Chapter one

Introduction

1.1 Overview:

Communication technologies have become a very important part of human life. Wireless communication systems have opened new dimensions in communications; People can be reached at any time and at any place. In the near future, High data rate 1 Gbps ranges will be needed, also mobile need to cope with very fast speed 350 Km/hr. The research community has generated a number of promising solutions for significant improvements in system performance. One of the most promising future technologies in mobile radio communications is multi antenna elements at the transmitter and at the receiver [1].

MIMO stands for Multiple-Input Multiple-Output and means multiple antennas at both link ends of a communication system, i.e., at the transmit and at the receive side. The idea behind MIMO is that the transmit antennas at one end and the receive antennas at the other end are" connected and combined" in such a way that the quality (the bit error rate (BER), or the data rate) for each user is improved. The core idea in MIMO transmission is space-time signal processing in which signal processing in time is complemented by signal processing in the spatial dimension by using multiple, spatially distributed antennas at both link ends.

Because of the enormous capacity increase MIMO systems offer, such systems gained a lot of interest in mobile communication research [2]. One essential problem of the wireless channel is fading, which occurs as the signal follows multiple paths between the transmit and the receive antennas. Under certain, not uncommon conditions, the arriving signals will add up destructively, reducing the received power to zero (or very near to zero). In this case no reliable communication is possible. Fading can be mitigated by diversity, which means that the information is transmitted not only once but several times, hoping that at least one of the replicas will not undergo severe fading. Diversity makes use of an important property of wireless MIMO channels, different signal paths can be often modeled as a number of separate, independent fading channels. These channels can be distinct in frequency domain or in time domain. Space-time coding (STC), introduced first by Tarokh at el. [3], is a promising method where the number of the transmitted code symbols per time slot are equal to the number of transmit antennas. Space-time coding finds its application in cellular communications as well as in wireless local area networks. There are various coding methods as space-time trellis codes (STTC), space-time block codes (STBC). A main issue in all these schemes is the exploitation of redundancy to achieve high reliability, high spectral efficiency and high performance gain. This thesis provides an OSTBC design principles and performance. The main focus is devoted to orthogonal space-time block codes OSTBCs for two and four transmit antennas and one or two or four receive antenna and to analyze their performance [4].

1.2 Problem Statement:

In modern communications networks (4G) that use systems with multiple antennas at the transmitter and receiver MIMO with STBC facing a fundamental problem, Is that all the signals are transmitted in the same transmission phase angle, which means that all the signals are exposed to the same constraints and influence in the Rayleigh fading channel, which cause an increase in BER, which is a big bump in the use of such systems, which leads to confront increasing the SNR which in turn exacerbates the problem in systems containing A large number of antennas. To resolve this problem presented a study under the title “Error performance of orthogonal space-time block code over fading channel”, Gave the numerical method for evaluating the performance of the OSTBC system but applied to the Single transmit antenna and Single receive antenna (SISO) system gave numerical results are good, but this method applied to the SIMO using a single antenna at the transmitter and four antennas at the receiver, in addition this method is applied on the practical system, as opposed to the previous method, which used a numerical functions to determine the expected value using the equations. Did not take into account the changes in the real channel and take all parameters as constants, and this is not true. This work was applied on Rayleigh fading channel, which is a good representation of variables and parameters in realism Channel.

1.3 Aim and Objectives of the Thesis:

The main Aim of This project is to “Performance of Orthogonal Space-Time Block Code over Rayleigh fading channel”, the objectives are:

- Improve the performance of wireless communication systems to increase data rate and reliability of OSTBC systems compared to conventional STBC schemes.
- Reduce Bit Error Rate (BER) without increasing Signal to Noise ratio.
- Reduce the complexity, processing time and higher cost in multi-antenna systems.

1.4 Methodology:

The main idea of this work is to study and analyze the performance of Orthogonal Space - Time Block Code Techniques due the Rayleigh Fading Channels exist, channel state and analyze the architecture of the system. In addition to discuss the performance of the orthogonal of the space-time block code and how it can solve the problems which are stand in the other networks. Submit a proposed method

(OSTBC 1x4) of dealing with deficiencies in previous studies as well as to reduce the economic costs compared with other methods of solution.

Using MATLAB as a simulation tool, we provide simulation results demonstrating the performance for one, two and four transmit antennas and proposed method over Rayleigh fading channels. We illustrate that using multiple transmit antennas and space-time coding outstanding performance can be obtained, under the impact of channel variation.

1.5 Research Outline:

Chapter 2: Displays some background for Multiple Antenna Systems and space-time coding techniques.

Chapter 3: Design of Orthogonal Space Time Block Code and theoretical analysis and displays previous studies on the subject and tried to provide an appropriate solution.

Chapter 4: displays results and Discussions.

Chapter 5: Conclusion and Recommendations.

Chapter Two

Multiple Antenna Systems and Space-Time Coding (STC)

2.1 Background:

Wireless communications are one of the most attractive research areas which have seen enormous growth in the last several years. After the first appeared, in 1897 when Marconi succeeded to contact with ships sailing in the English canal by the radio, wireless communications has experienced many milestones, for example, the use of AM and FM communication systems for radios, and the development of the cellular phone system from its first generation in the 1970s to the fourth generation[5].

Figure (2.1): Wireless communication applications. [6]

The growing demands of wireless communications due to new emerging applications, introduce many technical challenges in developing the modern wireless communication systems. The main two challenges are the capacity; how much information can go through the channel between the clients of the system, and the pair wise error probability (PEP); the probability of mistaking the transmitted signal with another one.

