Performance Analysis of MIMO-CDMA Using Space Time Block code (STBC)

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Abstract - A MIMO-CDMA system with N_t transmits antennas can transmit N_t symbols on a given signaling interval, and those N, symbols are referred to as a message vector. In conventional MIMO-CDMA systems, a message group is spread by using orthogonal direct sequence spreading codes. In this thesis, less known and recently introduced the parity-bit-selected spreading and the permutation spreading techniques are used for MIMO-CDMA system. This thesis develops the closed form theoretical expressions for parity-bit-selected spreading and permutation spreading techniques. We also introduce new design strategies for permutation spreading technique. In the MIMO-CDMA system employing parity bit selected spreading, rather than assigning each transmit antenna with different spreading sequences, the message vector is input to a systematic block encoder whose output parity bits select the spreading sequence to be used. In other words, with a given message vector, all the transmit antennas would use the same spreading sequence. In the MIMO-CDMA system using permutation spreading, rather than using the parity bits to select one spreading sequence, the parity bits are used to select N_t different spreading sequences from a set of spreading sequences. A unique permutation of spreading sequences is assigned for different parity bits. Compared to MIMO-CDMA systems employing conventional spreading method, the simulation results show that, in frequency-no selective Rayleigh fading channel, parity bit selected spreading improves the system performance, while permutation spreading can further improve the system performance in both single-user and multi-user environments.

Keywords - *MIMO-CDMA, transmit Antenna, spreading sequence, parity bit*

I. INTRODUCTION

In a spread spectrum system, the narrowband message signal is spread over a much larger frequency band [1], [2], [3]. One of the more common spread spectrum techniques is direct sequence spread spectrum (DS-SS). In the direct sequence spread spectrum (DS-SS) system, the information symbols are directly multiplied by a wideband spreading sequence [1], [4], [5].

The Code-Division Multiple-Access (CDMA) proposed by Qualcomm for digital cellular phone applications is utilized in the second (2G) and third generation (3G) wireless communication systems [6]. It provides some attractive features such as interference rejection, protection from multipath interference, low transmit power density, etc. [7]. In its generic form, direct-sequence Code-Division Multiple Access (DS-CDMA) is a spread spectrum system [8], and is often referred to as DS-SS CDMA, or DS-CDMA. Employing forward error correction (FEC) in the DS-CDMA system can significantly improve the bit error rate (BER) performance as well as the spectral efficiency of the system

In the never-ending search for increased capacity in a wireless communication channel it has been shown that by using MIMO (Multiple Input Multiple Output) system architecture it is possible to increase that capacity substantially. Usually fading is considered as a problem in wireless communication but MIMO channels uses the fading to increase the capacity. MIMO systems transmits different signals from each transmit element so that the receiving antenna array receives a superposition of all the transmitted signals. All signals are transmitted from all elements once and the receiver solves a linear equation system to demodulate the message. The idea is that since the receiver detects the same signal several times at different positions in space at least one position should not be in a fading dip.

If the transmitters have CSI (Channel State Information) then the transmitter can use the “Waterfilling technique” (see section 1.3.4) to optimize the power allocation between the antenna elements so that an optimal capacity is achieved. When the CSI is supplied to the transmitter a decrease in spectral efficiency is unavoidable so therefore it is interesting to know in what cases it is important to have CSI and when the benefits are negligible. This will be answered after a series of measurements.

Consider two transmitting antennas where the first antenna is transmitting and the second does not. The electro-magnetic wave from the first antenna will induce a voltage in the other antenna and then the other antenna will also transmit a signal and so on, this is called “Mutual coupling”. The effects of Mutual coupling on the capacity will be investigated in this work. The Rayleigh-distribution is a well-known estimation of the PDF (Probability Density Function) of the fading statistics in a radio channel. In this thesis another distribution will be used that is called the “Nakagami m distribution”. The Nakagami m distribution has different shapes depending on the m-value and for m=1 it equals the Rayleigh distribution. Two different ways to estimate the m-parameter is presented (see section 1.2.5) and by measurements it will be shown if the Nakagami m distribution is a good way to estimate the PDF of the fading statistics or not. Since the MIMO system architecture uses the independent fading between different antenna-elements perhaps it could be possible to increase the independent fading by using some sort of mixer in the channel so that the channel doesn't get stuck in a stat of low diversity gain. There will be some experiments made with a retrodirective antenna that should work as a mixer.

