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Space-Time Block Coded Spatial Modulation System using CDMA

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الجامعة الإسلامية – غزة
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كلية الهندسة
الهندسة الكهربائية

Space-Time Block Coded Spatial Modulation System using CDMA

الترميز الزمكاني الكتلي للتوليف الفضائي باستخدام السي دي أم أي

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **محمد أحمد حسن البراجنه** لنيل درجة الماجستير في **كلية *الهندسة*** / قسم **الهندسة الكهربائية – أنظمة الاتصالات** وموضوعها:

الترميز الزمكاني الكتلي للتوليف الفضائي باستخدام السي دي أم أي

Space-Time Block Coded Spatial Modulation System using CDMA

وبعد المناقشة التي تمت اليوم الأربعاء 26 محرم 1436هـ، الموافق 2014/11/19م الساعة التاسعة صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/** قسم **الهندسة الكهربائية - أنظمة الاتصالات.**

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

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أ.د. فؤاد علي العاجز

Space-Time Block Coded Spatial Modulation System using CDMA

By:

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ABSTRACT

In this thesis, the performance of space time coded (STBC) spatial modulation system – system is investigated with the use of code division multiple access (CDMA) using a simulation on MATLAB program of bit error rate (BER).

The system under study uses 4 antenna at both side – transmitter and receiver- to deploy a multipath system, where the channels in each receiver is considered to be un-correlated channel, which mean any change in each channel doesn't affect the other channels.

The system is designed starting with MPSK/MQAM modulator followed by spatial modulation encoder then STBC encoder. Finally CDMA encoder with pseudo random code is used and full synchronized between transmitter and receiver.

At the receiver side the opposite is made by starting with CDMA decoder followed by STBC decoder then spatial modulation decoder and finally the MPSK/MQAM decoder, taking into consideration that the error was evaluated using maximum likelihood detection method (ML).

The BER is simulated on MATLAB program and investigated for different modulation schemes and number of parameters such as M-array size and spreading code length.

The investigation is carried out assuming Alamouti's scheme and uncorrelated Rayleigh fading channels, the results show that the performance of the system is very promising.

الترميز الزمكاني الكتلي للتوليف الفضائي باستخدام السي دي أم أي

إعداد : محمد أحمد حسن البراجنه

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الملخص

في هذه الأطروحة يتم الجمع بين أداء الترميز الزمان الفضائي (STBC) مع نظام التعديل المكاني (SM) ونظام تقسيم الترميز متعدد الوصول (CDMA) من خلال برنامج المحاكاة الماتلاب (MATLAB) لإيجاد نسبة الخطأ (BER).

النظام الذي تحت الدراسة يستخدم اربعة هوائيات في كل جانب (المرسل والمستقبل) ليستخدم نظام الانتشار متعدد ،حيث يعتبر كل قناة مستقبل غير مترابطة مع القنوات الاخرى.

تم تصميم النظام بحيث يبدأ ب (MPSK/MQAM) تليها عملية تشفيرالتعديل المكاني (SM) ثم عملية الترميز الزمان الفضائي (STBC) وأخيرا نظام تقسيم الترميز متعدد الوصول (CDMA) باستخدام كود (pseudo random code) وتزامن كامل بين المرسل والمستقبل.

عند المستقبل يتم عكس ذلك بحيث يبدا بفك تقسيم الترميز متعدد الوصول (CDMA) تليها فك الترميز الزمان الفضائي (STBC) ثم فك التعديل المكاني (SM)وأخيرا فك (MPSK/MQAM)، مع الأخذ بعين الاعتبار أن تم تقييم الخطأ باستخدامطريقة الكشف بأقصى أحتمال (maximum likelihood).

تم عمل المحاكاة لمعدل الخطأ على برنامج الماتلاب بعدت مخططات تشكيل مختلفة وعدت متغيرات مثل نوع المجموعة وطول الكود.

وتم تحقيق برنامج المحاكاة على مخطط (Alamouti) وقنوات (Rayleigh) الغير مترابطة مع بعضها البعض، وقد بينت النتائج أن أداء النظام واعد جدا.

DEDICATIONS

All praises goes to Allah, the Creator of all things in the world

To my parents
Who encouraged me and have given me endless support during the work of this thesis.

To my dear wife and brothers
For their patience and their continued support

To my children Ahmad and Sama
For their preeminence face

To my great family

To my special friends

To my beloved country

To all whom I love

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Last, my most sincere thanks go to my beloved mother, who departed us in 2003, special regards to my dear father for her love. Special thanks to my wife for her support, patience and prayers which accompanied me all the way along and special thanks to my children.

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Mohammed A. Albarajna
2014

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
STBC	Space Time Block Coding
SM	Spatial Modulation
CDMA	Code Division Multiple Access
ICI	Inter Carrier Interference
PN	Pseudo Noise
ML	Maximum Likelihood
MAI	Multiple Access Interference
AWGN	Additive White Gaussian Noise
QAM	Quadrature Amplitude Modulation
PSK	Phase Shift Keying
LPF	Low Pass Filter
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
MISO	Multiple Input Single Output
MIMO	Multiple Input Multiple Output
SNR	Signal to Noise Ratio
RF	Radio Frequency
IAS	Inter Antenna Synchronization
MRC	Maximum Ratio Combining
EGC	Equal Gain Combining
CGD	Coding Gain Distance
DSSS	Direct Sequence Spread Spectrum
CHI	Channel State Information
FHSS	Frequency Hopping Spread Spectrum

Chapter 1

Introduction

1.1 Introduction:

In this chapter, a quick view over thesis is introduced, and an overall view of how the system is simulated. . This chapter also shows motivations for this research and a quick survey on the previous works.

1.2 Motivation:

The demands of the wireless systems are increasing in a vast scale. These demands force the designers to design system with high capacity, wide bandwidth allocation and with extreme reliability. The fading nature of wireless channel and interference between users are the main obstacles that designers have to overcome.

The use of space time block codes (STBC), with multiple antennas at both the transmitter and the receiver, can improve the spectral efficiency and the capacity of the communication system. This is because the STBC codes exploit the spatial diversity. On the other hand, the channel state information (CSI) is extremely important at the receiver in STBC systems because the CSI is used in the decoding algorithm. Thus, if the CSI is not recognized at the receiver the whole system performance will be extremely low.

There have been many schemes that combines STBC and spatial modulation systems, the spatial modulation is an interesting scheme that improve the bandwidth allocation and enhance the BER [1].

Recently a combination a between STBC and CDMA has been introduced [2]. The CDMA is very interesting technique with very promising advantages. CDMA system can serve many users in a very narrow bandwidth, and can achieve a very good BER. However, the inter carrier interference (ICI) is the major problem in CDMA. This problem can be overcome by choosing a very long pseudo code (PN).

In CDMA environments, the number of users affects the performance of the system especially when the system channels are frequency-selective-fading channels. These systems suffer from multiple-access interference (MAI). In such systems the maximum likelihood (ML) receiver treats MAI signals as additive white Gaussian noise (AWGN). So, it is extremely important in CDMA systems to suppress the MAI.

In our system we combine the STBC, spatial modulation and CDMA together. The hybrid system is simulated by MATLAB program, using phase shit keying (PSK), Quadrature amplitude (QAM) and by considering different code length.

1.3 Methodology:

The STBC-SM-CDMA system was designed considering the number of antennas and the number of users.

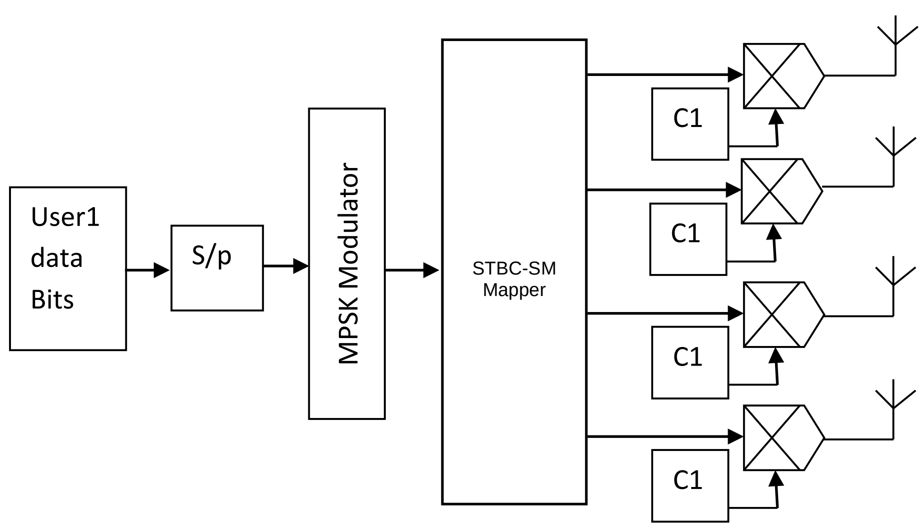


Figure 1: STBC-SM-CDMA System Transmitter Side.

Figure 1 shows the transmitter side of one user only for the sake of simplicity. User data are converted from serial to parallel then fed to the MPSK modulator. The STBC encoder will then change the data stream according to the generating matrix of the encoder. Spatial modulation mapper divide the data to index and data to be modulated followed by STBC code and then the spreading code.

The receiver side of the uplink system is shown in Figure 2.

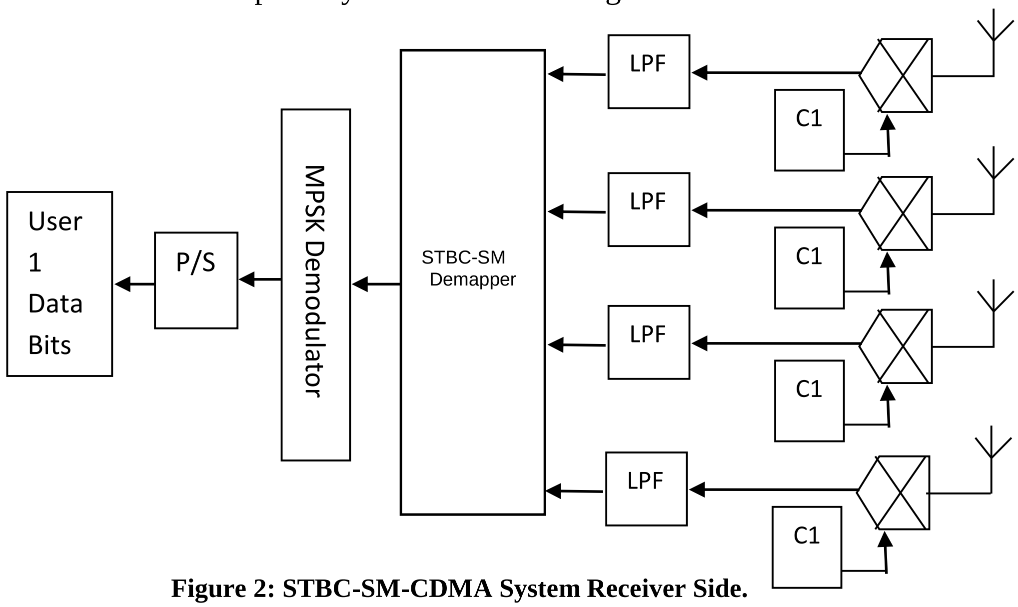


Figure 2: STBC-SM-CDMA System Receiver Side.

The received data is dispread with its proper spreading code. This will change all other users signal to look like a white additive Gaussian noise. The resulted signal will be fed to a low pass filter (LPF) to reduce the effect of the AWGN and MAI.The spatial demapper decides which antenna made the transmission and retrieve the data index. The MPSK demodulator will demodulate the data to regenerate the original data of the user.

1.4 Literature Review:

In 1998, Alamouti [8] achieved a diversity order of two using two branch transmitted diversity scheme, with two antennas on the transmitter and single antenna on the receiver.

In 1999, Tarokh, Jafarkhani and Calderbank documented the performance of space-time block codes providing a new paradigm for transmission over Rayleigh fading channels using multiple antennas [3].

In 2005, Maaref and Aïssa [4] derived general close form expressions for the Shannon capacity for STBC in MIMO Rayleigh Fading Channels with Adaptive Transmission and Estimation Errors

In 2008, Mesleh [13] designed system based on multiple antennas called Spatial Modulation where only one active antenna in the transmitter.

1.5 Thesis Overview

In chapter 2 gives a brief of MIMO communication theory and explanation of the basic concepts of the MIMO system which are array gain, diversity gain, spatial multiplexing gain, channel model, and capacity theorem.

In Chapter 3, STBC communication theory is reviewed, with explanation of the system model components in the transmitter and receiver. Moreover, clarification some of the characteristics of the Alamouti STBC system is summarized.

In Chapter 4, SM communication theory is revised, with explanation of the system model components in the transmitter and receiver. Clarification some of the advantages and dis advantages of the system SM is also revised.

Chapter 5 introduces the STBC-SM communication theory with explanation of the system model components in the transmitter and receiver. Explanation of how the BER account and clarification some of the advantages of the STBC-SM system is also reviewed.

Chapter 6 states the CDMA communication theory and description of the basic concepts of the CDMA system which are spread spectrum, code correlation, pseudo noise spreading and system capacity.

Chapter 7 describes the new system (SM-STBC-CDMA) and how to combine SM, STBC and CDMA. Finally, the BER results and comparison between the new system results with the some other systems are demonstrated.

In Chapter 8, conclusion and the most important attained results is summarized and suggestions for different research topics for future work are proposed.

Chapter 2

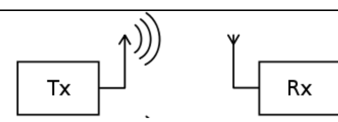
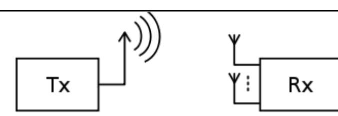
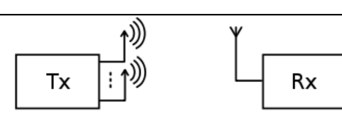
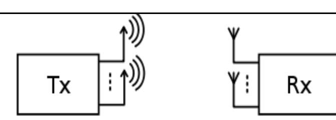
Multiple-Input Multiple-Output (MIMO) COMMUNICATIONSYSTEMS

2.1 Introduction:

Multi input multi output or as known as MIMO is based on the idea of using multiple antenna at transmitter side and receiver side. The number of antennas varies from side to side or can be the same. The MIMO system uses diversity techniques to improve the system overall performance, and can achieve lower the BER of the system significantly. Many studies have been done on MIMO systems and its combination with other types of system.