Moreover, the wireless channel suffers from another great disadvantage beside the low capacity: it's the high error rate and it decreases nearly linearly with the increasing of the signal-to-noise ratio (SNR) not exponentially decay like a wired communication channel that also is due to multipath effect [7]. Therefore, to achieve the same performance, a much longer code or much higher transmit power is needed for wireless communication systems than a wired system. As noticed, the main cause of the previous disadvantages of wireless communication is the multiple-path propagation phenomena in wireless channels, so we need a system that can deal with the impact of this issue to meet the rising demand on the high data rate and the quality of the wireless communication systems. Recently, the Multiple Input - Multiple Output (MIMO) communication system provides a feasible solution for some challenges such as low channel capacity and high probability of errors. It uses the multiple antennas at the transmitter and the receiver to turn multiple-path propagation, which is the disadvantage of wireless communications, into a benefit to the clients. In 1996 and 1999, Foschini and Telatar proved in [8] and [9] that communication systems with multiple antennas have a much higher capacity than single antenna systems. Also, it can be used to improve the BER of the wireless system.

2.2 Wireless Communication Channel:

The signal through a wireless channel experiences many factors, such as noise, attenuation, distortion and interference which may cause the result of detection at the receiver done in a wrong way. It is then useful to briefly summarize the main impairments that affect the signals.

2.2.1 Additive white Gaussian noise:

Additive white Gaussian noise (AWGN) is a noise term which generally used to model background noise in the channel as well as noise introduced at the receiver front end and it is the most common noise model in communication systems [10]. The term additive comes from that the effect of this noise to the original signal is additive in nature, this is clear in the relation between the output of the channel (y(t)) and the input x(t) signal which is given by equation below and illustrated in figure (2.2).

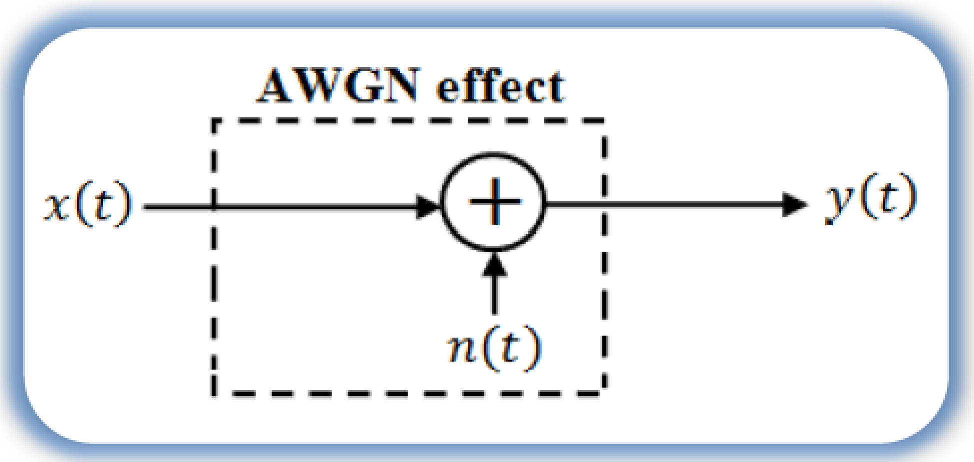


Figure (2.2): The AWGN channel effect.

$$y(t) = x(t)/\sqrt{\Gamma} + n(t) \tag{2.1}$$

Where Γ is the loss in power of the transmitted signal x(t) and n(t) is the AWGN noise.

White term means that the frequency spectrum is continuous and uniform for all frequency bands. The term, white, originated from the fact that white light contains equal energy over the visible frequency band. Finally, the term Gaussian comes from that the additive noise n(t) is modeled as a random variable with a Gaussian distribution.

2.2.2 The propagation effects:

The transmitting signal in wireless channel suffers from two main categories propagation effects which are large-scale fading effects and small-scale fading effects. Figure (2.3) shows the power (in dB) of the signal at a moving receiver which moves far away from the transmitter.

From this figure, you can observe there are two types of changes of the signal power, decay over a curve with increasing in the distance and a repaid variation over the curve, which are the effect of the two types will be consider.