Consider a communication link with n_T transmitting antennas and n_R receiving antennas. Some important assumptions are made:

- There is only a single user transmitting at any given time, so the received signal is corrupted by AWGN (Additive White Gaussian Noise) only.
- The communication is carried out in packets that are of shorter time span then the coherence time of the channel. This means that the channel is constant during the transmission of a packet.
- The channel fading is frequency-flat. This means that the channel gain can be represented by a complex number. This also means that the transmission is very narrowband and the complex number, which represents the fading, is constant over the bandwidth.

Wireless communication system with multiple transmit and receive antennas are referred to as multiple input multiple output (MIMO) system. MIMO systems have been shown to provide an effective way to increase transmission rate over the fading channel [9]. MIMO systems can also achieve large capacity gains [10]. The combination of CDMA and MIMO system can provide the advantages of both systems. The ideas of spatial multiplexing and transmit diversity have been applied to many systems including the third generation (3G) CDMA standards [10]

II. EXPERIMENTAL APPROACH

A MIMO-CDMA system using conventional method is given in [4]. It is a simple, easy to implement system, and does not use any space time coding technique. At the transmitter, each transmit antenna is assigned a unique spreading sequence, and all the information messages being transmitted by that antenna are spread by this spreading sequence. The transmitter model for the conventional MIMO-CDMA system is given at Figure 1. The input message bits are grouped and mapped into symbols by signal mapping. Then the symbols are converted into parallel data streams through a serial-to-parallel converter. The information data (SJ~SM) is directly multiplied with the spreading sequences {ci (t) ~CMt(t)) before transmission. A unique, orthogonal spreading sequence is assigned for each transmit antenna. If there are N_t antennas at transmitter; then, accordingly, N_t different spreading sequences are required.

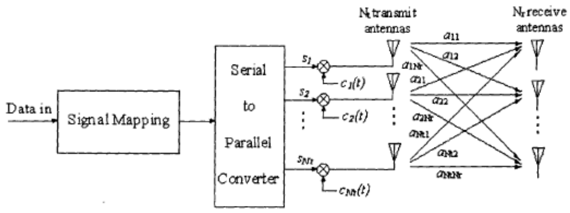

Fig.1.1: Transmitter Model of Conventional MIMO-CDMA System

Parity bit selected spreading sequence technique, based on FEC block code, and was first proposed in [11]. In a CDMA system using (n,k) systematic block code, the calculated n-k parity bits are used to select a spreading sequence from a set of mutually orthogonal spreading sequences. Once the spreading sequence is selected, it is used to spread all k message bits in the block. At the receiver, the system first determines which spreading sequence in the set was most likely employed by the transmitter by observing the magnitudes of the matched filter outputs over the duration of the block. Then, assuming the first step is correct; it determines the most likely transmitted message block by comparing the matched filters outputs to the subset of Messages that correspond to the selection of that spreading sequence. Since the parity bits are not appended at the end of information message bits, this technique can improve the system performance in the additive white Gaussian noise (AWGN) channel with no transmission rate loss. The transmitter model for the CDMA system using parity bit selected spreading, given in [11], is shown in Figure 1.2.