As the communication system includes transmitter and receiver with different antenna allocation, there are a simple category of multi-antenna types:

Table I: Multiple-antenna system types

SISO	Single-input-single-output means that the transmitter and receiver of the radio system have only one antenna.	
SIMO	Single-input-multiple-output means that the receiver has multiple antennas while the transmitter has one antenna.	
MISO	Multiple-input-single-output means that the transmitter has multiple antennas while the receiver has one antenna.	
MIMO	Multiple-input-multiple-output means that the both the transmitter and receiver have multiple antennas.	

Multiple–Input–Multiple–Output (MIMO) technology is a wireless technology that uses multiple antennas at both the transmitter and receiver to improve communication performance. The MIMO system is characterized by:

1- Multiple data streams transmitted in a single channel at the same time
2- Multiple radios collect multipath signals
3- Delivers simultaneous speed, coverage, and reliability improvements

The multiple–antenna in t (MIMO) systems depends on a number of variable factors to get multiplexing, diversity, or antenna gains. The most important advantages of the MIMO system is the improvement of error performance and data rate.The main drawback is an increase in complexity and cost. This is primarily due to Inter–Channel Interference (ICI), Inter Antenna Synchronization (IAS) and multiple Radio Frequency (RF) chains.

2.2 Array gain

Array gain means a power gain of transmitted signals that is achieved by using multiple-antennas at transmitter and/or receiver. The two main types of array gain:

- Combining signals are average power of combined signals relative to the individual average power.
- The diversity gain related to the probability level of outage.

The channel should be known to the receiver side and does not depend on the degree of correlation between the branches [5].

The most important goal of the array gain is to evaluate the increase in average output SNR, which leads to decrease of the error rate for a fixed transmit power. We define the array gain as [6]

$$ga = \rho_{out}/\rho, \tag{2.1}$$

where ρ is relative to the single-branch average SNR and $\rho_{out}$is the output SNR.

2.3 Diversity gain

Diversity is used to improve the quality and reliability of the wireless link [7]. There are several types of diversity schemes:

1- Space diversity: Transmitter and/or Receiver have multiple antennas.

2- Frequency diversity: signal is transmitted over two carrier frequencies.

3- Time diversity: the same signal is re-transmitted with a delay time.

There are some differences between Time/Frequency diversity and Space diversity as shown in the table II:

Table II: Comparison between Space and Time/Frequency diversity

Space diversity	**Time/Frequency diversity**
No additional bandwidth required	Time/frequency is sacrificed
Increase of average SNR is possible	Averaged receive SNR remains as that for AWGN channel.
Additional array gain is possible	No array gain

2.3.1 Spatial diversity

1- Transmit diversity– MISO

2- Receiver diversity – SIMO

3- Transmit and Receive diversity – MIMO

Figure 3: A block diagram of a Transmit diversity– MISO

2.3.1.1 Transmit Diversity [8]

System that has a transmit diversity consists of two or more antennas at the transmitter and one antenna at the receiver. The same data is sent on both transmitting antennas but coded in such a way that the receiver can identify each transmitter.

Features of transmit diversity

1- Transmit diversity increases the robustness of the signal to fading.
2- It can increase the performance in low Signal-to-Noise Ratio (SNR) conditions.
3- It supports the same data rates using less power.

Figure 4: A block diagram of a Receive diversity– SIMO.

2.3.1.2 Receive Diversity [7]

System with Receive Diversity consists of one antenna at the transmitter and two or more antennas at the receiver.

Features of receive diversity

1- Receive diversity is particularly well suited for low SNR conditions in which a theoretical gain of 3 dB.
2- No change in the data rate since only one data stream is transmitted, but coverage can be improved.

There are four forms of signal combining in receive diversity that can be used:

1- Selection combining: the strongest signal is selected and switches to that antenna.
2- Maximum ratio combining (MRC): is often used in large phased-array systems. It is both signals and sums them to give the combination. In this way, the signals from both antennas contribute to the overall signal.
3- Switched combining: The receiver switches to another signal when the currently selected signal drops below a predefined threshold.
4- Equal Gain Combining (EGC): All the received signals are summed coherently.

2.3.1.3 Transmit and Receive diversity (MIMO) [6]

Figure 5: A block diagram of transmit and Receive diversity – MIMO

System with transmit and receive diversity consists of two or more antennas at the transmitter and receiver. This kind of technology has led to a lot of development in wireless communications.

Features of transmit and receive diversity

1- Higher Bit Rates with Spatial Multiplexing.
2- Smaller Error Rates through Spatial Diversity.
3- Improved Signal-to-Noise Ratios with Smart Antennas.

2.4 Spatial Multiplexing Gain [9]

Spatial Multiplexing is required multiple antennas on the transmitter and receiver. It increases in data capacity by transmitting independent information streams on different antennas. The bit stream to be transmitted is demultiplexed into several data segments. These segments are then transmitted through different antennas simultaneously which leads to significant increases in the relevance and speed of data transmission without increasing the transmit power or additional bandwidth.

In spatial multiplexing the number of receive antennas must be equal to or greater than the number of transmit antennas. It utilize a matrix mathematical approach. Data streams t_1,t_2,...,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. For example: system consists of three transmit and three receive antenna system a matrix can be set up:

$$r_1 = h_{11}\, t_1 + h_{21}\, t_2 + h_{31}\, t_3 \qquad (2.2)$$

$$r_2 = h_{12}\, t_1 + h_{22}\, t_2 + h_{32}\, t_3 \qquad (2.3)$$

$$r_3 = h_{13}\, t_1 + h_{23}\, t_2 + h_{33}\, t_3 \qquad (2.4)$$

where r_1 is the signal received at antenna 1 and so forth. h_{12} is the channel coefficient from transmit antenna one to receive antenna 2 and so forth. In matrix format this can be represented as:

$$T = H R \qquad (2.5)$$

To recover the signal sent at the time instances, t_1,t_2,...,t_N at the receiver, it is necessary to perform a considerable amount of signal processing. First, the system decoder must determine the channel transfer matrix by estimating the individual channel transfer characteristic, h_{ij}.

Then, the transmitted data streams can be reconstructed by multiplying the received vector with the inverse of the channel matrix,

$$T = H^{-1} R \qquad (2.6)$$

2.5 MIMO Channel Model

Diagram of a MIMO wireless transmission system is shown in Figure 6. The transmitter and receiver are equipped with multiple antenna elements. The transmit stream goes through a matrix channel which consists of multiple receive antennas at the receiver.

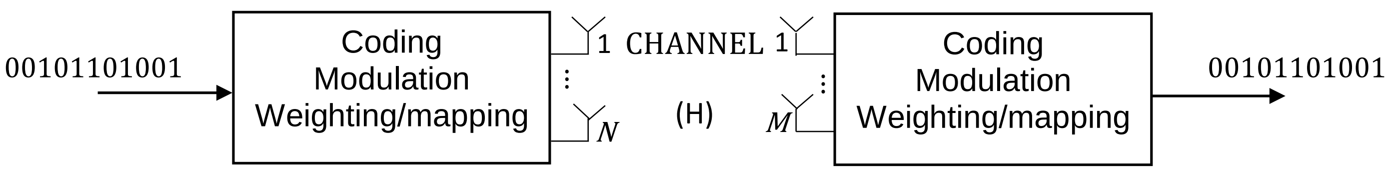


Figure 6: A block diagram of a MIMO system.

Then the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information.

$$r = Hs + n \qquad (2.7)$$

where r is the $M \times 1$ received signal vector as there are M antennas in the receiver, H represented channel matrix, s is the $N \times 1$ transmitted signal vector as there are N antennas in transmitter and n is an $M \times 1$ vector of additive noise term.

2.6 Capacity of MIMO System [10]

For a SISO system the capacity is given by

$$C = \log_2(1 + \rho|h|^2)\; b/s/Hz\,, \qquad (2.8)$$

where h is the normalized complex gain of a fixed wireless channel or that of a particular realization of a random channel. ρ is the SNR at any receive antenna. As we deploy more transmit antennas, the statistics of capacity improve and with *M* receive antennas, we have a SIMO system with capacity given by

$$C = \log_2(1 + \rho \textstyle\sum_{i=1}^{M} |h_i|^2)\; b/s/Hz\,, \qquad (2.9)$$

where h_i is the gain for R_X antenna i. The crucial feature of above equation in that increasing the value of *M* only results in a logarithmic increase in average capacity. Similarly, if we opt for transmit diversity, in the common case, where the transmitter does not have channel knowledge, we have a MISO system with *N* transmit antennas and the capacity is given by

$$C = \log_2\left(1 + \frac{\rho}{N} \textstyle\sum_{i=1}^{N} |h_i|^2\right) b/s/Hz \qquad (2.10)$$

where the normalization by *N* ensures a fix total transmitter power and shows the absence of array gain in that case. Again, note that capacity has a logarithmic relationship with *N*. Now, we consider the use of diversity at both transmitter and receiver giving rise to a MIMO system. For *N* and *M* transmit and receive antennas, we have the famous capacity equation:

$$C_{EP} = \log_2\left[\det\left(I_M + \frac{\rho}{N}\mathrm{HH}^*\right)\right] b/s/Hz \qquad (2.11)$$

where (*) means transpose-conjugate and H is the channel matrix.

2.7 Summary

This chapter provided an introduction into multiple antenna systems. Transmit and receive methods have been discussed and a brief overview on the algebraic framework used to describe MIMO channel has been given. In addition, Channel models have been presented. One of the most important parameters of a MIMO system, the channel capacity, has been also studied. Moreover, the basic concepts which are relevant to understanding the MIMO channel capacity have been given.

Chapter 3

Space Time Block Coding (STBC)

3.1 Introduction:

Space Time Block Coding (STBC) is a technique that is used within wireless communication networks for the purpose of transmitting multiple copies of one data stream across many antennas. As a result, the different received versions of that data can be utilized to help improving the data-transfer reliability rating [8].

3.2 Transmitter (Alamouti's code)

Alamouti introduced the first design for the STBC in 1998. The Alamouti STBC scheme uses two transmit antennas and N_r receive antennas and can accomplish a maximum diversity order of $2Nr$ [8]. A block diagram of the Alamouti space-time encoder is shown in Figure 7.

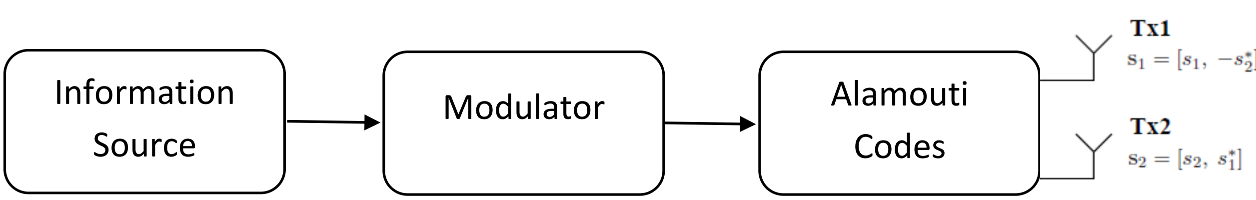


Figure 7: A block diagram of the Alamouti space-time encoder.

In the encoder is the two modulated symbols S_1 and S_2 in each encoding operation and sent up to the transmit antennas in the form of a matrix as follows:

$$S=\begin{bmatrix} S_1 & S_2 \\ -S_2^* & S_1^* \end{bmatrix} \quad (3.1)$$

where S_1 is sent from the first antenna and S_2 from the second antenna in the first transmission period. Whereas $-S_2^*$ is sent from the first antenna and S_1^* from the second antenna in the second transmission period. The two rows and columns of S matrix are orthogonal to each other.

3.3 Receiver

The channel experienced between each transmit and receive antenna is randomly varying in time. However, the channel is assumed to remain constant over two time slots. The channels h_1 and h_2 are assumed to be known only at the receiver. A block diagram of the Alamouti space-time decoder is shown in Figure 8.

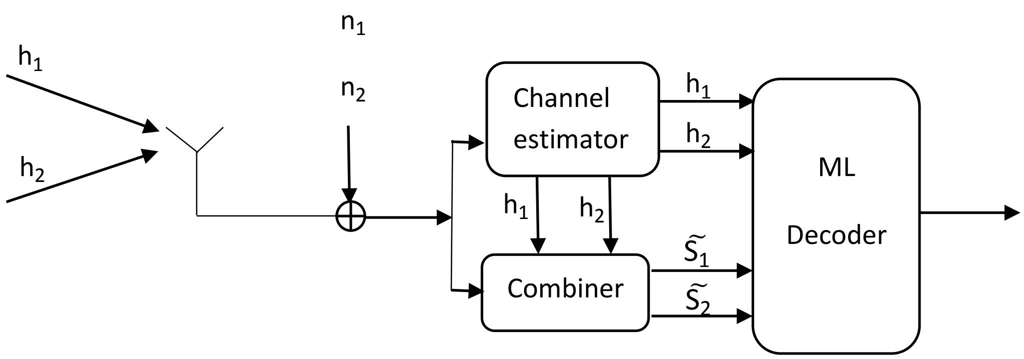


Figure 8: A block diagram of the Alamouti space-time decoder.

In the first time slot, the received signal is,

$$y_1 = h_1S_1 + h_2S_2 + n_1 = [h_1h_2]\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + n_1 \qquad (3.2)$$

In the second time slot, the received signal is,

$$y_2 = -h_1S_2^* + h_2S_1^* + n_2 = [h_1h_2]\begin{bmatrix} -S_2^* \\ S_1^* \end{bmatrix} + n_2 \qquad (3.3)$$

where y_1, and y_2 are the received symbol on the first and second time slot, respectively.
n_i is the AWGN noise in the i^{th} time slot, i =1, 2.

3.4 Analysis (Alamouti STBC)

Since the estimate of the transmitted symbol with the Alamouti STBC scheme is identical to that obtained from Maximal Ratio Combining (MRC). MRC used to select the most effective signal of all receiving antennas, the BER with above described Alamouti scheme should be same as that for MRC. However, there is a small catch.