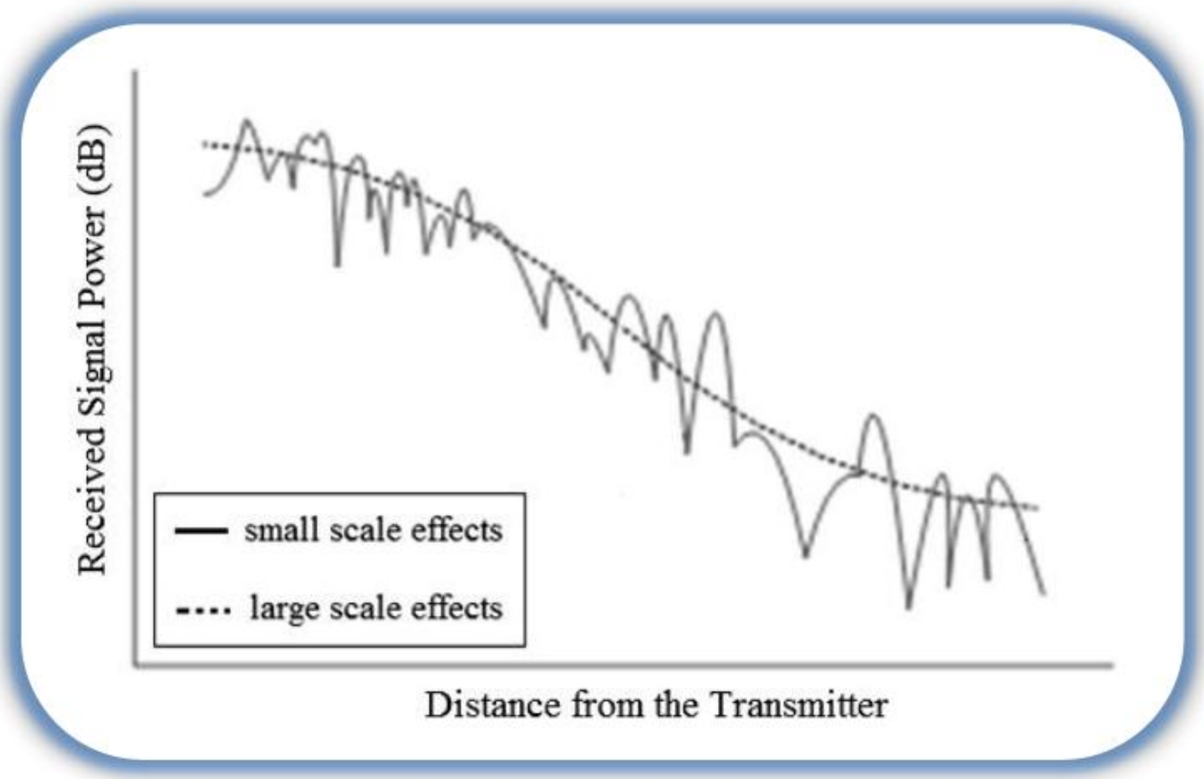


Figure (2.3): The propagation effects through wireless channel.

2.2.2.1 Large-scale fading effects:

It refers to the loss of the transmitting signal power due to distance between the transmitter node and the destination node, also it is called path loss and measured in decibels (dB) of the ratio between the transmitted and received signal power. The path loss is proportional to the distance; it means that the attenuation increases as the signal propagates from the transmitter to the receiver. Due to that the degradation occurs slowly in time and phase over the distance, it classified as large-scale propagation effects. These variations occur over distances of hundreds of meters and involve variation up to around 20 dB.

2.2.2.2 Small-scale propagation effects:

While the signal propagates through the wireless channel it will experience random reflectors, scatterers, and attenuators, which is resulting a multiple copies of the signal arriving at the receiver after each has traveled through different paths, this channel known as a multipath channel, this scenario shown in figure (2.4).

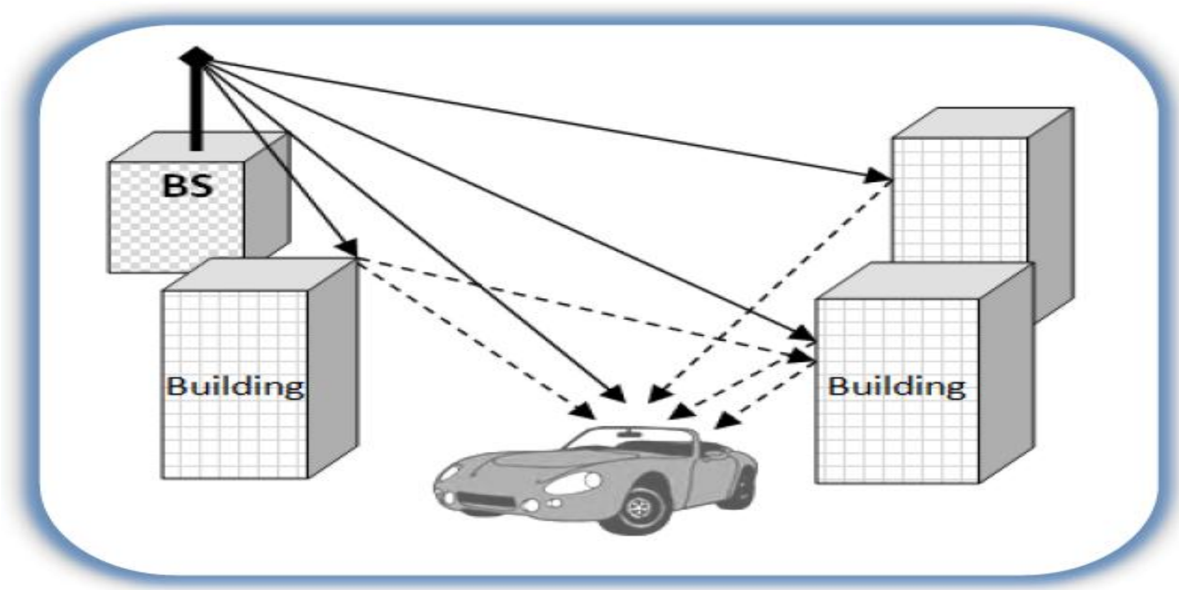


Figure (2.4): Signal propagation over a wireless channel.

2.3 Multiple-Antenna Wireless Communication Systems:

A successful method to improve reliable communication over a wireless link is to use multiple antennas. The main arguments for this method are:

2.3.1 Array gain:

Array gain means the average increase in signal to noise ratio (SNR) at the receiver that can be obtained by the coherent combining of multiple antenna signals at the receiver or at the transmitter side or at both sides. The average increase in signal power is proportional to the number of receive antennas. In case of multiple antennas at the transmitter, array gain exploitation requires channel knowledge at the transmitter.

2.3.2 Interference reduction:

Co-channel interference contributes to the overall noise of the system and deteriorates performance. By using multiple antennas it is possible to suppress interfering signals what leads to an improvement of system capacity. Interference reduction requires knowledge of the channel of the desired signal, but exact knowledge of channel may not be necessary [11].