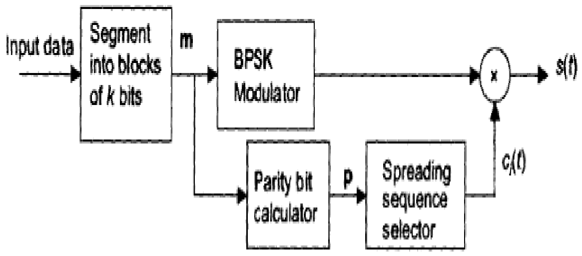

Fig.2: Transmitter Model of Parity Bit Selected Spreading CDMA System

When the receiving antenna is moved relative to the transmitter there will be temporary local minimum in the amplitude of the incoming electromagnetic wave. This is called fading. This will of course happened twice every wavelength in the standing wave scenario. This effect can be reduced by using two receiving antennas at a distance of quarter of a wavelength apart from each other. The receiver then checks from which antenna it gets the strongest signal and uses that one. This is called space diversity. Suppose a receiver has one antenna at point A in the Figure 1.1 below and one antenna at point B, it is obvious that the amplitude in the received signal from antenna B is much greater than the received signal from antenna A. It is also evident that there is a great advantage to be able to choose between these two antennas.

III. FADING AND FADING MODELS

In this section the concept of fading will be explained and two different fading distributions, Rayleigh and Nakagami m will be introduced. Consider a simple communication system with one transmitting and one receiving antenna, the fading in this system can be approximated by the so-called "Two ray model". When the transmitting antenna transmit a signal the receiving antenna will receive a signal that comes directly from the transmitter and a short while later there will come another signal that has been reflected by something, perhaps the ground or a large building.

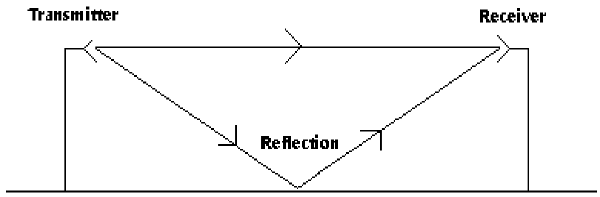

Fig.3: Fading Concept

This is called multipath propagation and when many reflections exist this makes the nature of the mobile radio channel to be more easily described statistically. The ability to predict this fading behavior is very important to the receiver. If this is not possible there will not be an optimal reception of the signals at the receiver, which will be shown later. The received signal strength affected by channel fading, due to multipath propagation and shadow fading, due to large obstacles. The received signal is also affected by noise, both internal and external interference. In Figure 1.3 it is shown that globally the signal-strength decreases proportionally to $\frac{1}{4\pi d^{3.5}}$, and as $\frac{1}{4\pi d^{2}}$ in free space (not shown here). By closely examine the graph it can be seen that it varies more rapidly and this behavior comes from the quick fading and the multipath behavior of the channel. And in the receiver AWGN is added.

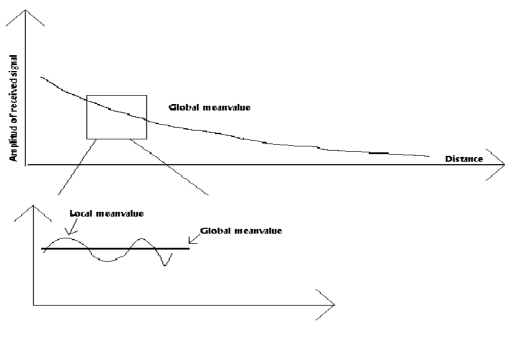

Fig.4: the signal strength decreases proportionally to 1/distance

The received signal can be expressed as eq. (1) $r_t = Hs_t + v_t$ where H is the fading matrix and v is noise. Making a histogram of the received signal gives us an approximation of the PDF of the fading coefficients in the channel if the noise is negligible. There are several distributions used to model the fading statistics. The most commonly used distribution functions for the fading envelopes are Rice, Rayleigh and Nakagami-m. Rayleigh is a special case of Nakagami-m, when m equals one. The fading models are related to some physical conditions that determine what distribution that best describe the channel.