With Alamouti STBC, we are transmitting from two antennas. Hence the total transmit power in the Alamouti scheme is twice that of that used in MRC. To make the comparison fair, we need to make the total transmit power from two antennas in STBC case to be equal to that of power transmitted from a single antenna in the MRC case. With this scaling, we can see that BER performance of 2Tx, 1Rx Alamouti STBC case has a roughly 3dB poorer performance that 1Tx, 2Rx MRC case. [11]

From the post on Maximal Ratio Combining, the bit error rate in Rayleigh channel with 1 transmit, 2 receive case is, [11]

$$\mathrm{P}_{e,\mathrm{MRC}} = \mathrm{P}_{\mathrm{MRC}}^{2}[1 + 2(1 - \mathrm{P}_{\mathrm{MRC}}) \, , \qquad (3.4)$$

where $\mathrm{P}_{\mathrm{MRC}} = \frac{1}{2} - \frac{1}{2}\left(1 + \frac{1}{E_b/N_0}\right)^{-1/2}$ (3.5)

3.5 Characteristics of Alamouti's scheme:

Alamouti's scheme can achieve transmit diversity without a feedback from receiver to transmitter. It does not require CSI at the transmitter to obtain full transmit diversity and a full rate. The diversity order of two is achieved without a bandwidth expansion (as redundancy is applied in space across multiple antennas, not in time or frequency). Moreover, low complexity Maximum Likelihood decoders can be used at the receiver to detect the transmitted symbols. The low complexity comes from the utilization of the orthogonally of the space time coding matrix to convert the ML search for each symbol independently from the others and identical performance. If the transmit power is kept constant, this scheme suffers a 3-dB penalty in performance compared to MRC since the transmit power is divided in half across the two transmit antennas. The existing systems does not need to be redesigned fully to incorporate this diversity scheme. Hence, it is very popular as a candidate for improving link quality based on dual transmit antenna techniques, without any drastic system modifications.

3.6 Summary

This chapter provided a summary of Alamouti space-time codes. Performance and design criteria of the Alamouti STBC have been discussed. A substantial part of this chapter was dedicated to system model and how to transmit and receive data. Finally, Alamouti properties were discussed.

Chapter 4

Spatial Modulation (SM)

4.1 Introduction:

Spatial modulation (SM) is a transmission technique that uses MIMO system [12]. It is used one active antenna at the transmitter and another antennas are silent. The basic idea is to map a block of information bits to two kind of information carrying units:

1) A symbol that was chosen from a constellation diagram.

2) A unique transmit antenna number that was chosen from a set of transmit antennas.

The main aim of the SM is to reduce the complexity and cost without affecting the system performance and to improve data rates compared to SISO systems. These goals have been achieved because of several factors in the design of the system which are avoiding the Inter Channel Interference (ICI) and the need only to one Radio Frequency (RF) chain for data transmission. This is due to the use of just one transmit–antenna for data transmission at any signaling time instance.

4.2 SM Model

The SM system model is shown in Figure 9. As it can be seen in the figure, the input data $Q(k)$ is modulated using spatial modulation map then fed to the antenna assigned to its index. The transmitted data is received at the receiver side to be fed to the MRRC which decide the antenna whom transmitted the data based on its symbol detection. The final stage is the demodulation to retrieve the original data.

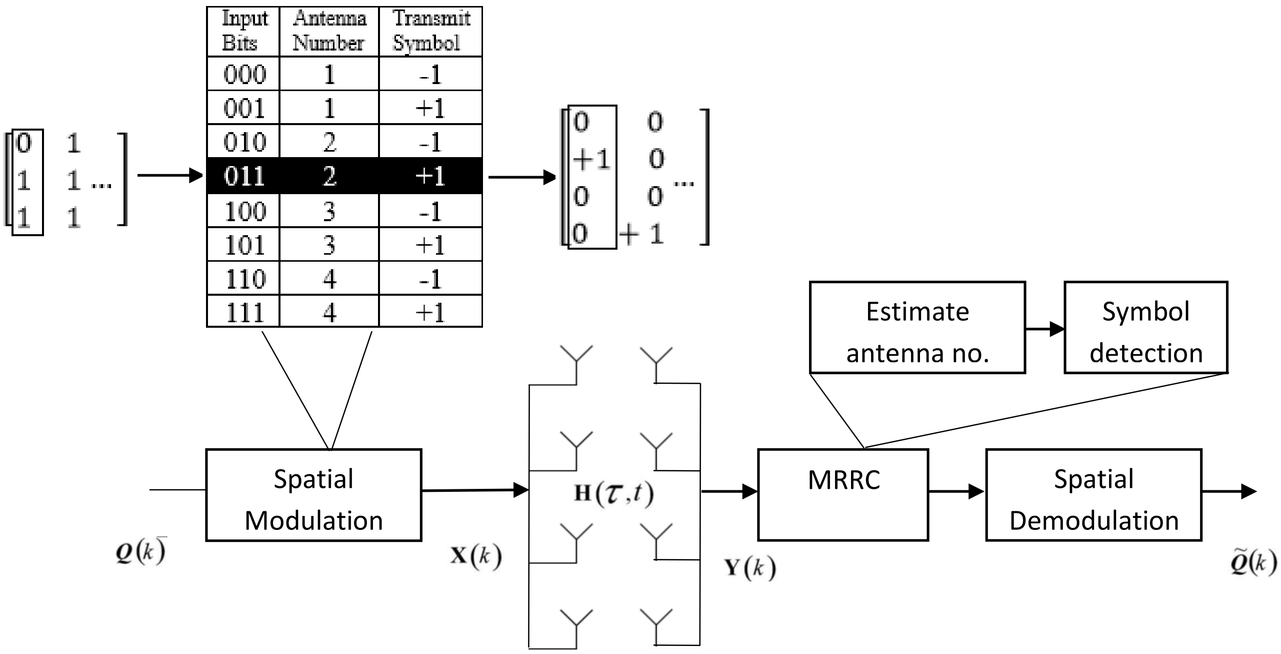


Figure 9: A block diagram of a SM system.

4.2.1 Transmitter

Q(k)is an $m \times n$ binary matrix to be transmitted, where $m = \log_2(Mod)$ is the number of bits/symbol and n is the total number of sub channels. The SM maps this matrix into another matrix $\mathbf{X}$(k) of size $N \times n$, N is the number of transmit antennas. The matrix $\mathbf{X}$(k) has one nonzero element in each column at the position of the transmit antenna number. All other elements in that column are set to zero. The resulting symbols in each row vector $\boldsymbol{x_t}$ are the data that will be transmitted on all sub channels and from antenna t. In general, the number of bits that can be transmitted is given by: [13]

$$n = \log_2(N) + m \quad (4.1)$$

For example: The combination of BPSK and four transmitting antennas results in a total of three bits of information to be transmitted on each sub channel. Meanwhile, we can also use four modified quadrature amplitude (QAM) and two transmitting antennas to send the same rate of information (3 bits/s), as shown in Table III.

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Table III: SM MAPPING
3 b/SYMBOL/SUBCHANNEL

Input bits	$N = 2, Mod = 4$		$N = 4, Mod = 2$	
	Antenna number	Transmit symbol	Antenna number	Transmit symbol
000	1	+1+j	1	-1
001	1	-1+j	1	+1
010	1	-1-j	2	-1
011	1	+1-j	2	+1
100	2	+1+j	3	-1
101	2	-1+j	3	+1
110	2	-1-j	4	-1
111	2	+1-j	4	+1

Whenever data is transmitted, there is only one active antenna and the rest of the antennas remain silent (zero power).

4.2.2 Receiver

The received matrix is given by:

$$\boldsymbol{Y}(t) = \boldsymbol{H}(t) \otimes \boldsymbol{S}(t) + \boldsymbol{N}(t) , \qquad (4.2)$$

where $\boldsymbol{S}(t)$ is a transmit matrix, $\boldsymbol{N}(t)$ is the noise matrix, and $\otimes$ denotes time convolution. The size of matrix $\boldsymbol{Y}(t)$ is $M \times n$. In the following, a multi-rate resource control (MRRC) is used to detect the transmit antenna number and the transmitted symbol in the frequency domain for each sub channel. Matrix of the channel $\boldsymbol{H}(\tau, t)$ is assumed to be known at the receiver and the size is $N \times M$.

$$\mathbf{g}(k) = \mathbf{H}^{\boldsymbol{H}}(k)\mathbf{y}(k) \qquad (4.3)$$

When the time and frequency synchronization are done and no noise, $\boldsymbol{g}(k)$ is the same as $\boldsymbol{x}(k)$.

4.3 Advantages and Disadvantages

In this section, we summarize the advantages and disadvantages of the SM

4.3.1 Advantages

Spatial modulation requires only single Radio Frequency (RF) chain at the transmitter. It uses one active antenna at the transmitter and all the other antennas remain silent. This provides high spectral efficiency code with an equivalent code rate greater than one by a factor of $log2\ (N)$ and without any bandwidth expansion. It can attain ML decoding via a simple single–stream receiver. Also, SM is suitable for downlink settings with low–complexity mobile units because a single receive–antenna is needed to exploit the SM paradigm, inherently able to work in multiple–access scenarios and provides a larger capacity than conventional low– complexity coding methods for MIMO systems by exploiting the spatial domain to convey part of the information bits.

4.3.2 Disadvantages

The main disadvantages in spatial modulation that required two transmit antennas are required at least to exploit the SM concept and paradigm. Moreover, it cannot be used or does not provide adequate performance if the transmit–to–receive wireless links are not sufficiently different. Also, SM can be limited to achieve very high spectral efficiencies for practical numbers of antennas at the transmitter because the relationship between the numbers of transmit antennas and the increase of the data rate are logarithmic, not linear.

4.4 Summary

Spatial modulation is an entirely new transmission technique, which combines modulation, coding, and multiple–antenna transmission and exploits the location specific property of the wireless channel for communication. This enables the position of each transmit antenna in the antenna array to be used as an additional dimension for conveying information. Recent results have indicated that SM can be a promising candidate for low complexity MIMO implementations.

Chapter 5

Space Time Block Coding - Spatial Modulation (STBC-SM)

5.1 Introduction

STBC-SM is a system which combines between Space Time Block Coding STBC and Spatial Modulation (SM). In this scheme, the transmitted data is dependent on the space, time and antenna indices. STBC-SM takes the advantage of this combination to achieve high spectral efficiency which is realized using antenna indices to rely information. Moreover, STBC-SM is optimized for diversity and coding gain to minimize the BER which is the done using the space and time domains. Low complexity maximum likelihood (ML) decoder is used in this scheme [1] which gains from the orthogonality of the STBC code.

5.2 Transmitter

The adopted system is designed for four transmit antennas and depends on Alamouti, (STBC) in forming the transmitter matrices as follows: [14]

$$X_1 = \{S_{11}, S_{12}\} = \left\{ \begin{pmatrix} S_1 & S_{\text{٢}} & 0 & 0 \\ -S_2^* & S_1^* & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 0 & S_1 & S_{\text{٢}} \\ 0 & 0 & -S_2^* & S_1^* \end{pmatrix} \right\} \quad (5.1)$$

$$X_2 = \{S_{21}, S_{22}\} = \left\{ \begin{pmatrix} 0 & S_1 & S_{\text{٢}} & 0 \\ 0 & -S_2^* & S_1^* & 0 \end{pmatrix}, \begin{pmatrix} S_{\text{٢}} & 0 & 0 & S_1 \\ S_1^* & 0 & 0 & -S_2^* \end{pmatrix} \right\} e^{j\theta} \quad (5.2)$$

Every two STBC-SM code words ($S_{ij}, j = 1{,}2$) is a one STBC-SM codebooks ($X_i, i = 1{,}2$). θ is a rotation angle to be optimized for a given modulation scheme to ensure maximum diversity and coding gain at the expense of expansion of the signal constellation.

The spectral efficiency of the STBC-SM scheme for four transmit antennas becomes:

$$m = \left(\frac{1}{2}\right) \log_2 4M^2 = 1 + \log_2 M \ bit/s/Hz, \quad (5.3)$$

where the normalizing factor of 1/2 is used for the two channel matrices in (5.1) and (5.2) as in Table IV.

Table IV: STBC-SM MAPPING RULE FOR 2 BITS/S/Hz TRANSMISSION USING BPSK, FOUR TRANSMIT ANTENNAS AND ALAMOUTI'S STBC

		Input Bits	Transmission Matrices			Input Bits	Transmission Matrices
X_1	$l = 0$	0000	$\begin{pmatrix} 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$	X_2	$l = 2$	1000	$\begin{pmatrix} 0 & 1 & 1 & 0 \\ 0 & -1 & 1 & 0 \end{pmatrix}$
		0001	$\begin{pmatrix} 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$			1001	$\begin{pmatrix} 0 & 1 & -1 & 0 \\ 0 & 1 & 1 & 0 \end{pmatrix}$
		0010	$\begin{pmatrix} -1 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 \end{pmatrix}$			1010	$\begin{pmatrix} 0 & -1 & 1 & 0 \\ 0 & -1 & -1 & 0 \end{pmatrix}$
		0011	$\begin{pmatrix} -1 & -1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$			1011	$\begin{pmatrix} 0 & -1 & -1 & 0 \\ 0 & 1 & -1 & 0 \end{pmatrix}$
	$l = 1$	0100	$\begin{pmatrix} 1 & 1 & 0 & 0 \\ -1 & 1 & 0 & 0 \end{pmatrix}$		$l = 3$	1100	$\begin{pmatrix} 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & -1 \end{pmatrix}$
		0101	$\begin{pmatrix} 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$			1101	$\begin{pmatrix} -1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 \end{pmatrix}$
		0110	$\begin{pmatrix} -1 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 \end{pmatrix}$			1110	$\begin{pmatrix} 1 & 0 & 0 & -1 \\ -1 & 0 & 0 & -1 \end{pmatrix}$
		0111	$\begin{pmatrix} -1 & -1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$			1111	$\begin{pmatrix} -1 & 0 & 0 & -1 \\ -1 & 0 & 0 & 1 \end{pmatrix}$

An important design parameter is the minimum coding gain distance (CGD) between two

STBC-SM code words (matrices). The minimum CGD in any code should be maximized to achieve better performance in term of BER. The minimum CGD between two codebooks is defined as:

$$\delta_{\min}(X_{i,} X_j) = \min_{k,l} \delta_{\min}(S_{ik}, S_{jl}) \qquad (5.4)$$

And the minimum CGD of an STBC-SM code is defined by:

$$\delta_{\min}(X) = \min_{i,j,i\neq j} \delta_{\min}(X_{i,} X_j) \qquad (5.5)$$

In the following, we give an algorithm to design the STBC-SM scheme:

1) Determine the total number of transmitter antennas N and calculate the number of possible antenna combinations for the transmission of Alamouti's STBC.