2.3.3 Diversity gain:

An effective method to combat fading is diversity. According to the domain where diversity is introduced, diversity techniques are classified into time, frequency and space diversity. Space or antenna diversity has been popular in wireless microwave communications and can be classified into two categories: receive diversity and transmit diversity [12], depending on whether multiple antennas are used for reception or transmission.

2.3.3.1 Transmit Diversity:

Transmit diversity is applicable to channels with multiple transmit antennas and it is at most equal to the number of the transmit antennas, especially if the transmit antennas are placed sufficiently apart from each other. Information is processed at the transmitter and then spread across the multiple antennas.

2.3.3.2 Receive Diversity:

It can be used in channels with multiple antennas at the receive side. The receive signals are assumed to fade independently and are combined at the receiver so that the resulting signal shows significantly reduced fading. Receive diversity is characterized by the number of independent fading branches and it is at most equal to the number of receive antennas.

Wireless systems consisting of a transmitter, a radio channel and a receiver are categorized by their number of inputs and outputs. The simplest configuration is a single antenna at both sides of the wireless link, denoted as single-input/single output (SISO) system. Using multiple antennas on one or both sides of the communication link are denoted as multiple input/multiple output (MIMO) systems. The difference between a SISO system and a MIMO system with n_t transmit antennas and n_r receive antennas is the way of mapping the single stream of data symbols to n_t streams of symbols and the corresponding inverse operation at the receiver side. Systems with multiple antennas on the receive side only are called single input/multiple output (SIMO) systems and systems with multiple antennas at the transmitter side and a single antenna at the receiver side are called multiple input/single output (MISO) systems. The MIMO system is the most general and includes SISO, MISO, SIMO systems as special cases. Therefore, the term MIMO will be used in general for multiple antenna systems.

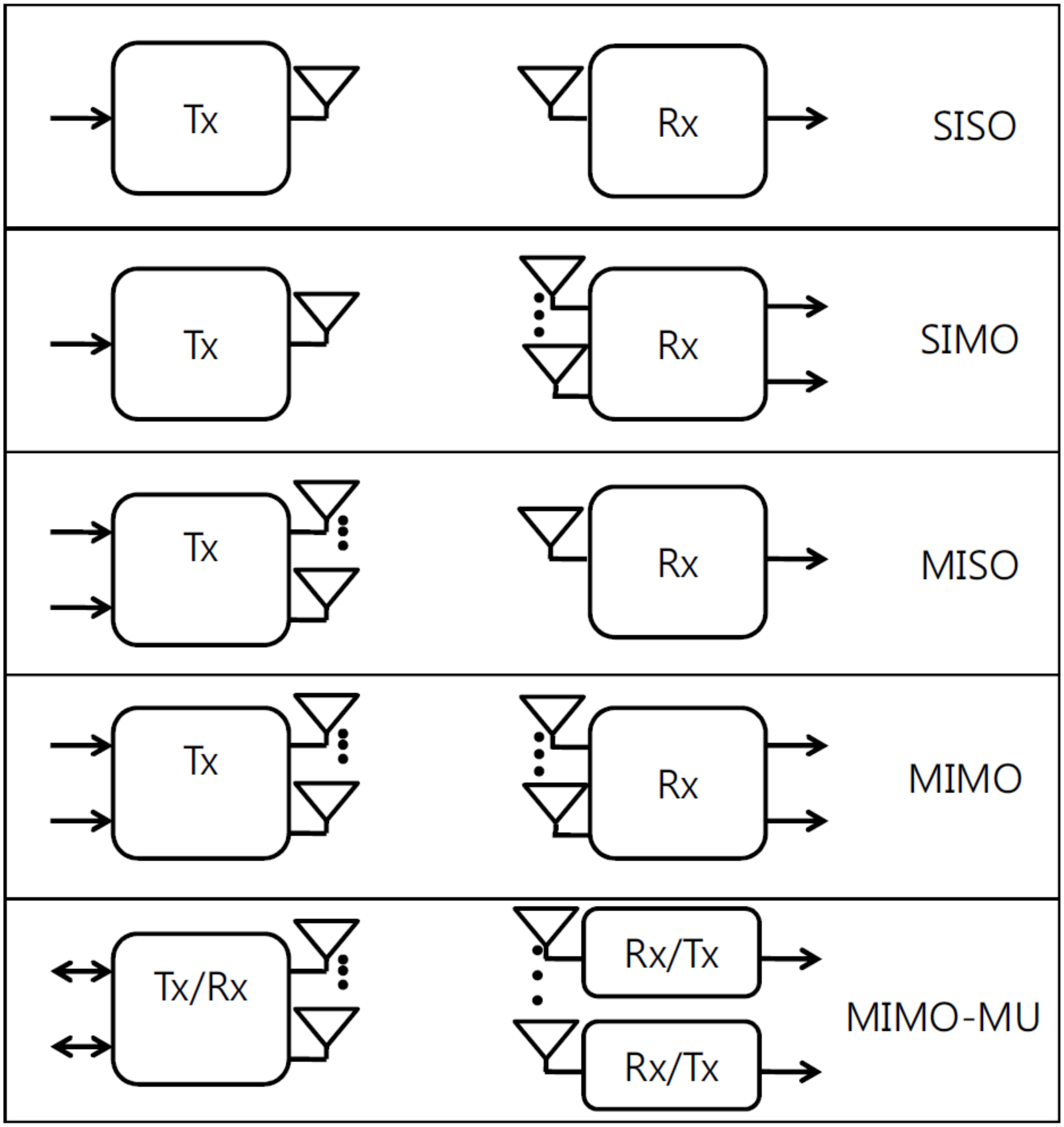


Figure (2.5):Antenna configuration in wireless systems (Tx: transmitter, Rx: Receiver)

2.3.4 Multi - Antenna Transmission Methods:

To transmit information over a single wireless link, different transmission and reception strategies can be applied. Which one of them should be used depends on the knowledge of the instantaneous MIMO channel parameters at the transmitter side. If the channel state information (CSI) is not available at the transmitter spatial multiplexing (SM) or space-time coding (STC) can be used for transmission. If the CSI is available at the transmitter, beamforming can be used to transmit a single data stream over the wireless link. In this way, spectral efficiency and robustness of the system can be improved.