- The Rayleigh distribution assumes that there are a sufficiently large number of equal power multipath components with different and independent phase.
- The Nakagami one distribution equals the Rayleigh distribution above. It is a general observation that an increased m value corresponds to a lesser amount of fading and a stronger direct path

IV. MIMO MEASUREMENT SETUP

Four transmitting antennas n_T, and four receiver antennas n_R are used. The antennas are tuned at 1.8GHz and have linearly polarization. The antenna 3dB beam width is 80° and a half power bandwidth of 170 MHz. There are six switches of the model hp8762a that is used to switch between the antennas because it's only possible to measure one antenna pair at the time. It took three seconds to measure the H matrix

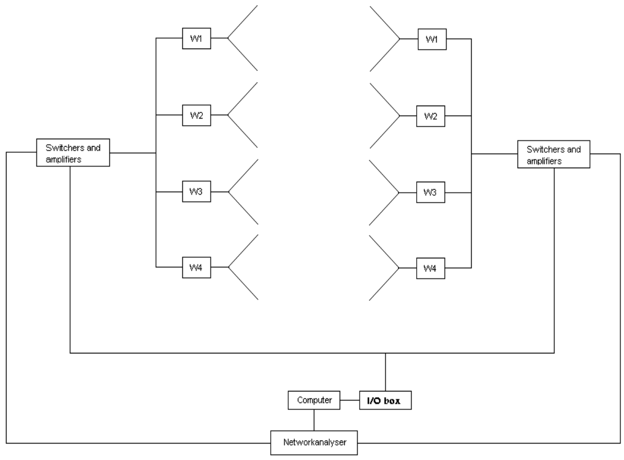

Fig.5: This figure shows an overview over the measurement equipment

In CDMA system, multiple users share the same bandwidth at the same time. Each user is assigned a unique, large bandwidth spreading sequence. The number of simultaneous users in the system is a function of the number of spreading sequences [4]. In CDMA system, if the spreading is done by direct sequence spreading that is called the direct sequence spread spectrum CDMA (DS-SS CDMA) or DS-CDMA [5].The wireless communication system with multiple transmit and receive antennas (MIMO) has been shown to provide an effective way to increase transmission rate and capacity gain over the fading channel without increasing the bandwidth [9], [10].

The combination of CDMA and MIMO system can provide the advantages of both systems. The ideas of spatial multiplexing and transmit diversity have been applied to systems and also are now being used in the third generation (3G) CDMA standards [10]. Several diversity transmission techniques have been proposed for the wireless MIMO systems. Alamouti introduced a simple space time code for transmit diversity technique in [6]. Bell laboratory introduced the V-BLAST for spatial multiplexing (SM) technique in [7]. In general, the transmit diversity techniques 'spread' bit stream over space and/or time to see multiple channel gains [10].

A. Transmitter Model

The transmitter model for MIMO-CDMA system using conventional method is given in Figure 2.11. The input message bits are grouped and mapped into symbols by signal mapping. Then the symbols are converted into parallel data streams through a serial-to-parallel converter. The information data *(SI~SM)* is directly multiplied with the spreading sequences *(ci(t)-CNt(t))* before transmission. A unique, orthogonal spreading sequence is assigned for each transmit antenna. If there are N_t transmit antennas; accordingly, N_t different spreading sequences are required

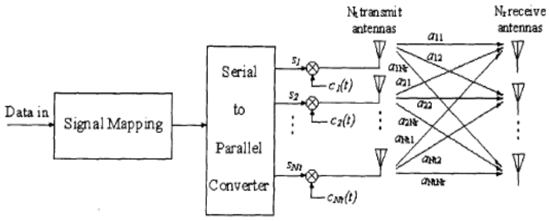

Figure 6: Transmitt modelfor MIMO-CDMA

B. Receiver Model

The receiver model for MIMO-CDMA system using conventional method is given in Figure 2.2. The received symbols are determined through optimal receivers at receiver. The optimal receiver consists of the optimal detector, which has a set of matched filters, and the decision device. Each receive antenna is connected to an optimal detector. If there are N_t transmit antennas, the total number of matched filters for each optimal receiver are N_t as well. Each matched filter filters and samples the received signal corresponding to one of the spreading sequences given from *{ci(t),c₂(t),...,CNt(t)}*. In Figure 2.12, *ru,ri2,...,rNrNt* are the decision variables output from the matched filters. The maximal ratio combiner (MRC) combines the decision variables from the same transmit antennas together; and the decision device determines the message bits $\{b_l,b_2,...,b_k\}$.