2) Calculate the number of code words in each codebook.

3) Start with the construction of X_i which contains a noninterfering code words.

4) Using a similar approach, construct X_i for $2 \leq i \leq n$ by considering the following two important facts:

A) Every codebook must contain non-interfering code words chosen from pairwise combinations of n_T available transmit antennas.

B) Each codebook must be composed of code words with antenna combinations that were never used in the construction of a previous codebook.

5) Determine the rotation angles θi for each X_i, $2 \leq i \leq n$.

The block diagram of the STBC-SM transmitter is shown in Figure 10. There are two cases to take advantages of the system of STBC in the best shape:

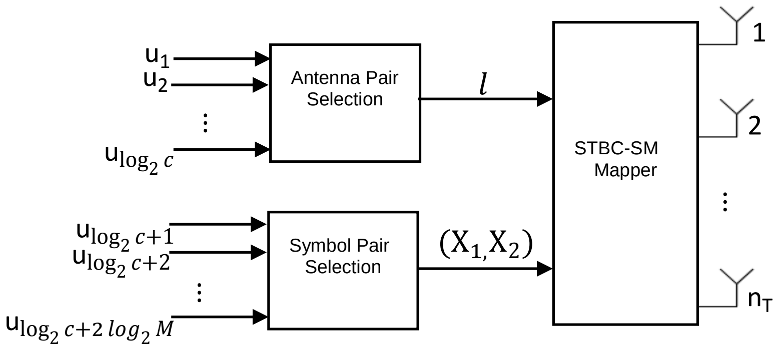

Figure 10: Block diagram of the STBC-SM transmitter.

Case 1 - $n_T \leq 4$: We have, in this case, two codebooks X_1 and X_2 and only one non-zero angle, say θ, to be optimized. It can be seen that δ_{min} (X_1, X_2) is equal to the minimum CGD between any two interfering codewords from X_1 and X_2.

Case 2 - $n_T > 4$: In this case, the number of codebooks, n, is greater than 2. Let the corresponding rotation angles to be optimized be denoted in ascending order by

$$\theta 1 = 0 < \theta 2 < \theta 3 < \cdots < \theta n < p\pi/2 \qquad (5.6)$$

5.3 Receiver

The block diagram of the STBC-SM receiver is shown in Fig. 2.4. STBC-SM with transmit n_T and receive antennas n_R is considered in the presence of a quasi-static Rayleigh flat fading MIMO channel [8]. The receiver matrix, Y can be expressed as:

$$Y = \sqrt{\frac{\rho}{\mu}} S_X H + N, \qquad (5.7)$$

where $S_X \epsilon X$ and μ is a normalization factor to ensure that ρ is the average SNR at each receive antenna. We assume that H remains constant during the transmission of a code word and takes independent values from one code word to another. H is known at the receiver, but not at the transmitter.

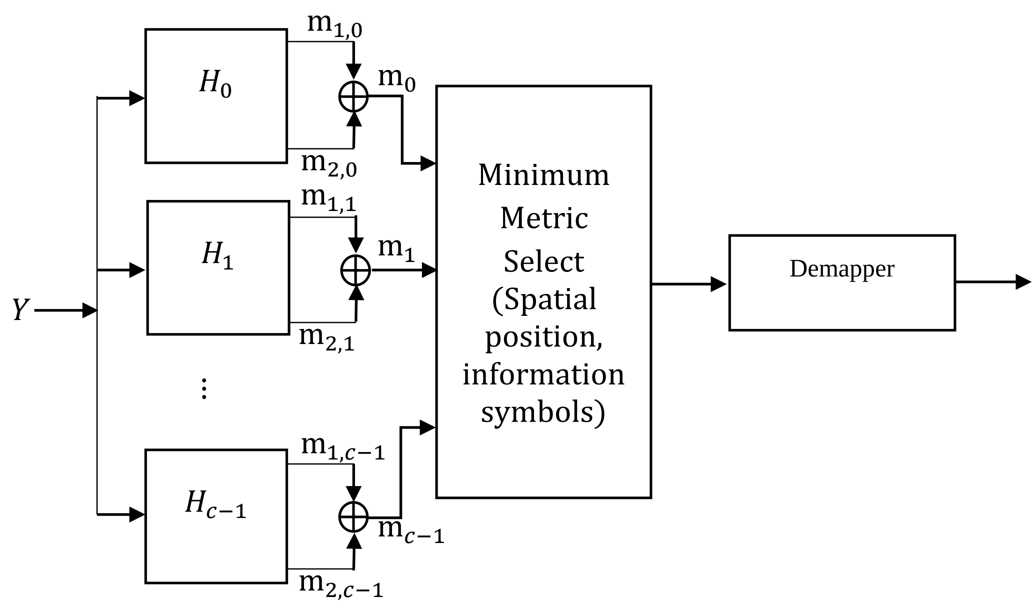

Figure 11: Block diagram of the STBC-SM receiver.

The associated minimum ML metrics $m_{1,\ell}$ and $m_{2,\ell}$ for X_1 and X_2 are; respectively.

$$m_{1,\ell} = \min_{X_1 \epsilon \gamma} \left\| Y - \sqrt{\frac{\rho}{\mu}} h_{\ell,1} X_1 \right\|^2 \tag{5.7}$$

$$m_{2,\ell} = \min_{X_2 \epsilon \gamma} \left\| Y - \sqrt{\frac{\rho}{\mu}} h_{\ell,2} X_2 \right\|^2 \tag{5.8}$$

Since $m_{1,\ell}$ and $m_{2,\ell}$ are calculated by the ML decoder.

5.4 BER analysis of the STBC-SM system

We analyze the error performance of the STBC-SM system, in which 2m bits are transmitted during two consecutive symbol intervals using one of the $cM^2 = 2^{2m}$ different STBC-SM transmission matrices. An upper bound on the average bit error probability (BEP) is given by the well-known union bound.

$$p_b = \frac{1}{2^{2m}} \sum_{i=1}^{2^{2m}} \sum_{j=1}^{2^{2m}} \frac{P(X_i \rightarrow X_j)\, n_{i,j}}{2m} \tag{5.9}$$

$$p_b \leq \sum_{j=2}^{2^{2m}} \frac{w[\,(j\text{-}1)_2]}{2m\pi} \int_0^{\pi/2} \left(\frac{1}{1 + \frac{\rho \lambda_{1,j,1}}{4\, sin^2\, \theta}} \right)^{n_R} \left(\frac{1}{1 + \frac{\rho \lambda_{1,j,2}}{4\, sin^2\, \theta}} \right)^{n_R} d\theta \tag{5.10}$$

where ($X_i \rightarrow X_j$) is the pair wise error probability (PEP) of deciding STBC-SM matrix X given that the STBC SM matrix X_i is transmitted, and $n_{i,j}$ is the number of bits in error between the matrices X_i and X_j, λ_1 and λ_2 are the eigenvalues of the matrix $\Delta\Delta^H$. Since in each transmission interval. Hint $\Delta = X_i - X_j$

5.5 Summary

STBC-SM utilizes multiple transmit antennas to create spatial diversity. It allows the system to have better performance in a fading environment and good performance with minimal decoding complexity. It can achieve maximum diversity gain and receiver that use only linear processing to recover transmitted data.

Chapter 6

Code Division Multiple Access (CDMA)

6.1 Introduction

Code division multiple access is a new concept using channel access method through a form of multiplexing that allows multiple signals occupying single transmission channel and optimizing the available bandwidth. This allowed for dramatic development to wireless communication in this century and gained a wide spread international use by cellular radio system [15].

Previously known cellular communications usually wastes resources when a number of users is much larger than the number of active users. The reason behind that the CDMA gained its importance and wide spread use is because the CDMA has overcome these problems through an efficient utilization of the fixed frequency spectrum, using larger signal bandwidth. There is no limits on the number of users as well as easy to add more users with a compromised signal quality for large number of users. A major advantage for CDMA exist in network accommodation voice communications. Also it is easy to be combined with multi beamed antenna arrays.

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6.2 Spread-spectrum [16] [17]

CDMA is a form of spread-spectrum communications. In order for spread spectrum to work properly it uses carrier waves which resemble noise and the bandwidth is wider than usual. The spread is done through pseudo random or orthogonal codes which are independent from the data. This independency allows multiple users to access the same frequency band at the same time.

6.2.1 Frequency Spectrum

The nature of PN sequence is periodicity which allows frequency spectrum spectral lines to be closer to each other. The length is increasing with each periodical cycle which later on filled by data which will be spreaded through each spectral line continuously.

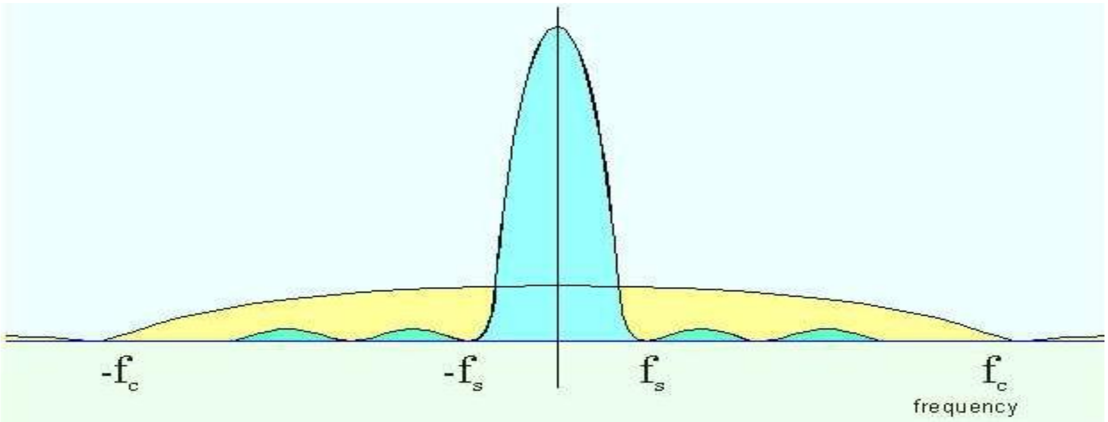

Figure 12: Frequency spreading [18].

As seen in figure 12 [18] the data has power more than the bandwidth, so the spreading technique spread the high power bit in to smaller bits with lower power.

6.2.2 Advantages of spread spectrum

A) Privacy: It is a computational burden for an unintended user to demodulate an SS signal.

B) Low probability of intercept: because of the low level of its power spectrum, an SS-signal can be "hidden" in the background noise. This feature makes an SS signal difficult to be detected by an unintended user.

C) High tolerance against interference:

• Intentional interference (jamming).

• Unintentional interference (multiuser interference in a multiuser communication system).

D) Multiple access operation (CDMA).

6.2.3 Types of Spread Spectrum Communications

Three ways to spread the bandwidth of the signal:

1) Direct sequence spread spectrum (DSSS): The digital data is coded at a much higher frequency. The code is generated pseudo-randomly and the receiver generates the same code, correlates the received signal with that code to extract the data through the following steps:

1- Signal transmission through:

a) Pseudo-random code which generated, differently for each channel and each successive connection.

b) The Information data modulates the pseudo-random code (spread).

c) The resulting signal modulates a carrier.

d) The modulated carrier is amplified and broadcasted.

2- Signal reception through:

a. The carrier is received and magnified.
b. The received signal is mixed with a local carrier to recover the spread digital signal.
c. A pseudo-random code is generated, matching the anticipated signal.
d. The receiver acquires the received code and phase locks its own code to it.
e. The received signal is correlated with the generated code, extracting the information data.

2) Frequency hopping spread spectrum (FHSS): within this hopping bandwidth the signal switches rapidly between different frequencies pseudo-randomly and at the same time the receiver knows in advance how to find the signal at any given time.

3) Time hopping: The signal is transmitted in short bursts pseudo-randomly, and the receiver knows in advance when to expect the burst.

6.3 Code Correlation [15]

The correlation is mathematical dependent and has the following qualities:

First: when both codes are identical it equals one.

Second: when both codes have nothing in common between them it equals zero.

The correlation occurs in two ways:

1) Cross-Correlation: The correlation of two different codes.

2) Auto-Correlation: The correlation of a code with a time-delayed copy of the same code.

Any multipath interference is rejected and it should equal zero for any time delay except the zero. The receiver acts in two ways: the first to separate the signal needed from signals of other receivers and uses cross correlation to do that. The second is to reject any multipath interference and uses auto-correlation to do that.

6.3.1 Cross-correlation

Cross-correlation describes the interference between codes. Cross-correlation is the measure of agreement between two different codes. When the cross-correlation *Rc*(*t*) is zero for all *t*, the codes are called orthogonal.

$$Rc(\tau) = \int_{-\frac{NcTc}{2}}^{\frac{NcTc}{2}} pn_i\,(t).pn_j(t+\tau)dt \qquad (6.1)$$

In CDMA multiple users occupy the same RF bandwidth and transmit simultaneous. When the user codes are orthogonal, there is no interference between the users after dispreading which protects the users' privacy.

6.3.2 Autocorrelation

The name pseudo-noise is originated from the digital signal because it has an autocorrelation function.

The autocorrelation function for the periodic sequence (PN) is defined as the number of agreements less the number of disagreements in a term by term comparison of one full period of the sequence with a cyclic shift (position *t*) of the sequence itself:

$$Ra(\tau) = \int_{-\frac{NcTc}{2}}^{\frac{NcTc}{2}} pn_i\,(t).pn_j(t+\tau)dt \qquad (6.2)$$

For PN sequences, the autocorrelation has a large peaked maximum (only) for perfect synchronization of two identical sequences. The synchronization of the receiver is based on this property.

6.4 Pseudo-Noise Spreading

A Pseudo-Noise (PN) works as a code sequence that resemble the noise (but deterministic) and acts as a carrier that used for bandwidth spreading of the signal energy. The selection of a good code before transmission is important, because the type and length of the code sets bounds on the system capability.

Processing Gain an important concept relating to the bandwidth (G_P) which is a theoretical system gain that reflects the advantage that frequency spreading provides. The processing gain is equal to the ratio of the chipping frequency to the data frequency:

$$G_p = \frac{f_c}{f_i} \qquad (6.3)$$

We can benefits the following from high processing gain:

- Interference rejection: the system ability to reject the interference is directly proportional to G_p.
- System capacity: the capacity of the system is directly proportional to *Gp*.