2.4 Space-Time Coding (STC):

Space-Time Codes (STCs) have been implemented in cellular communications as well as in wireless local area networks. Space time coding is performed in both spatial and temporal domain introducing redundancy between signals transmitted from various antennas at various time periods. It can achieve transmit diversity and antenna gain over spatially uncoded systems without sacrificing bandwidth. The research on STC focuses on improving the system performance by employing extra transmit antennas. In general, the design of STC amounts to finding transmit matrices that satisfy certain optimality criteria. Constructing STC, researcher have to trade-off between three goals: simple decoding, minimizing the error probabilty, and maximizing the information rate. Most of modulation schemes have a poor performance over Rayleigh wireless channel, the error probability decays very slowly over increasing the value of signal to noise ratio (SNR). The main cause of that poor is that all schemes rely on the strength of single signal path which have a significant probability to face a deep fade. To overcome that problem, a system rely on receiving the data from multiple channels must be created .The probability to face deep fading at the same time of the transmission is reduced because of the diversity. There are many forms of diversity, such as space, time, polarization and frequency diversity. Diversity schemes are implemented in different ways, but all of them aim to the same objective which is providing multiples uncorrelated copies of transmission to the receiver. The receiver will select the better copy or will coherently combine the independent fading paths so that the effects of fading are reduced [13].

In space diversity the transmitting signal extend over space by multiple antennas, and when it is extend over time (transmit multiple copy over time) the diversity known as time diversity, but when the transmitting signal extends over space and time simultaneously, the model of space time coding will be created. Space Time Coding is a method to employ time and space diversity to improve the reliability of data transmission in wireless communication systems. There is two main categories of space time coding: Space time trellis coding (STTC): which transmits a trellis code version of the data over multiple time slot and multiple antennas and, Space–time block coding (STBC): which acts on a block of data at once like block coding. Coherent and Non Coherent are other categories that STC can be classified into. In coherent STC, the receiver knows the channel model, but in non coherent STC, the receiver does not know the model but knows the statistics of the channel. In differential space–time codes neither the channel nor the statistics of the channel are available [14].

2.4.1 Space Diversity/MIMO system:

Space diversity also called antenna diversity; It is implemented using multiple antennas arranged together at transmitter and/or at the receiver, Figure (2.6).

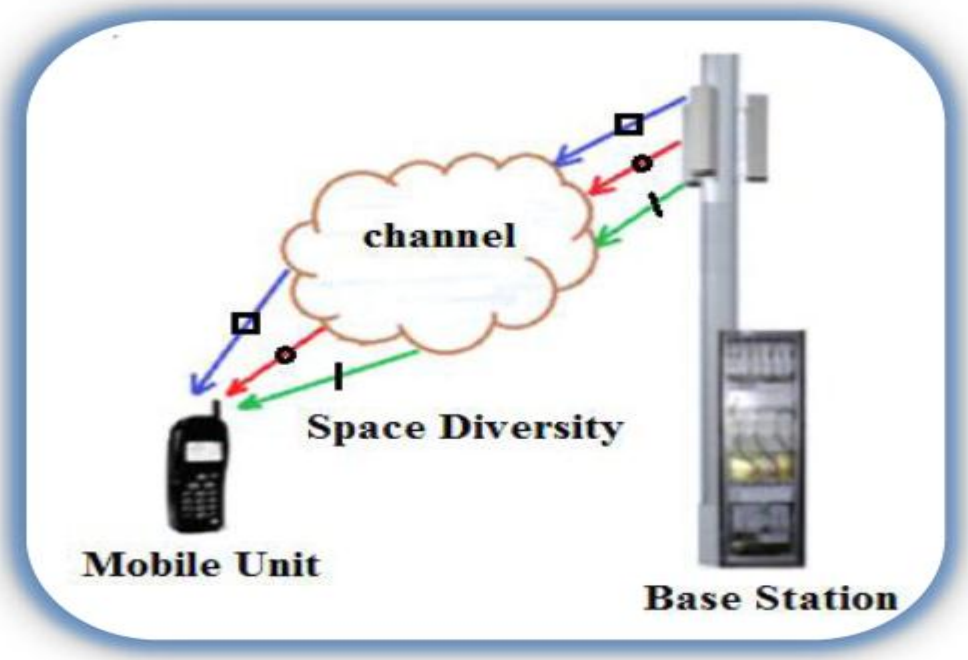


Figure (2.6): The Space diversity scheme.

These antennas are separated physically by distance to produce signals which are uncorrelated. The value of this physical separation depends on many factors such as antenna height, propagation environment and frequency. In space diversity, there is no loss in bandwidth, data rate and transmitting power, since it is not use the time or frequency to provide a replica of signal. Depending on whether multiple antennas are used for transmission or reception, we can classify space diversity into two categories: receive diversity and transmit diversity. These multiple antennas can be used to increase data rates through multiplexing instead of diversity which improve the performance, so there are a tradeoff between diversity and multiplexing.

2.4.2 Time Diversity:

Time diversity can be done by transmitting same signals in different time slots separated by at least the coherence time of the channel, which will produce uncorrelated fading signals at the receiver, Figure (2.7).