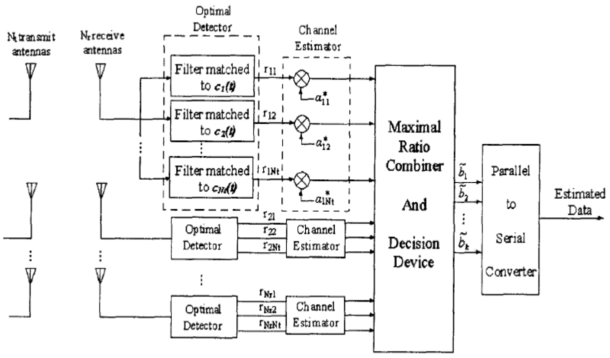

Fig.7: Receiver Model of Conventional MIMO-CDMA System

C. Assumption and discussion

The following assumptions are used for the simulation performances in this thesis

1) All the MIMO-CDMA systems use BPSK signal mapping only.
2) All the orthogonal spreading sequences used in this thesis are Walsh-Hadamard codes; the length of the code is 2^4=16.
3) In order to simplify the simulations, all the MIMO-CDMA systems only consider the Cases with either 1 receive antenna, or with the numbers of receive antennas equalling to the number of transmit antennas, N_t=N_r.
4) The fading channel is frequency no selective (flat fading) channel, and there is no channel induced inter-symbol interference (ISI).
5) The channel impulse response slowly changes over many symbol durations. In other words, the channel is a slowly fading channel.
6) The channel gain between transmit and receive link are uncorrelated.

It is assumed that perfect channel state information (CSI) is available at the receiver

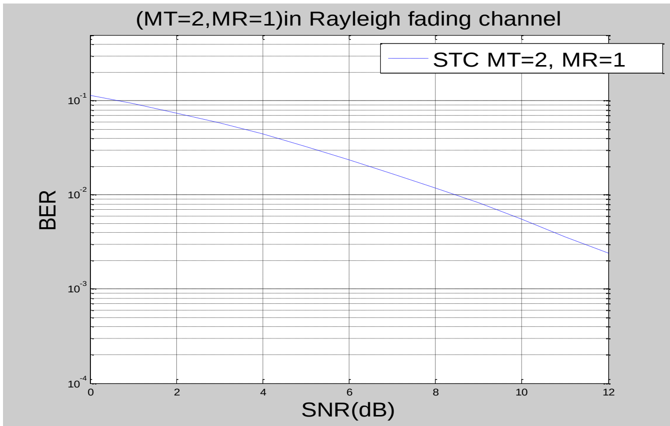

Fig.6: Conventional BPSK MISO-CDMA System over Flat Fading Channel

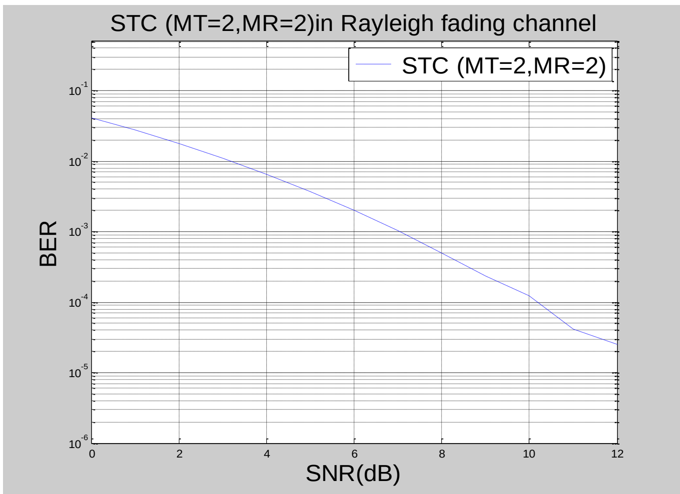

Fig.7: Conventional BPSK MIMO-CDMA System over Flat Fading Channel

V.WIRELESS MULTI INPUT MULTI OUTPUT (MIMO) CHANNEL SIMULATION PACKAGE

A. Overview of the Package

The package consists of seven modules each of which incorporates an important part of any simple communication system. The output of each module is cumulative and is used as an input to the next module in the system. The diagram below briefly shows how these modules are arranged:

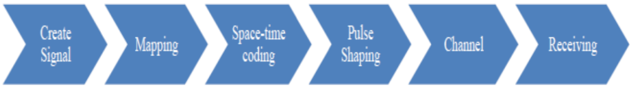

Fig 8: The process in which the modules are used

The 'main' file is used to call each module accordingly. If all seven modules (the six above plus 'Mapping.m') are to be used in the program then they all must be used according to the process above, otherwise if the user wishes to exclude any of the modules and replace it with one of their own, it must be added to the main file accordingly

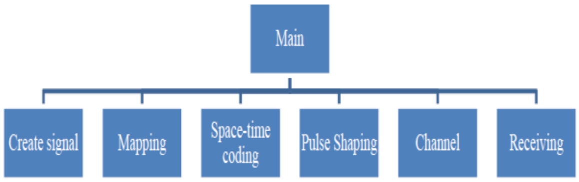

Fig 9: How the 'Main' file is used to call the different modules

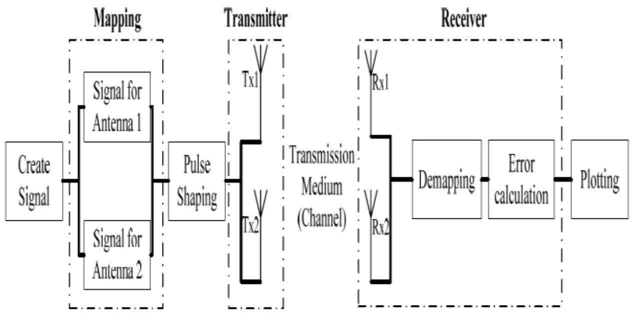

Fig 10: Simple communication system

In this package the different modules are implemented such that the inputs and outputs are organized in an 'object' oriented style. Each module will be fed with one or two objects, which includes certain parameters that need to be used in each specific module. The output data of each module is also generated as an object. This technique makes it easier for the user to locate and use any of the parameters in each different module. Below is a breakdown of the different

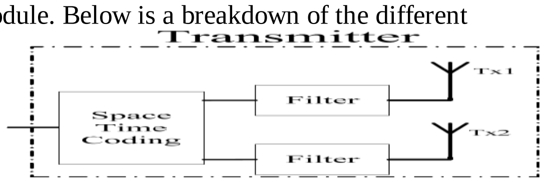

Fig 5: Transmitter Block Diagram

B. Generate Channel Coefficients

First the module generates the channel coefficients that will be used for each transmission path, ch0, ch1, ch2, and ch3 as shown below:

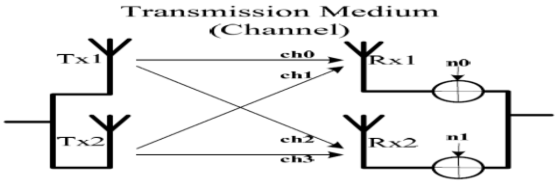

Fig 6: Transmission Medium

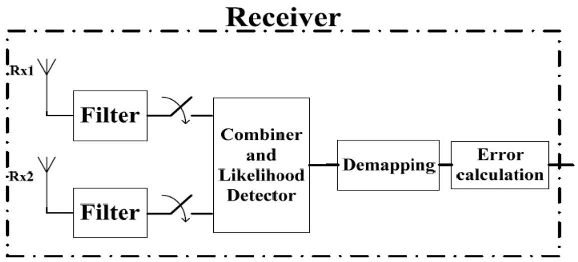

Fig 7: Receiver Block diagram

VI. RESULT AND CONCLUSION

In order to demonstrate the possible performance difference between the different pulse shaping techniques, three sets of simulations were conducted for the following three Square Root raised Cosine pulse shape filters: sqrtrcos (normal), sqrttrrcos (truncated), and sqrtmrcos (modified). Alamouti's 2x2 transmission technique is implemented in the simulation. The three simulations were conducted with length equal to 5000, iteration count equal to 500, SNR range of 0 to 12 and BPSK modulation. The filters in the three simulations had period equal to 0.01, duration equal to 0.05, rolloff factor equal to 0.25 and an oversampling rate of 4. The performance results were plotted and compared as shown below:

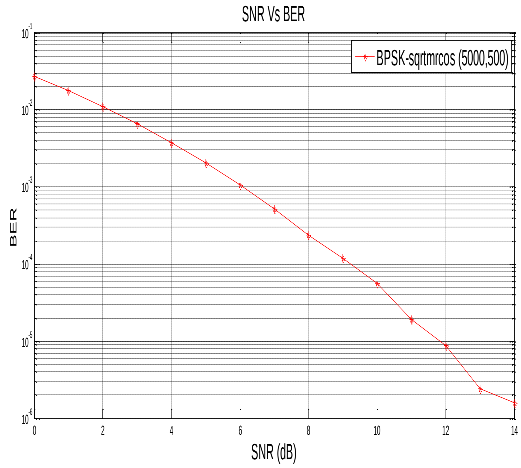

Fig.8: Performance Comparison between Sqrtmrcos

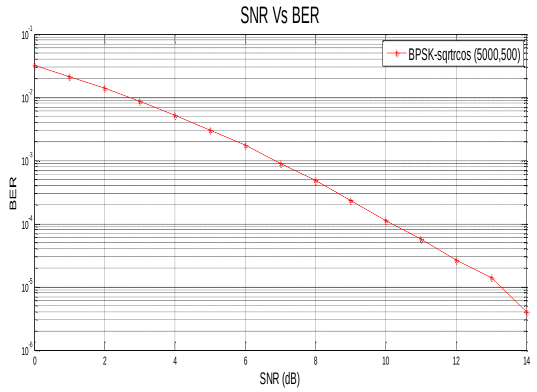

Fig.9: Performance Comparison between Sqrtcos

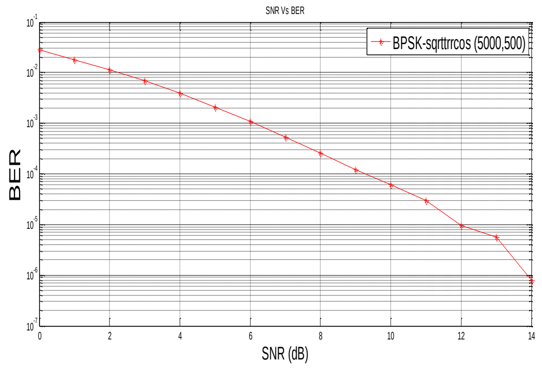

Fig.10: Performance Comparison between Sqttrcos

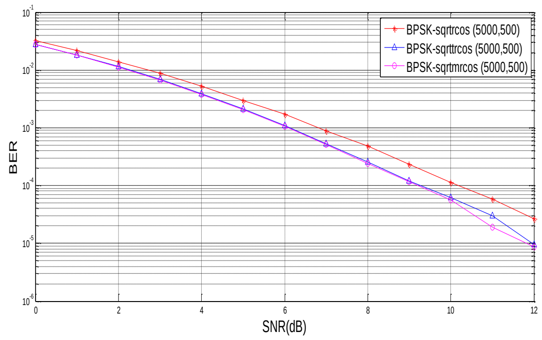

Fig.10: Performance Comparison between Different Pulse shaping Filters

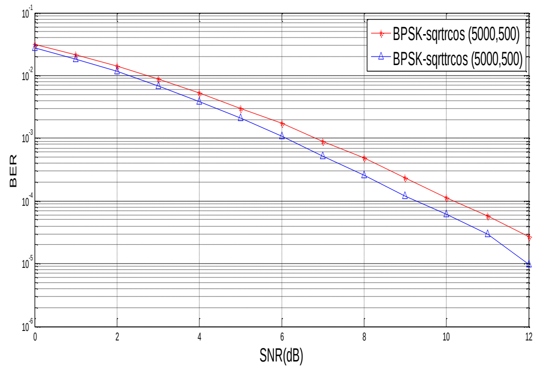

Fig.11: Performance Comparison between Different Pulse shaping Filters

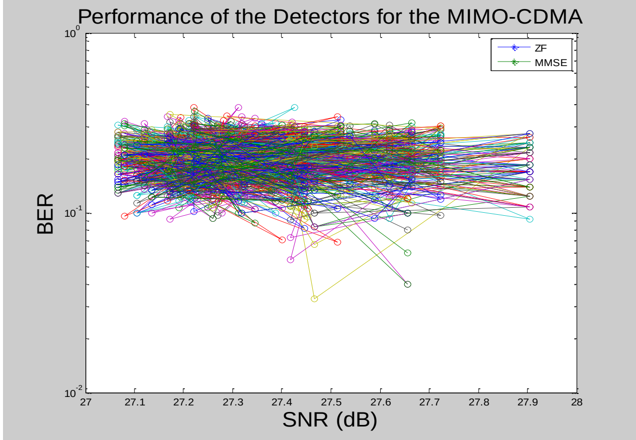

Fig.12: Performance of Detector for the MIMO-CDMA

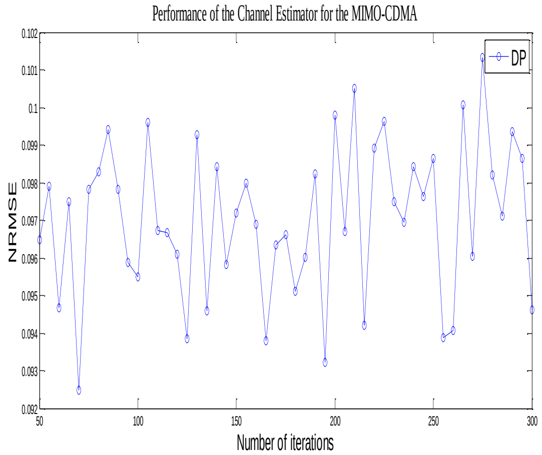

Fig.13: Performance of channel Estimator for the MIMO-CDMA

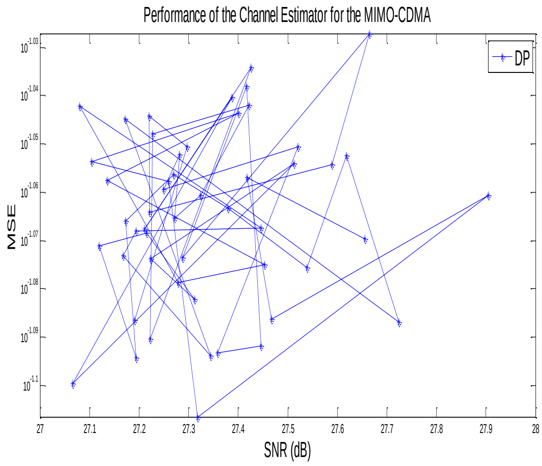

Fig.14: Performance of channel Estimator for the MIMO-CDMA for MSE

VII. RESULT AND CONCLUSION

We can observe that better results are produced by the system which uses more number of receiver antennas. This is due to the fact that as the number of receiver antennas increases, the diversity of the system will increase. Higher diversity will give better performance. So while designing the STBC for a particular application, it is needed to select the number of antennas at both ends of the communication link, the modulation and the rate of transmission. By using the proper STBC technology, it is possible to improve the data rate and range of the wireless communication systems.

Future Scope: Finally as a future expansion of this work, it is possible to introduce different modulation schemes to increase the data rates. Also we can increase the number of antennas at both transmitter and receiver without introducing any interference in between the antennas.

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