The best system performance can be gained when we gain higher PN code bit rate because the CDMA bandwidth will be wider whenever the PN code is higher.

The PN code sequence is a Pseudo-Noise or Pseudo-Random sequence of 1's and 0's. But it is not a real random sequence because it is periodic. Absolute random signals cannot be predicted.

6.4.1 Pseudo-Random

- Not random, but it looks random for the user who doesn't know the code.
- Deterministic, periodical signal that is known to both the transmitter and the receiver.

Whenever the PN spreading code period is longer, the closer will be the transmitted signal a true random binary wave, and the harder it is to be detected. As seen in figure 13. [18]

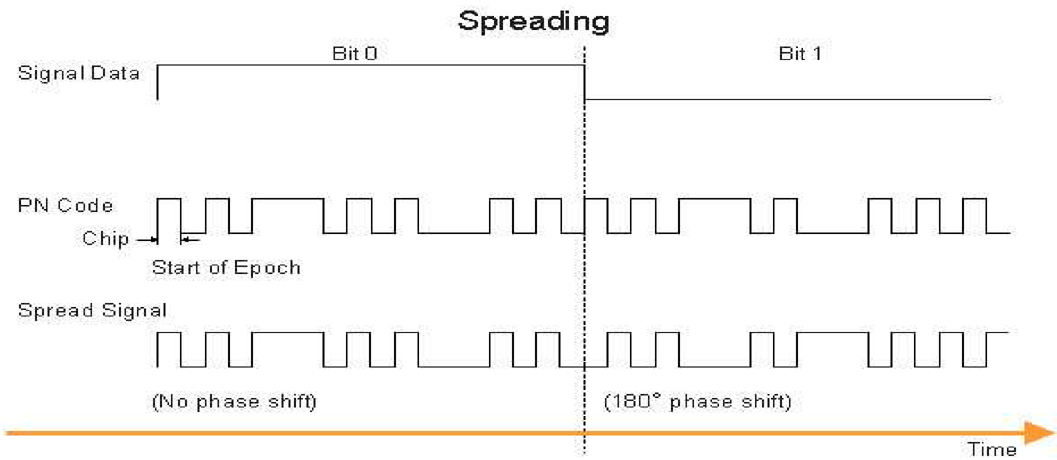

Figure 13: Pseudo noise spreading.

6.4.2 Properties of the PN sequences:

- **Balance Property:**

In each period of the sequence the number of binary ones differs from the number of binary zeros by at most one digit (for N_c odd).

$$PN = +1 +1 +1 -1 +1 -1 -1 \rightarrow \sum = +1 \quad (6.4)$$

When adjusting a carrier with a PN coding sequence, one-zero balance can limit the degree of carrier suppression obtainable. This is because carrier suppression is dependent on the symmetry of the adjusting signal.

- **Run-length Distribution:**

A run is a sequence of a single type of binary digits. From all runs of ones and zeros in each period it is favored that about one-half the runs of each type are of length 1, about one-fourth are of length 2, one-eight are of length 3, and so on.

Other qualities for PN sequence that it uses spread spectrum, cross correlation as well as autocorrelation.

6.5 Transmitting Data:

Code Division Multiple Access (CDMA) is a method of multiplexing (wireless) users by distinct (orthogonal) codes. Transmission can be at the same time to all users, and each is user is given the all available frequency spectrum for transmission. In CDMA each user:

· has its own PN code,

· uses the same RF bandwidth,

· transmits simultaneously (asynchronous or synchronous).

In DS-CDMA transmitter, PN sequence generator spreads the input data bits. The spreading occurs after multiplying the data bits with that of the PN sequence code generated. The frequency of PN sequence is higher than the Data signal. After spreading, the data signal is modulated and transmitted. The modulation occurs through the following schemes, viz. BPSK, QPSK, M-QAM etc.

- **Complex Modulation:**

A Cosine wave and a Sine wave are components that expresses the carrier wave with applied phase shift, $\iota(t)$.

$$A(t)\cos\left(2\pi f_c t_0 + \iota(t)\right) = I(t)\cos(2\pi f_c t_0) + \mathrm{Q(t)}\sin(2\pi f_c t_0) \qquad (6.5)$$

$I(t)$ is called the real, or In-phase, component of the data, and $Q(t)$ is called the imaginary, or Quadrature-phase, component of the data, which produces superimposed two Binary PSK waves and later are easier to modulate and demodulate.

The transmitter generates two carrier waves of the same frequency, a sine and cosine. $I(t)$and $Q(t)$ are binary, modulating each component by phase shifting it either 0 or 180 degrees. Both components are then summed together. The receiver generates the two reference waves, and demodulates each component. It is easier to detect 180^0 phase shifts than 90^0 phase shifts. For Digital Signal Processing, the two-bit symbols are considered to be a complex numbers, $I + jQ$.

- **Working with Complex Data:**

Full efficient use of Digital Signal Processing can be gained by converting the Information data into complex symbols before the modulation. The system generates complex PN codes made up of 2 independent components, $PNi + jPNq$. The Information data can be spreaded when the system performs complex multiplication between the complex PN codes and the complex data.

- **Summing Many Channels Together:**

Many channels are added together and transmitted simultaneously. This addition happens digitally at the chip rate.

- **At the Chip Rate**

  - Information data is converted to two-bit symbols.
  - The first bit of the symbol is placed in the I data stream, the second bit is placed in the Q data stream which considered a complex PN code
  - The complex PN code is generated.
  - The complex Information data and complex PN code are multiplied together.

For each component (I or Q):

- Each chip is represented by an 8 bit word and when each one chip is either a one or a zero, the 8 bit word equals either 1 or -1.
- When many channels are added together, the 8-bit word, as the sum of all the chips, can take on values from between -128 to +128.
- The 8-bit word then goes through a Digital to Analog Converter, resulting in an analog level proportional to the value of the 8-bit word.
- This value then modulates the amplitude of the carrier (the I component modulates the Cosine, the Q component modulates the Sine)
- The modulated carriers are added together.

Since I and Q are no longer limited to 1 or -1, the phase shift of the composite carrier is not limited to the four states.

- **At the Symbol Rate**

Since the PN-code has the statistical properties of random noise, it averages to zeroover long periods of time (such as the symbol period). Therefore, fluctuations in I and Q, and hence the phase modulation of the carrier, that occurs at the chip frequency, average to zero.

6.6 Receiving Data

To extract the Information needed the receiver performs the following:

- Demodulation
- Code acquisition and lock
- Correlation of code with signal
- Decoding of Information data

Demodulation: The receiver generates two reference waves, a Cosine wave and a Sine wave and mixes each with the received carrier, the receiver extracts I(t) and Q(t).Analog to Digital converters restore the 8-bit words representing the I and Q chips.

- **Code Acquisition and Lock:**

The receiver generates its own complex PN code that matches the code generated by the transmitter. However, the local code must be phase-locked to the encoded data.

- **Correlation and Data Dispreading:**

Once the PN code is phase-locked to the pilot, the received signal is sent to a correlated that multiplies it with the complex PN code, extracting the I and Q data meant for that receiver. The receiver reconstructs the Information data from the I and Q data.

A typical matched filter implements convolution using a finite impulse response filter (FIR) whose coefficients are the time reverse of the expected PN sequence. This filter is used to decode the transmitted data.

The most sensitive part of the DSSS receiver is the synchronization of the locally generated PN sequence and the sequence obtained from the decision device. Even a single bit mismatch may lead to noise instead of the data signal.

Suitable technique is used to achieve synchronization and multiply the local PN sequence code with that of the received PN code. The data signal is obtained after the multiplication process.

6.7 System Capacity

The capacity of a system is approximated by:

$$C_{max} = \frac{G_p}{E_b/N_0} \cdot \frac{1}{1+\beta} \quad (6.6)$$

where $C_{max}$is the maximum number of simultaneous calls G_p is the processing gain, E_b/N_0 is the total signal to noise ratio per bit, and β is the inter-cell interference factor.

6.8 Advantages and Disadvantages

6.8.1 Advantages

In CDMA there is no frequency management or assignment and the capacity increases. It reducing the average transmitted power, the number of sites needed to support any given amount of traffic and operating cost because fewer cell sites are needed. CDMA also improves the telephone traffic capacity and the voice quality and eliminate audible and effects of multipath fading. Also the advantage of the CDMA that it providing reliable transport mechanism for data communication, such as facsimile and internet traffic while it simplifying site selection.

6.8.2 Disadvantages

Multi-user interference or multiple access interference (MAI), multi-path fading and near for problem.

6.9 Summary

CDMA is a technology that allows multiple users. The CDMA will allow many signals to be transmitted at the same channel at the same time. This is done by giving each user a Pseudo-Noise code which is a binary sequence. This code should have a low cross correlation between each other. The CDMA scheme is based on unique signatures assigned to the users, and transmissions from different users require no coordination in time or frequency by the serving network. Multiple user transitions using other techniques, such as FDMA and the TDMA required tight synchronization in time and frequency. Multiple access interference has bad effect on the CDMA system so the multiple user detection is used to reduce the MAI.

Chapter 7

Spatial Modulation (SM) - STBC – CDMA coding

7.1 Introduction:

Combining space-time coding, spatial modulation and CDMA techniques can benefit from the advantages of the three techniques. The proposed system can achieve high BER due to the use of spatial modulation and Alamouti STBC since it's well known that Alamouti STBC can reach small values of BER because it allows for transmit diversity. Adding spatial modulation, makes the system less vulnerable to the channel state because it reduces the number of bits being transmitted. It reduces the modulation order as some of the bits are transmitted through the transmit antenna location.

More the less, the use of CDMA makes the system capable of serving high number of users by assigning each user with its unique PN code. Moreover, since spatial modulation is used the inter antenna interference is not much of problem in the system.

7.2 Spatial modulation- STBC – CDMA coding

The results were achieved using simulation via MATLAB program. The simulation started by generating random data using built in function (randn) to generate random data to be modulated. The data is generated to each user individually. Each user data is modulated using the same algorithm at the transmitter side. After generating the data, it is modulated using the phase shit keying (PSK) or the quadrature amplitude modulation (QAM) by passing the signal in built in PSK modulator using the function (psk.mod) or QAM modulator (QAM.mod).

When the random data is generated, spatial modulation is the next step to be done. By using the spatial modulation technique, in each frame we consider the first two bits to be the signal index, and the remaining bits refer to the antenna that should transmit the signal.

Table V: The first two bits on each data frame to be the signal index.

Bit	Antenna number
00	Antenna 1
01	Antenna 2
10	Antenna 3
11	Antenna 4

In this case, each antenna is only transmitting when the corresponding bits match its number according to the table. However, when the STBC is considered in conjunction with the SM, the system must have at least an active pair of antennas in each time. The data is split to index data and transmitted dat. a lookup table is used to define the first two bits of each frame as an index and rest to be transmitted via PSK or QAM modulation.

After each bit is defined, the rest of the modulation is done only on the bits to be transmitted from the active antennas. Each *m* bits are modulated using the PSK (*m* = 2) modulator or QAM modulator (*m* = 4) as previously explained.

Now the modulated data need to be encoded using the STBC encoder side. In our case, the Alamouti code are used as follows

$$\mathrm{S} = \{s[0] \quad s[1] \quad \cdots \quad s[N-1]\}^T \tag{7.1}$$

$$S1 = \ [\ s(2k) - s^*(sk+1)]^T \tag{7.2}$$

$$S2 = \ [\ s(2k+1) s^*(sk)]^T \tag{7.3}$$

$$O2 = \ [\ 00]^T \qquad \text{where} \qquad 0 \le k \le F-1 \tag{7.4}$$

Each antenna transmitting data is defined as in table VI.

Table VI: Frequency Mapping.

	Antenna 1	Antenna 2
Subcarrier $2k$	$s(2k)$	$s(2k+1)$
Subcarrier $2k$+1	$-s^{*}(2k+1)$	$s^{*}(2k)$

Each symbol is generated in MATLAB using counter to rearrange each bit as in the previous equations.

After each symbol is generated a mapping algorithm is defined as in table VII

Table VII: STBC-SM Mapping.

Group	**Code Matrix**
$X1$	$S1$ $S2$ 02 02
$X2$	0 0 $S1$ $S2$
$X3$	[0 $S1$ 0 $S2$] * $e^{j\theta}$
$X4$	[$S2$ 0 0 $S1$] * $e^{j\theta}$

After the STBC spatial modulation is done, the only remaining part in the transmitter is the CDMA part. This is done by defining PN code using Hadamard code built in function and then defining a code for each user. In our case we considered two users only for programming simplicity- then spread each bit in the user data by its PN code using kroon function in MATLAB. The next step is to send the data over uncorrelated Rayleigh fading channels.

By multiplying each data with its corresponding channel, the received signal is calculated. At the receiver side, the received signal is multiplied by its corresponding PN code to dispread the data. After that, the 'in dump' function is used to decompose the original signal. A decoding algorithm for spatial modulation and STBC is done, using the mapping, the index can be considered. Then the maximum likelihood algorithm is used to recover the transmitted signal (as explained in chapter 1.2).A comparison between the transmitted signal and the received signal is formed, to check the system BER.