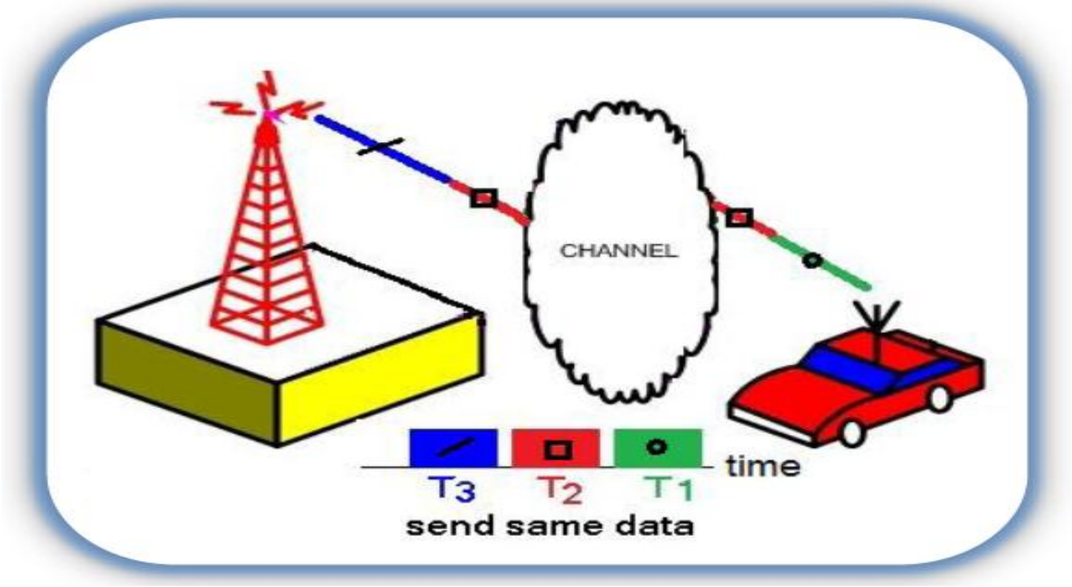


Figure (2.7): The Time diversity scheme.

The coherence time [15]: is a statistical measure of the period of time over which the channel fading process is correlated.

2.4.3 Frequency Diversity:

In frequency diversity a multiple of identical data are transmitting using different frequencies with enough frequency separation between them to have uncorrelated fading signal at the receiver as shown in Figure (2.8).

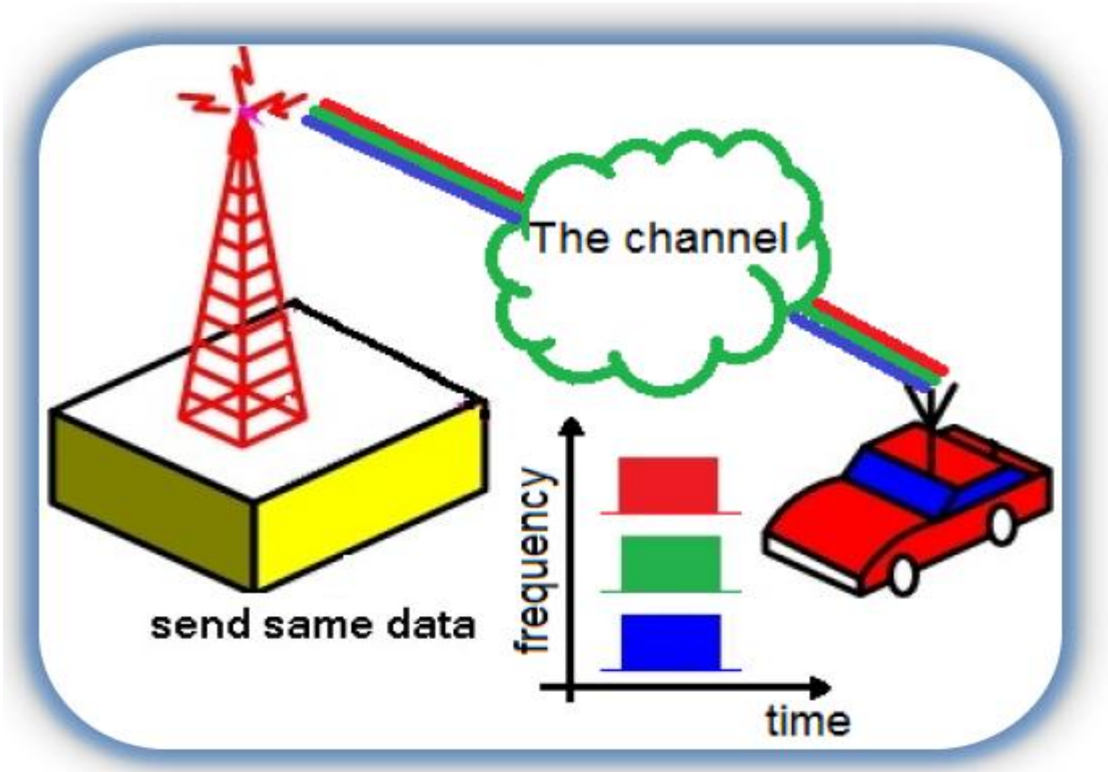


Figure (2.8): The Frequency diversity scheme.

In order to have independent fading signal, the frequency separation must be larger than the coherence bandwidth. The coherence bandwidth [16]: is a frequency bandwidth where the channel may be considered relatively constant. The coherence bandwidth is different for different propagation environments.

