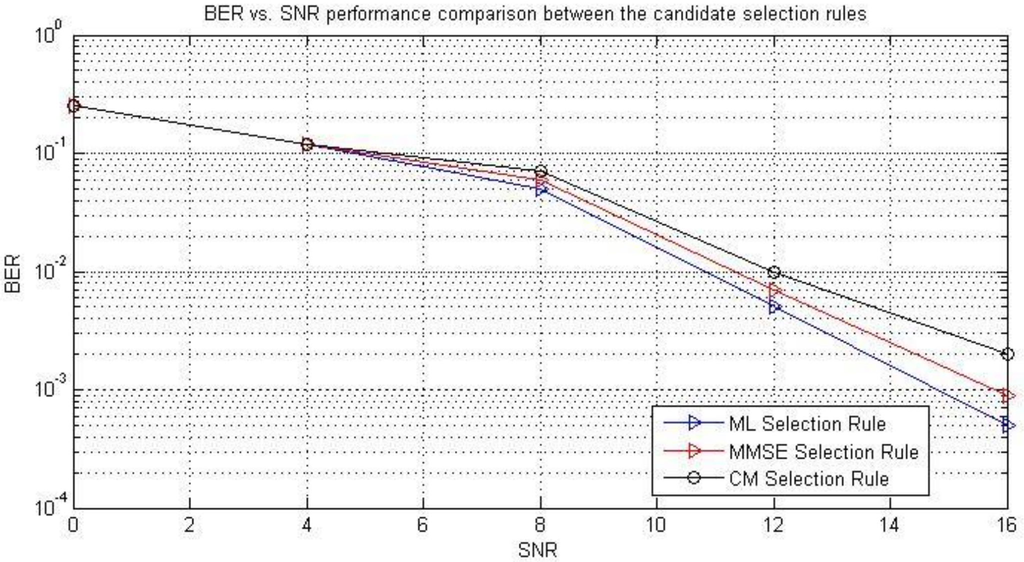

Figure 11: BER vs SNR for basic Selection Rules.

The detector with the ML criterion out performs the other criteria while thechannel information is known.

We average the experiments over 1000 runs and use packets with 100 symbols employing the QPSK modulation. Let us first compare the BER performance against SNR for our proposed detector by employing the three candidate selection rules. As shown in below figure 6.

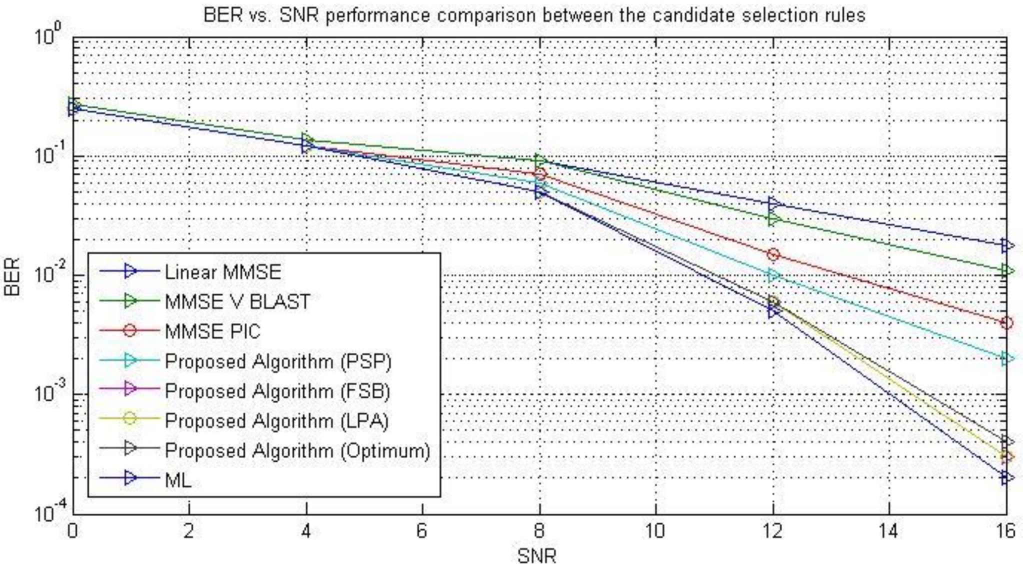

Figure 12:BER vs SNR for selection rules and algorithms.