7.3 Simulation result and Comparisons

7.3.1 Comparison of results in different CDMA codes length

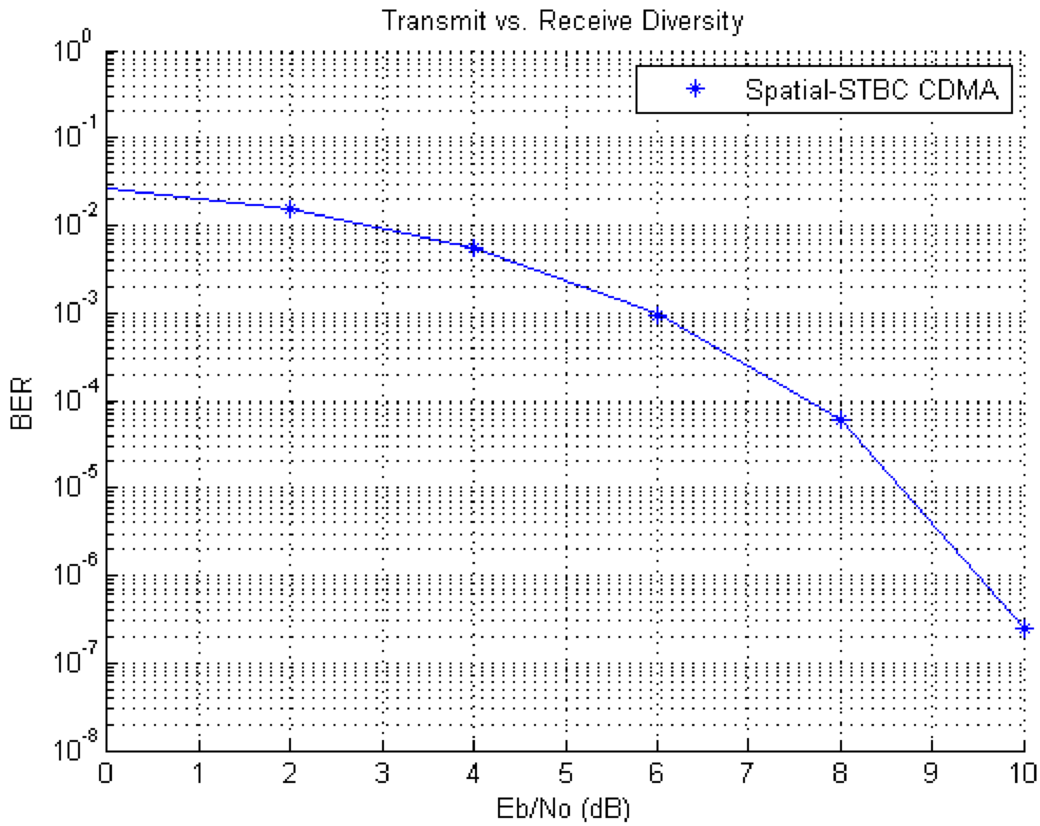

Figure 14: BER performance of SM- STBC – CDMA coding

for CDMA code length of 8 bits, BPSK modulation.

Figure 14 shows BER for spatial modulation- STBC CDMA system. With binary PSK modulation and CDMA code length of 8 bits. As we can see the BER starts at approximately $10^{-1.8}$ at 0 Eb/No and reached $10^{-6.9}$ at 10 Eb/No.This proves that the system has promising performance with very low BER and acceptable throughput.

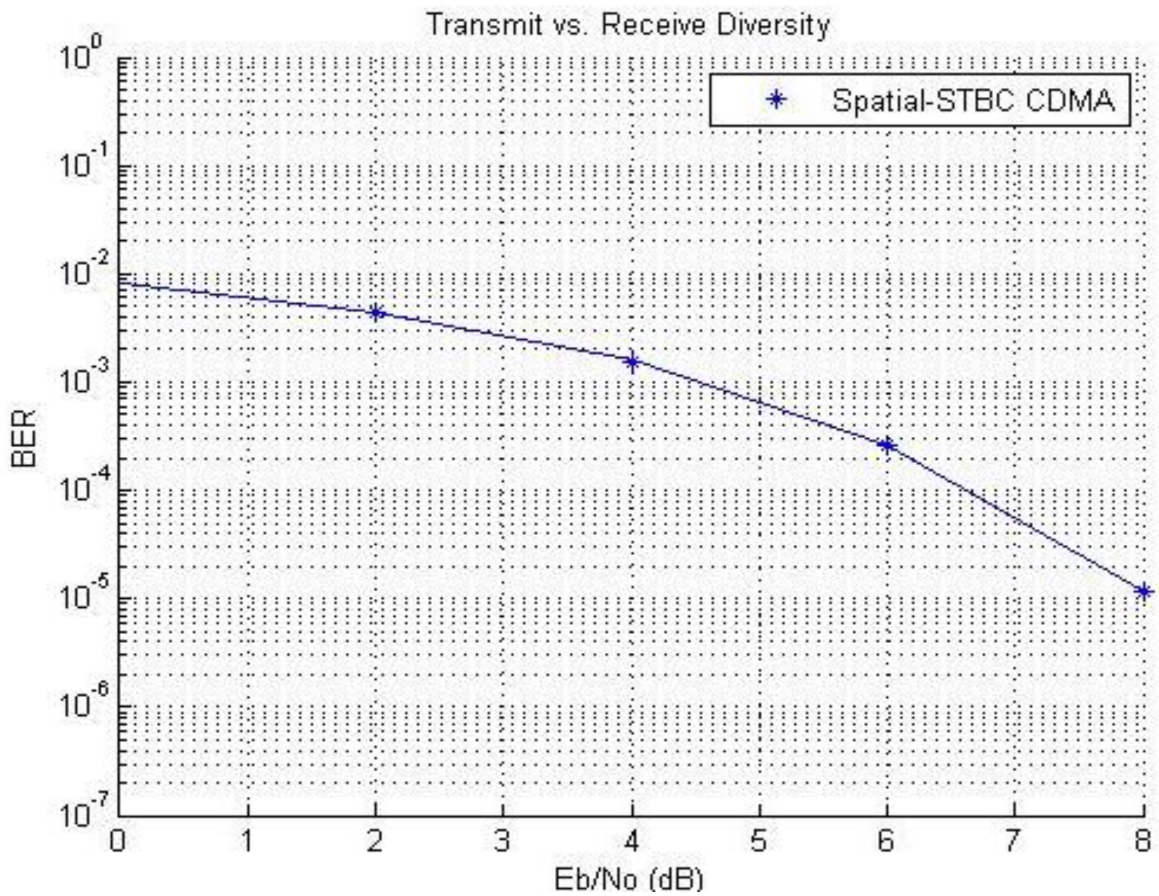

Figure 15: BER performance of SM- STBC – CDMA coding

for CDMA code length of 16 bits, BPSK modulation.

Figure 15 shows BER for spatial modulation- STBC CDMA system. With binary PSK modulation and CDMA code length of 16 bits, as we can see the BER starts at approximately $10^{-2.2}$ at 0 Eb/No and reached 10^{-5} at 8 Eb/No.

This proves that the system has promising performance with very low BER and acceptable throughput.

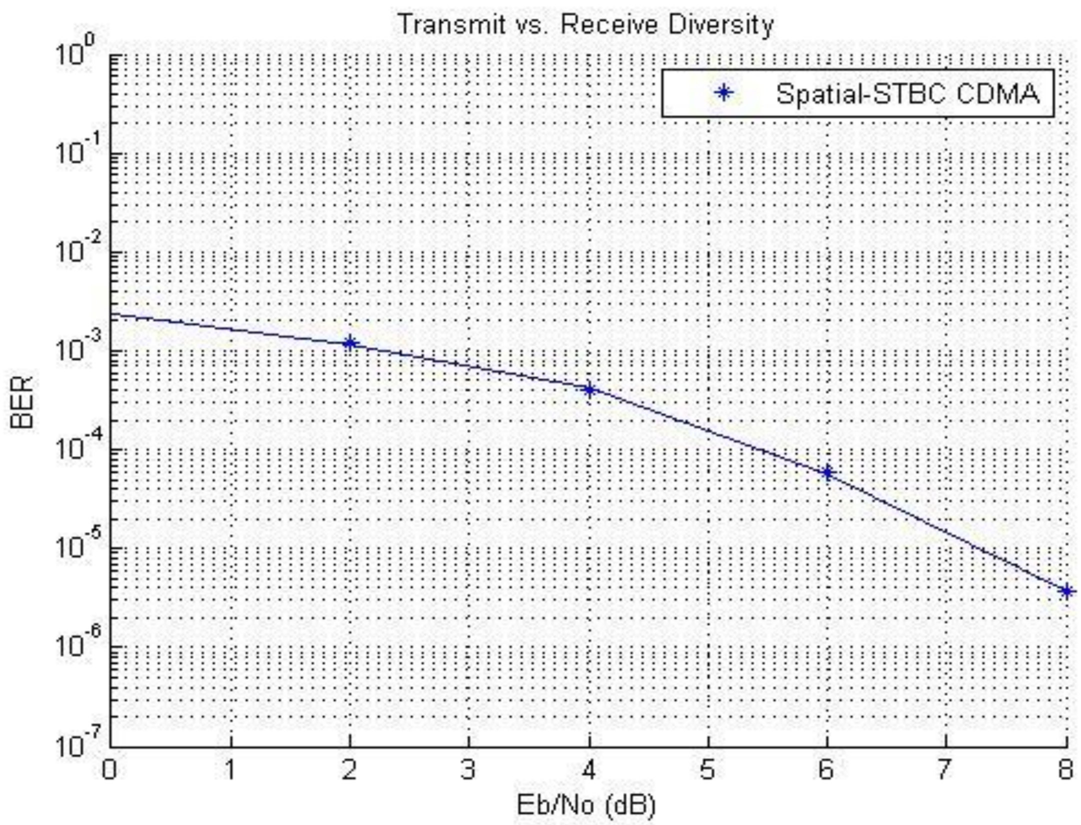

Figure 16: BER performance of SM- STBC – CDMA coding

for CDMA code length of 32 bits, BPSK modulation.

Figure 16 shows BER for spatial modulation- STBC CDMA system. With binary PSK modulation and CDMA code length of 32 bits. As we can see the BER starts at approximately $10^{-2.9}$ at 0 Eb/No and reached $10^{-5.7}$ at 8 Eb/No.

This proves that the system has promising performance with very low BER and acceptable throughput.

From the previous results we can observe that the BER affected by the CDMA code length respectively. This proves that with increasing the code length the system become less affected by the channel variation and therefore the BER increase respectively.

7.3.2 Comparison of results in different modulation techniques

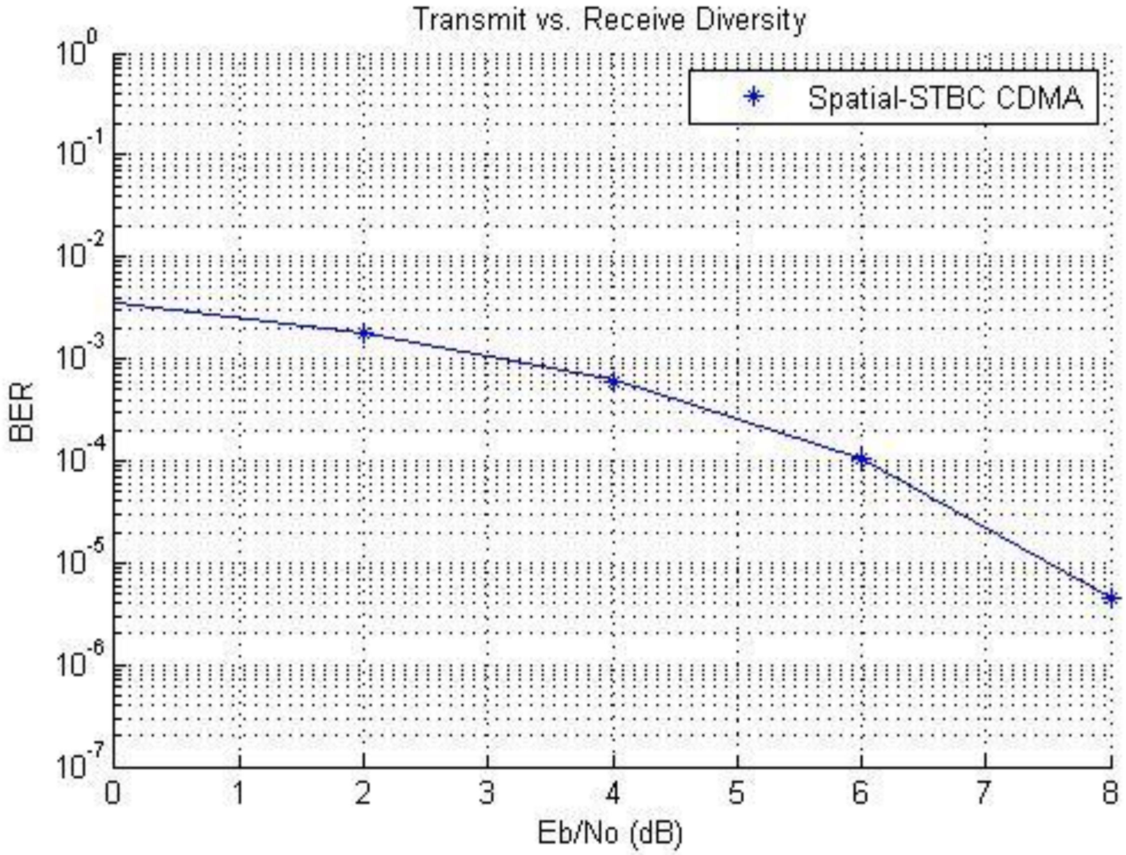

Figure 17: BER performance of SM- STBC – CDMA coding for CDMA code length of 32 bits, 4-PSK modulation.

Figure 17 shows BER for spatial modulation- STBC CDMA system. With 4-PSK modulation and CDMA code length of 32 bits. As we can see the BER starts at approximately $10^{-2.7}$ at 0 Eb/No and reached $10^{-5.6}$ at 8 Eb/No.

This proves that the system has promising performance with very low BER and acceptable throughput.