2.5 Space Time Block Coding:

Space Time Coding is a method employed time and space diversity to improve the reliability of data transmission in wireless communication systems. There are two main categories of space time coding: Space time trellis coding (STTC), and Space–time block codes (STBCs) where they differ in the way of coding process. Coherent and non-coherent are other categories due to another classification. In coherent STC, the receiver knows the channel model, but in non-coherent STC, the receiver does not know the model. This research will deal only with coherent STBCs.

Alamouti [17] was proposed the first code which implements the concept of exploring the time and space diversity simultaneously, then the concept was extended by Tarokh, Seshadri and Calderbank in [18] to start what so called space time block coding. To explore a spatial diversity through the STBC system, you will require a system to have nodes held with multiple antennas which is usually considering unrealistic condition in many situations.

In a general form, an STBC can be seen as a mapping of S_N complex symbols {s_1, s_2, · · · , s_N} onto a matrix S of dimension $n_t \times N$:

$$\{S1, S2, ..., SN\} \rightarrow S \tag{2.2}$$

An STBC code matrix S taking on the following form:

$$S = \sum_{n=1}^{n_N} (\overline{S_n} A_n + j\tilde{S}_n B_n) \tag{2.3}$$

where {s_1, s_2, · · · , s_{nN} } is a set of symbols to be transmitted with $\bar{s}_n = \mathrm{Re}\{s_n\}$ and $\tilde{s}_n = \mathrm{Im}\{s_n\}$, and with fixed code matrices {A_n,B_n} of dimension $n_t \times N$ are called linear STBCs. The following STBCs can be regarded as special cases of these codes.

As mentioned previously, the Alamouti scheme achieves full diversity with very simple ML detector, and this features attributed from the orthogonality between the sequences generated by the encoder to the antennas. Using the theory of orthogonal designs, you can generate codes to any arbitrary number of transmitting antennas [19]. These codes are known as space time block codes (STBCs), and it can achieve the full diversity with a very simple ML detector. This new encoding scheme of STBC can be modeled by $n_T \times n_{TX}$ matrix as follow:

Over the T_x antenna

$$\text{Over the time slots } n_T \downarrow \begin{bmatrix} S_{11} & S_{12} & \ldots\ldots & S_{1n_{Tx}} \\ S_{21} & S_{22} & \ldots\ldots & S_{2n_{Tx}} \\ . & \ldots\ldots & \ldots\ldots & . \\ . & \ldots\ldots & \ldots\ldots & . \\ S_{n_T 1} & S_{n_t 2} & \ldots\ldots & S_{n_T n_{Tx}} \end{bmatrix} \tag{2.4}$$

Where n_T represent the number of time slots for transmission of one block of coded data and n_{TX} represent the number of antennas. Each column represents a transmission of single antenna over time, each row considered as a transmission at a given period over all transmitting antennas. s_{ij} is the modulated symbol to be transmitted at time slot i from antenna j.

2.5.1 STBC transmitter:

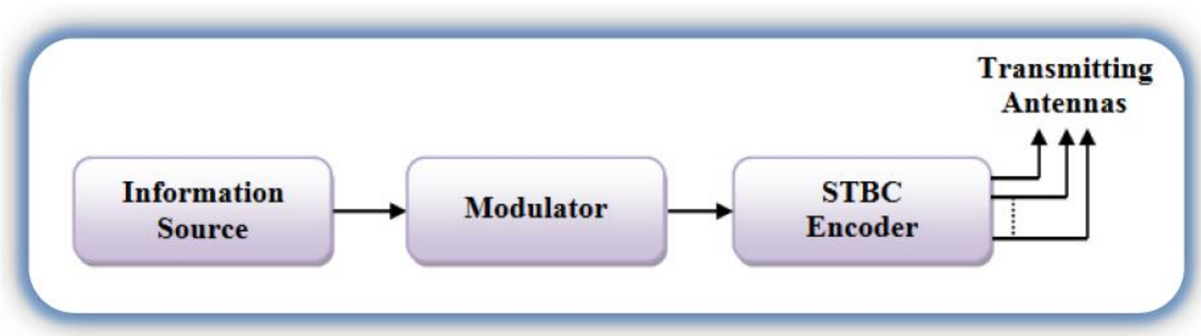


Figure (2.9): The STBC encoder.

STBC transmitter is shown in figure (2.9), and the procedure is listed as:

1. Take a block of K×M information bits, $[b_1\ b_2\ b_3 \ldots . b_{k*m}]$.

2. Map these bits into their signal cancellation where each group of m bits select a symbol according to the modulation type used, $[x_1, x_2 \ldots x_k]$

3. Encode the k modulated symbols by STBC code matrix to generate n_T parallel signal sequences of length T.

4. Transmit these sequences through n_{TX} antennas simultaneously in duration of n_T time slots.

The encoder takes k symbols at each encoding process and it requires n_T transmission periods to transmit their STBC symbols through the multiple transmit antennas. Usually n_T is greater (general case) than or equal(e.g.: Alamouti) k, so the definition of code rate arise here which is :

Code rate: the ratio between the numbers of symbols the encoder takes as its input (k) and the number of space-time coded symbols transmitted from each antenna (n_T) [20]. It is given by:

$$R = \frac{K}{n_T} \qquad (2.5)$$

The code rate is a measure tool which provides an indication of how much there is a redundant data due to coding in the code word. R depends on the design of the code matrix.