The selection rule can be chosen according to the different application requirements. In our following simulations, the ML criterion is the selection rule because we assume that the channel information is perfectly known.

we evaluate the BER performance against SNR2 4 6 8 10 1210−310−210−1Number of Antennas (NT = NR)BERV−BLAST Proposed Algorithm − PSP (L=NT)Proposed Algorithm − FSB (L=4)Proposed Algorithm − FSB (L=11)

We compare the proposed ordering algorithms with the optimal ordering scheme described in the previous section. We also compare the proposed MB-SIC detectors with different ordering schemes against the existing linear MMSE detector, VBLAST,MMSE-PIC and ML detector. For our proposed ordering schemes, we have to configure the number of branches L.

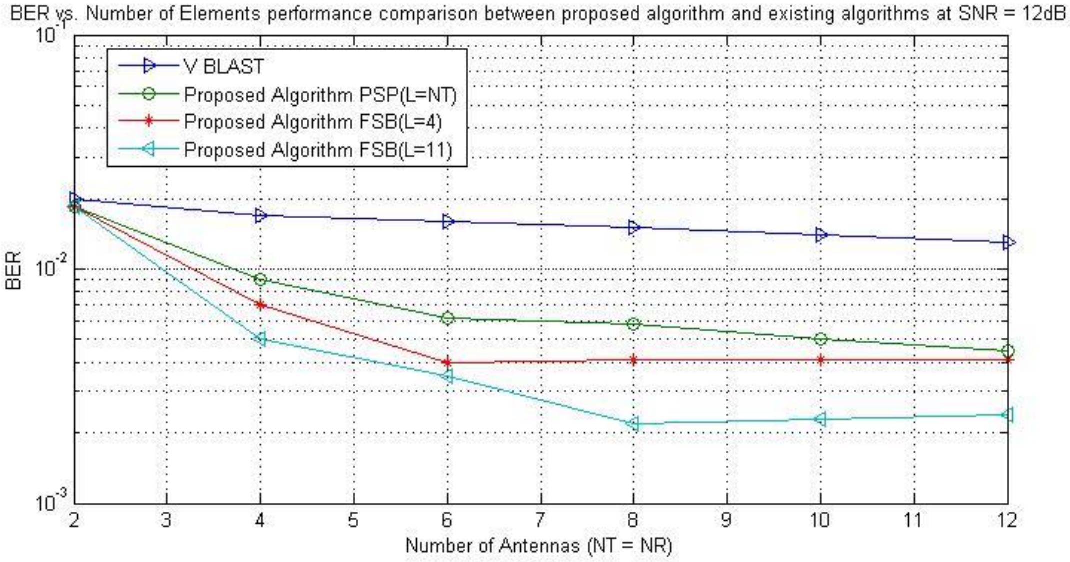

Figure 13: BER vs Number of Antennas for proposed algorithm and VBlast

In this context, the maximum L is set to N_T for PSPscheme due to the algorithm limitation. For the FSB and the LPA schemes, we set L = 10 considering the trade of between computational complexity and the performance. The indexes of branches which are selected into the codebook are for the FSB scheme. It is presented that the performance of the proposed MB-SIC detectors outperforms the linear MMSE detector, V-BLAST and MMSE-PIC detector.

The plots also show that the performance of the proposed detector with optimal ordering scheme, which tests all N_T possible branches and selects the most likely estimate, approaches the optimal ML detector closely and the proposed detector with the FSB and the LPA schemes performs good as that with optimal ordering. As depicted in Fig. 6, the BER performance against SNR is investigated when the MIMO system with N_T = N_R = 4antennas working in the 3GPP SCM environment. We use the MATLAB implementation of SCM developed by Salo *etc*.

The plots show a similar result as in Fig. 8. The performance of the proposed detector with optimal ordering scheme approaches the optimal ML detector and the FSB scheme is slight better than the LPA scheme .In the following experiment, shown in Fig. 5, we investigate the BER vs. the number of antennas performance of the proposed MB-SIC detectors and the V-BLAST when SNR =12dB.