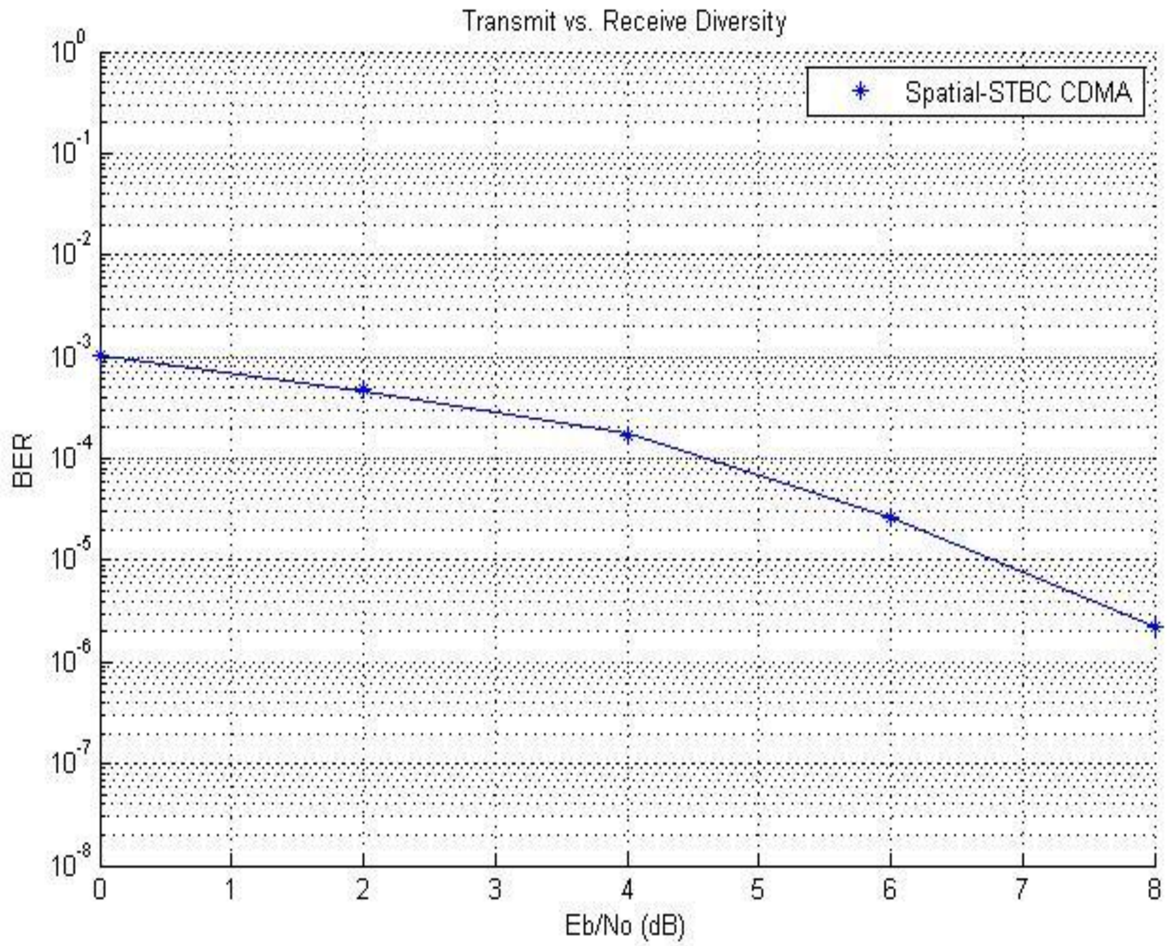

Figure 18: BER performance of SM- STBC – CDMA coding

for CDMA code length of 32 bits, QAM modulation.

Figure 18 shows BER for spatial modulation- STBC CDMA system. With QAM modulation and CDMA code length of 32 bits. As we can see the BER starts at approximately 10^{-3} at 0 Eb/No and reached $10^{-5.9}$ at 10 Eb/No.

This proves that the system has promising performance with very low BER and acceptable throughput.

.

By comparing the results for the same CDMA code length, we can see that the BER decrease with respective to increasing the modulation type. As it is clear from figures 16-18,the BER in BPSK is the most less BER in the all three systems.

7.3.3 Comparison between Alamouti and STBC-SM-CDMA

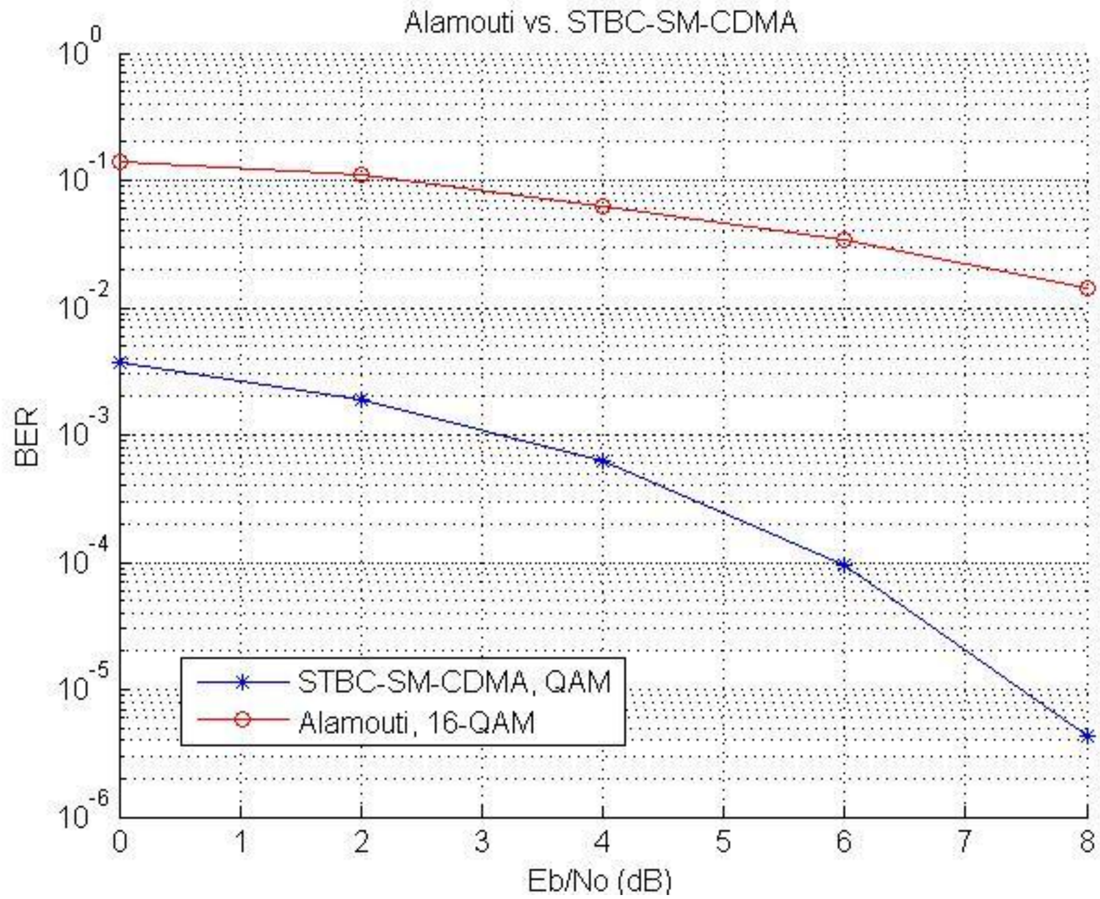

Figure 19: BER performance at 4 bits/s/Hz for STBC-SM-CDMA and Alamouti's STBC schemes.

In our system, for 4-QAM the system shows very low bit error rate which become clearly at the point 4 Eb\No, it reaches $10^{-3.4}$ BER.

With comparing this result to Alamouti scheme with 16-QAM system with two transmit antenna the system, where the two system has 4 bits per second transmit rate, the alamouti system has BER $10^{-1.4}$ at Eb\No =4.

This comparison shows that the new system has great improvement in the BER for the same EbNo. This improvement is logical since the new system uses 4-QAM which has lower BER than the 16-QAM. The difference between the two system doesn't come only from the difference in the modulation order. To be precise, it comes basically from the combination between the STBC, spatial modulation and CDMA. This is because, the benefits of combining the three systems become so clear on the BER performance. As stated previously, the spatial modulation allows for lower modulation order. It is well-known that the BER of lower modulation scheme is better than higher modulation schemes. For example, BPSK modulation has lower BER than 16-PSK- STBC add transmit diversity to the spatial modulation scheme which enable for even a better performance.

Also by adding the CDMA the system can stand the channel variation and become less affected by the noise. This is because the CDMA spread the bit for less power bits and uses higher bandwidth. This functionality obviously affects the system overall BER. This can be observed in the previous figures of performance of the considered system.

7.3.4 Comparison between SM and STBC-SM-CDMA

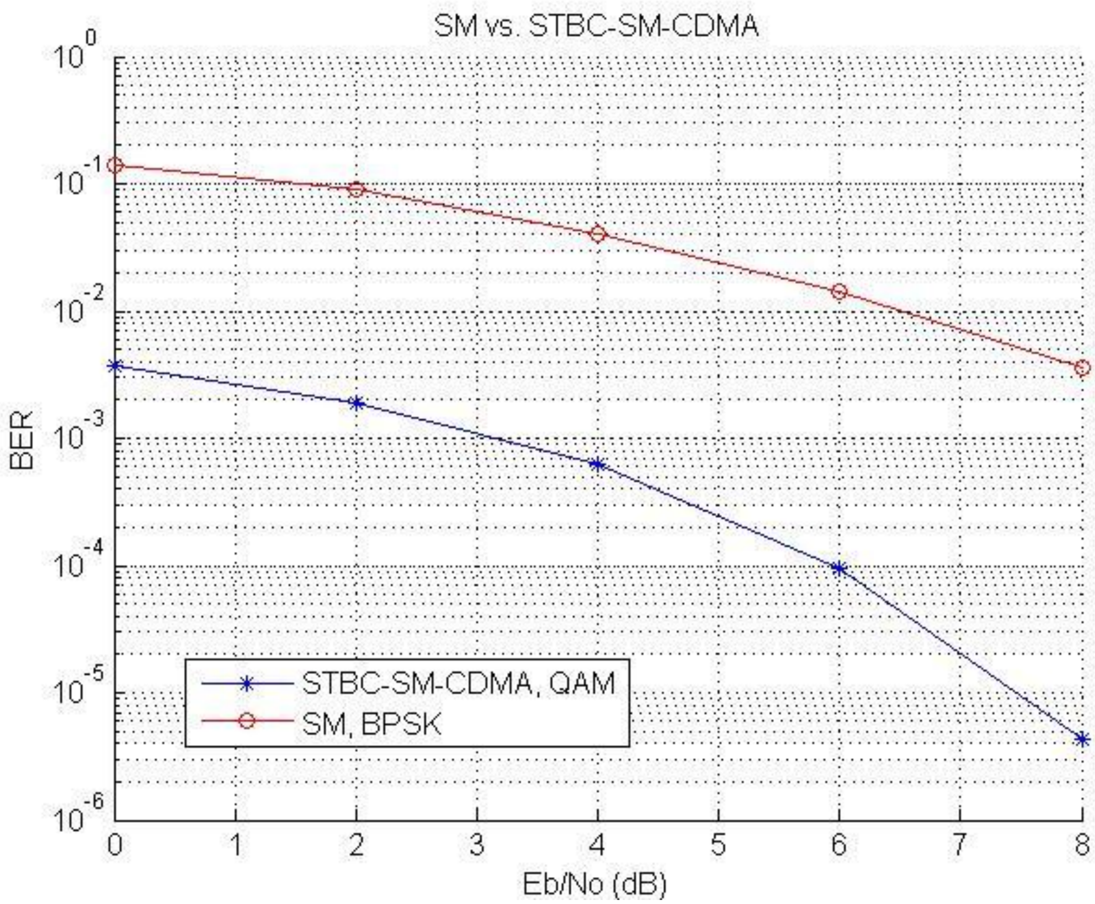

Figure 20: BER performance at 4 bits/s/Hz for STBC-SM-CDMA and SM.

For the same parameters as above the spatial modulation alone shows a BER equals to $10^{-1.7}$ at 4 EbNo.

Still our system exceeds this by a great deal. This comes from the STBC benefits which use the effect of using multiple antenna at both sides. This use can affect directly overall system performance, by sending multiple replicas of the original data. The receiver can retrieve the original data with much more precise accuracy. This can shows clearly how the STBC affects the BER performance of the overall system. Combining the stbc with CDMA the system can become more reliable.

This reliability is shown in our system with much less BER than previous systems for the same BER.

7.3.5 Comparison between STBC-SM and STBC-SM-CDMA

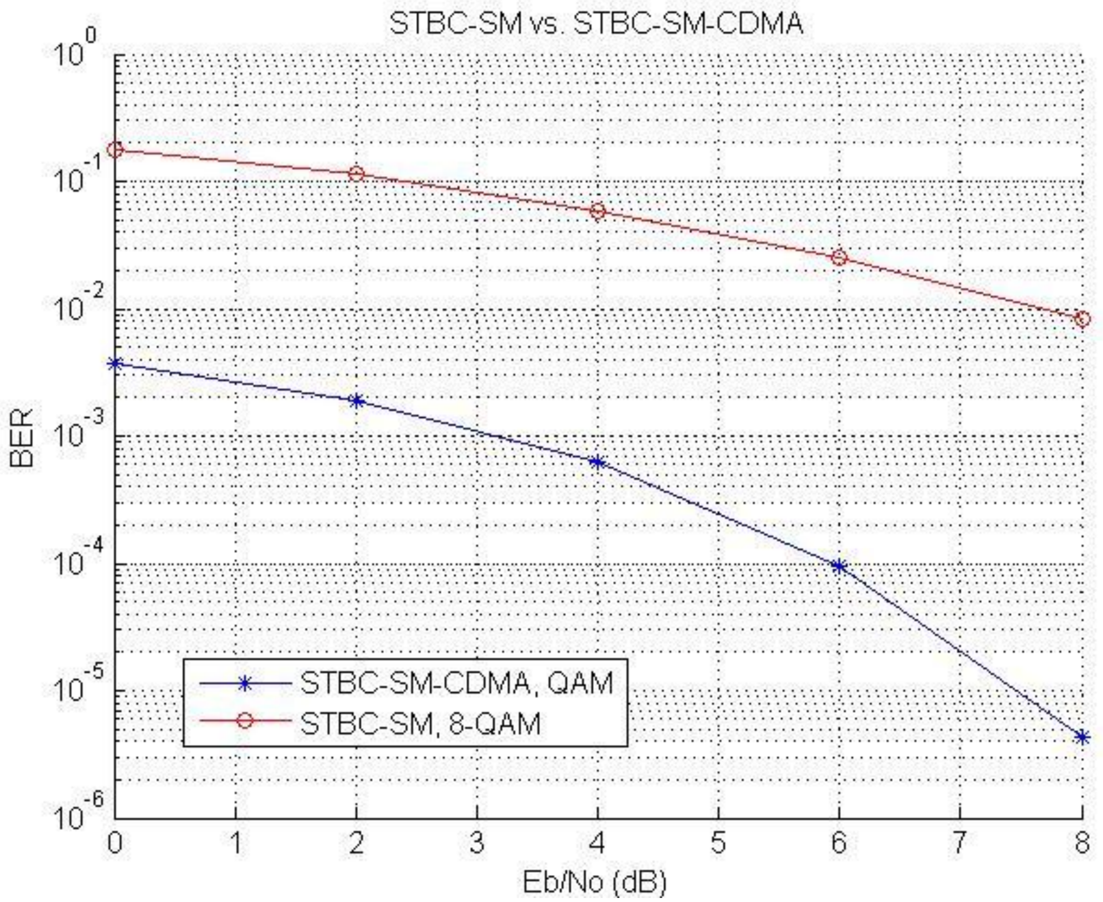

Figure 21: BER performance at 4 bits/s/Hz for STBC-SM-CDMA and STBC-SM.