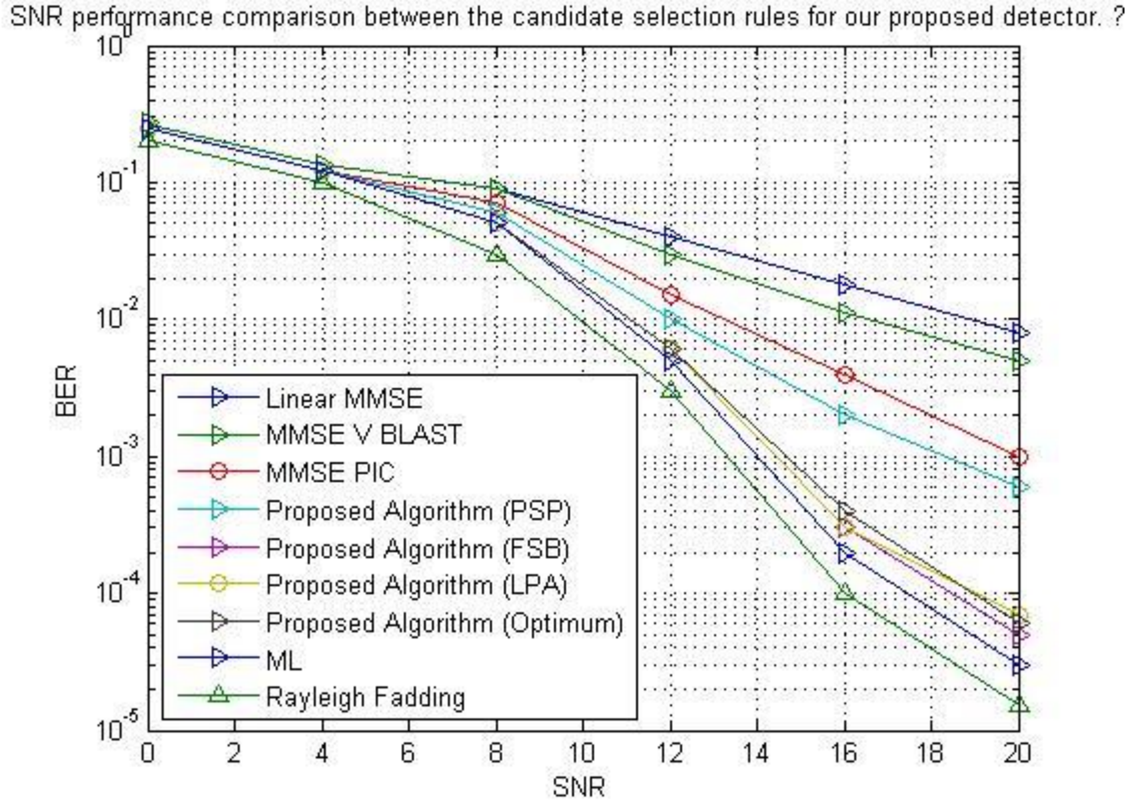

Figure 14: BER vs SNR comparison with in Rayleigh Fading .

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Due to the computational complexity of the optimal ordering increasing with the number of antennas, the optimal ordering scheme and the LPA scheme are not available in this case. We compare the BER performance of the V-BLAST, the proposed detector with PSP scheme when L = N_T and the proposed detector with the FSB scheme when L = 4 and L = 10 respectively. It is obvious that even though the number of branches in the FSB scheme is less than that in PSP scheme when the number of antennas is greater than or equal to 6, the performance of the FSB scheme is better than the PSP scheme.

We are implementing Raleigh fading which will generate better BER performance than other methods.

CHAPTER - 06

Conclusion and Future Work

We presented a novel MMSE SIC detector based on multiple parallel branches for MIMO spatial multiplexing system. The proposed detection structure is equipped with SICs on several parallel branches which employ different ordering patterns. Namely, each branch produces a symbol estimate vector by exploiting a certain ordering pattern. Thus, there are a group of symbol estimate vectors at the end of multi-branch (MB) structure. Based on different application requirements, different criteria, such as ML, MMSE and CM, can be used as selection rules to select the branch with the best performance. We also proposed three sub-optimal ordering schemes together with the optimal ordering scheme.

The proposed MMSE-MB-SIC detector, which achieves higher detection diversity, was compared with several existing detectors in the literature via computer simulations and was shown to approach the optimal maximum likelihood detector while reducing the complexity significantly. we presented and proved mathematically using simulation that proposed structure receiver will be efficiently performs the interference cancellation for multi branch systems in spatial multiplexing systems. we proposed rayleigh fading environment so that it can be improved for different environments for cellular and data transmission purpose.

6.1 Future Work:

In this work we have presented multi branch successive interference cancellation for spatial multiplexing systems. we added Rayleigh fading in simulation as a extension work. one can extend this work by using different environments in simulation and also can form different algorithms and strategies for interference cancellation with extending this topic.

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LIST OF JOURNALS ACCEPTED TO PUBLISH THIS WORK AS PAPER:

1) International Journal of Scientific & Technology Research(**IJSTR**)
   Reference Number: IJSTR-1214-10503
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4) International Journal of Science and Research **(IJSR**)
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6) Advances in Wireless and Mobile Communications (**AWMC**)]
   Paper Code: 28748
7) International Journal of Engineering Trends & Technology (**IJETT**),
   November, 2014 Edition.