This comparison between our system and STBC-SM system with 4 antenna at transmitter side for both system.

The STBC-SM system shows BER equals to $10^{-1.5}$ at EbNo is equals 4. To compare this with the considered system (EbNo $10^{-3.4}$). The SM-STBC-CDMA system has more lower bit error rate for the same SNR. Moreover, the system can serve more users due to the characteristics of CDMA codes.

This difference in results can be understood because of the use of CDMA which as we explained above, can with stand the channel changes much efficiently, and use less power in transmitting (from a single bit transmit prospective).

7.3.6 Comparison between STBC-CDMA and STBC-SM-CDMA

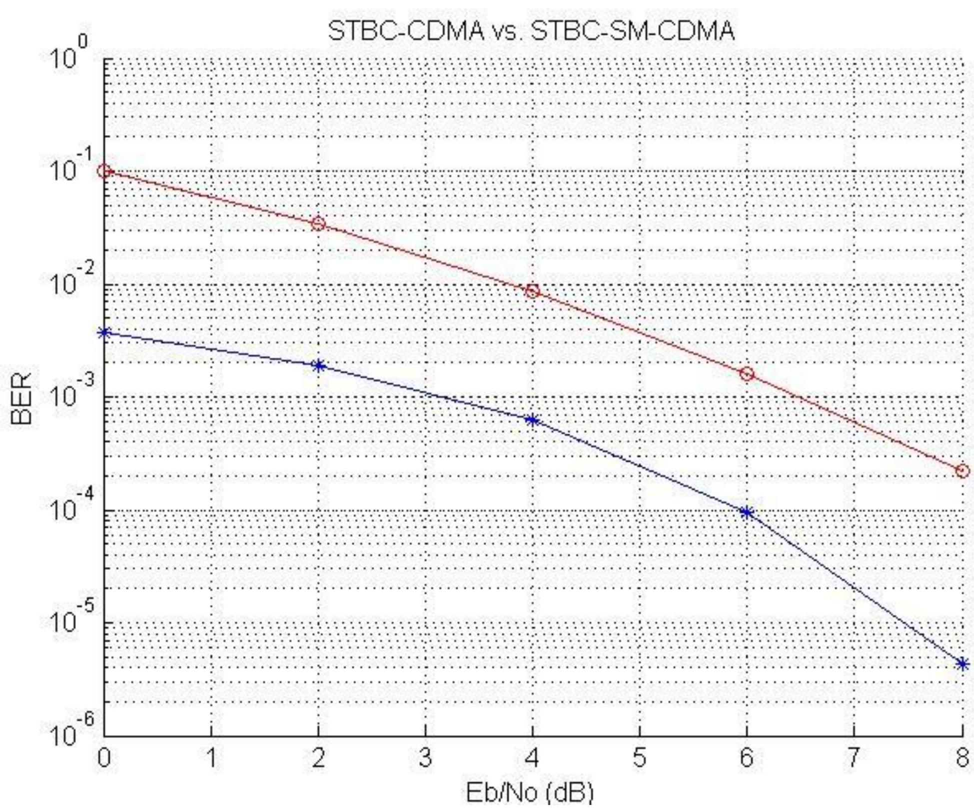

Figure 22: BER performance at 4 bits/s/Hz for STBC-SM-CDMA and STBC-SM.

The system showed better BER performance because of the spatial modulation (SM) is a novel and recently proposed multiple– antenna transmission technique which can offer, with a very low system complexity, improved data rates compared to single input single output (SISO) systems, and even a robust error performance.

Chapter 8

Conclusions& Future works

8.1 Conclusions

In this chapter we conclude the thesis over all, in chapter one an introduction to the thesis and its motivation followed by methodology, literature review and finally thesis overview.

In chapter two, a quick survey was made on the Multiple input Multiple output (MIMO) communication system, where the array again and diversity gain were discussed. We also illustrated the ideas of spatial multiplexing gain, MIMO channel model and capacity of MIMO system.

Chapter three entitled space time block coding (STBC). In this chapter, the idea of STBC is introduced by defining the transmitter and receiver sides as well as the analysis of the whole system and its characteristics.

In chapter 4, the spatial modulation is discussed and analysis of the transmitter and receiver as well as its advantages and disadvantages. Meanwhile the combination between STBC and SM is introduced, and its transmitter and receiver sides are discussed.

In chapter 6, the last part of the system is introduced which is CDMA, many principles of CDMA are introduced such as spread spectrum, code correlation and pseudo noise spreading, then the transmitting and receiving data techniques and its system capacity advantages and disadvantages.

In the last chapter the main idea of the thesis is introduced, which is a combining STBC, SM and CDMA, in that chapter a simulation of the system is done and a comparison is made between the system and number of systems.

The system uses 4 by 4 – multi input multi output- antenna system over uncorrelated Rayleigh fading channels. The simulation was carried over number of variables from the modulation type to PN sequence length.

The system modulated the data for several kind of modulation type such as binary PSK and QAM modulation, and over several length of PN sequences for the CDMA modulation.

The results obtained was very promising results with BER extremely low. The system proves to be able serve high number of users and less vulnerable to channel effects since the use of the channel state information is being used at the receiver side which increase the BER of the system significantly.

The results were compared and discussed for number of systems. The results we compared with spatial modulation, space time modulation, CDMA modulation, SM-STBC systems and STBC- CDMA systems.

The system showed huge improvement over the previous systems, with better BER results at a wide range of Eb/No.

8.2 Future work

The system can be modified by many aspects, for example an OFDM modulation can be used where the index is decided using the OFDM carrier, also CDMA can be modified by using various number of codes instead of Hadamard code such as, gold code. In our work we only simulated the system for 4-qam and BPSK, so the system can be simulated for 64-QAM and other modulation type to see how the system can work with other modulation techniques.

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Appendix A

```
clc
clear all
close all

%%%%%%%%%%%%%%%  Starting factors  %%%%%%%%%%%%%%%

numPackets = 1e6;
frmLen=4;
Mt = 4;
Nt = 4;
Nc = 32;
theta=deg2rad(90);                        %theta = pi/2;
EbNo = 0:2:10;
k = log2(4);                              %Number of bits/symbol
SNR =EbNo + 10*log10(k)+1.315;            %Signal to noise ratio
snr_linear=10.^(SNR./10);
f = exp(1i*theta);
m= zeros(1,16); Yhat= zeros(2,4);
error = 0;
error21 = zeros(1, numPackets);
BER21 = zeros(1, length(EbNo));

% %%%%%%%%%%  Set up the simulation  %%%%%%%%%%%%%%%

h= hadamard(Nc);
ds1 = h(1,:);
ds2 = h(2,:);
ds3 = h(3,:);
%we use symbol energy normalized to 1
%thus, DS energy is normalized to 1 (it is a pulsewaveform)
```

```
ds1_energy=norm(ds1)^2;
ds2_energy=norm(ds2)^2;

%%%%%%%%%%  Create BPSK mod-demod objects  %%%%%%%%%%

P = 2;                                  % modulation order
bpskmod = modem.pskmod('M', P, 'SymbolOrder', 'Gray');
bpskdemod = modem.pskdemod(bpskmod);

%%%%%%%%%  Set up a figure for visualizing BER results  %%%%%%%

h = gcf; grid on; hold on;
set(gca, 'yscale', 'log', 'xlim', [EbNo(1), EbNo(end)], 'ylim', [1e-8 1]);
xlabel('Eb/No (dB)'); ylabel('BER'); set(h,'NumberTitle','off');
set(h, 'renderer', 'zbuffer'); set(h,'Name','Transmit vs. Receive Diversity');
title('Transmit vs. Receive Diversity');

%%%%%%%%%%%%% Loop over several EbNo points  %%%%%%%%%

foridx = 1:length(EbNo)   % Loop over the number of packets
forpacketIdx = 1:numPackets

%%%%%%%%%%%%%% Data Generation user 1  %%%%%%%%%%%%%

data11 = randi([0 1], 1,frmLen);
antindex = data11(1:2);
index = bi2de(antindex,'left-msb')+1;
datasym = data11(3:end);

%%%%%%%%%%%%%%%  Alamouti scheme user 1  %%%%%%%%%%

x1data = datasym(1:2:end);
x2data = datasym(2:2:end);
x1dat = (modulate(bpskmod,x1data))/sqrt(2);
x2dat = (modulate(bpskmod,x2data))/sqrt(2);
```

```
%%%%%%%%%%%%%%  Mapping generation user 1  %%%%%%%%%

x1 = [x1dat;-conj(x2dat)];
x2 = [-conj(x2dat);conj(x1dat)];
X = [x1 x2];


x11 = [X zeros(2,2)];
x12 = [zeros(2,2) X];


x21 = [zeros(2,1) X zeros(2,1)]*f;
x22 = [x2 zeros(2,2) x1]*f;

%%%%%%%%%%%%% STBC-SM user 1  %%%%%%%%%%%%%%%%

if index == 1
tx = x11;
elseif index == 2
tx = x12;
elseif index ==3
tx = x21;
elseif index ==4
tx = x22;
end
txx1 = tx(1,:);
txx2 = tx(2,:);

%%%%%%%%%%%%%% CDMA modulation user 1  %%%%%%%%%%

txx1 = kron(txx1,ds2);
txx2 = kron(txx2,ds2);

%%%%%%%%%%%%%% Data Generation user 2  %%%%%%%%%%%

data12 = randi([0 1], 1,frmLen);
```

```
antindex2 = data12(1:2);
index2 = bi2de(antindex2,'left-msb')+1;
datasym2 = data12(3:end);

%%%%%%%%%%%%Alamouti scheme user2  %%%%%%%%%%%

x1data2 = datasym2(1:2:end);
x2data2 = datasym2(2:2:end);
x1dat2 = (modulate(bpskmod,x1data2))/sqrt(2);
x2dat2 = (modulate(bpskmod,x2data2))/sqrt(2);

%%%%%%%%%%%  Mapping generation user2  %%%%%%%%%%%

x21 = [x1dat2;-conj(x2dat2)];
x22 = [-conj(x2dat2);conj(x1dat2)];
X2 = [x21 x22];
x2_11 = [X2 zeros(2,2)];
x2_12 = [zeros(2,2) X2];
x2_21 = [zeros(2,1) X2 zeros(2,1)]*f;
x2_22 = [x22 zeros(2,2) x21]*f;

%%%%%%%%%%%  STBC-SM user2  %%%%%%%%%%%%%%%

if index2 == 1
   tx2 = x2_11;
elseif index2 == 2
   tx2 = x2_12;
elseif index2 ==3
   tx2 = x2_21;
elseif index2 ==4
   tx2 = x2_22;
end
txx2_1 = tx2(1,:);
txx2_2 = tx2(2,:);
```

```
%%%%%%%%%%  CDMAmodulation user 2  %%%%%%%%%%%

txx2_1 = kron(txx2_1,ds3);
txx2_2 = kron(txx2_2,ds3);
%% channles
h11 = randn(1,1)+1i*randn(1,1);
h12 = randn(1,1)+1i*randn(1,1);
h22 = randn(1,1)+1i*randn(1,1);
h21 = randn(1,1)+1i*randn(1,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rx11 = awgn(((txx1.*h11)+(txx2_1.*h21))/sqrt(Nt),snr_linear(idx));
rx22 = awgn(((txx2.*h12)+(txx2_2.*h22))/sqrt(Nt),snr_linear(idx));

%%%%%%%%%%% Received signal  %%%%%%%%%%%%%%%%%

r = awgn((tx*h)/sqrt(Nt),snr_linear(idx));
r1 = r(1,:);
r2 = r(2,:);

%%%%%%%%%%  CDMA demodulation  %%%%%%%%%%%%

ds2_1 = repmat(ds2,1,4);
r11 = rx11.*ds2_1;
r12 = rx22.*ds2_1;
r1_11 = intdump(r11,Nc);
r2_22 = intdump(r12,Nc);
rcdma = [r1_11;r2_22];
%% ML decoder
% generate mapping rule
rule = de2bi(0:15,'left-msb');
index = rule(:,1:2);
data = rule(:,3:end);
```

```
fori=1:length(rule)
xhat = rule(i,:);
indexhat = xhat(:,1:2);
indexhat = bi2de(indexhat,'left-msb')+1;
datahat = xhat(:,3:end);
    x1dathat = datahat(1:2:end);
    x2dathat = datahat(2:2:end);
    x1dathat = (modulate(bpskmod,x1dathat))/sqrt(2);
    x2dathat = (modulate(bpskmod,x2dathat))/sqrt(2);
    x1hat = [x1dathat;-conj(x2dathat)];
    x2hat = [-conj(x2dathat);conj(x1dathat)];
Xhat = [x1hat x2hat];
    x11hat = [Xhatzeros(2,2)];
    x12hat = [zeros(2,2) Xhat];
    x21hat = [zeros(2,1) Xhat zeros(2,1)]*f;
    x22hat = [x2hat zeros(2,2) x1hat]*f;
ifindexhat == 1
txhat = x11hat;
elseifindexhat == 2
txhat = x12hat;
elseifindexhat ==3
txhat = x21hat;
elseifindexhat ==4
txhat = x22hat;
end
Yhat(:,:,i)=txhat;
End

%%%%%%%%%%%%% Decoding  %%%%%%%%%%%%%%

for t=1:16
    m(t)=(norm(rcdma-Yhat(:,:,t).* [h11 h11h11 h11;h12 h12 h12 h12],'fro'))^2;
```

```
end
[vmin,imin]=min(m) ;    %Min metric (ML)
rhat=de2bi(imin-1,4,'left-msb');
error21(packetIdx) = biterr(data11,rhat);
end

BER21(idx) = sum(error21)/(numPackets*frmLen);

%%%%%%%%%%%%%  Plot results  %%%%%%%%%%%%%

semilogy(EbNo(1:idx), BER21(1:idx), 'b*');
legend('Spatial-STBC CDMA');
drawnow;
end
fitBER21 = berfit(EbNo, BER21);
semilogy(EbNo, fitBER21, 'b');
hold off;
```