2.5.2 STBC receiver:

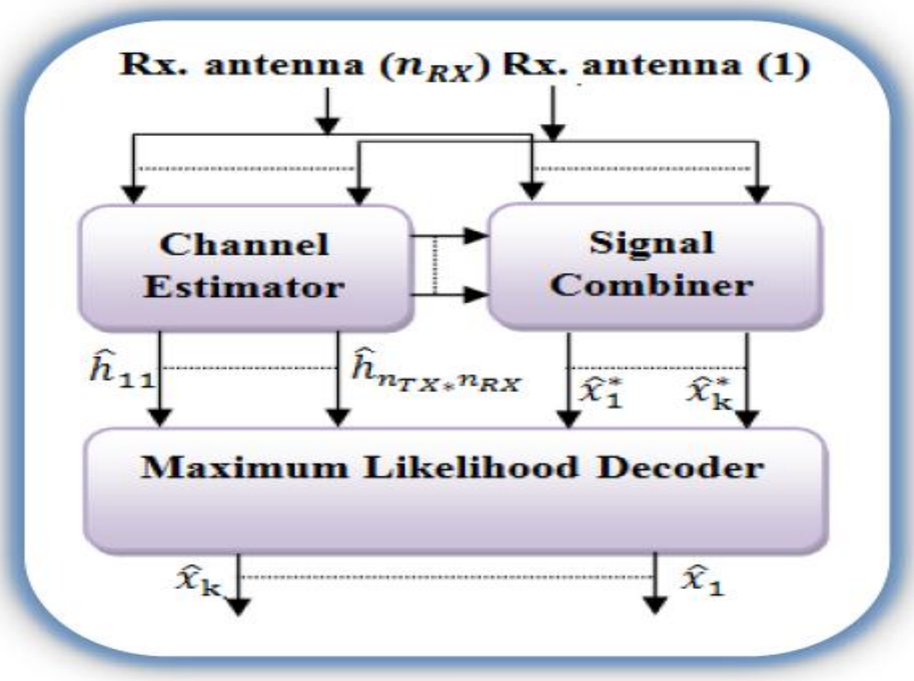


Figure (2.10): The STBC receiver.

As in Alamouti scheme, the receiver in STBC can have n_{RX} antennas, so the receiver will have signals from $n_{TX}\times n_{RX}$ different paths the receiver. Depending on that's different paths, the receiver will have a large capability to face a deep fading. The receiver for code has k symbols per block, n_{TX} transmitting antennas, and n_{RX} receiving antennas will be as shown in Figure (2.10). As previously mentioned, since any column of the coding matrix is orthogonal with other columns, only linear processing will be used at the receiver. This implies a very simple detection algorithm at the receiver is used. To show that, a received mathematical model will be required, which we can model as the following [21]:

At time t, the received signal at antenna j is:

$$r_t^{\,j} = \sum_{i=1}^{n_{Tx}} h_{ij} S_t^i + n_t^i \qquad (2.6)$$

Where h_{ij} is the path gain from Tx antenna i to Rx antenna j, S_t^i is the symbol transmitted from antenna i at the time period t, n_t^i is AWGN noise sample, n_{Tx} is the number of Tx antennas.

2.6 Block Code:

In coding theory, a block code is any member of the large and important family of error-correcting codes that encode data in blocks. There is a vast number of examples for block codes, many of which have a wide range of practical applications. Block Codes are conceptually useful because they allow coding theorists, mathematicians, and computer scientists to study the limitations of all block codes in a unified way. Such limitations often take the form of bounds that relate different parameters of the block code to each other, such as its rate and its ability to detect and correct errors.

We assume that the output of an information source is a sequence of binary digits "0" or "1", this binary information sequence is segmented into message block of fixed length, denoted by u, each message block consists of k information digits and there is a total of 2^k distinct message. The encoder transforms each input message u into a binary n-tuple v with n > k. This n-tuple v is referred to as the code word (or code vector) of the message u. There are distinct 2^k code words; this set of 2^k code words is called a block code.For a block code to be useful there should be a one-to-one correspondence between a message u and its code word v. A desirable structure for a block code to possess is the linearity. With this structure, the encoding complexity will be greatly reduced.

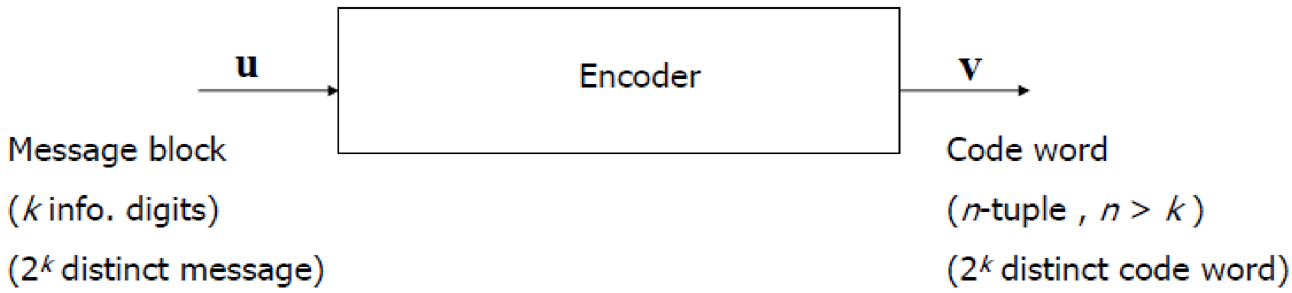


Figure (2.11): The block code encoder.

- Definition: A block code of length n and 2^k code word is called a linear (n, k) code iff its 2^k code words form a k-dimensional subspace of the vector space of all the n-tuple over the field.

In fact, a binary block code is linear if the module-2 sum of two code word is also a code word. The block code given in Table below is a (7, 4) linear code.

Table (2.1): Block Code with k=4 and n=7 :

Message block	Code words
0000	0000000
1000	1101000
0100	0110100
1100	1011100
0010	1110010
1010	0011010
0110	1000110
1110	0101110
0001	1010001
1001	0111001
0101	1100101
1101	0001101

0011	**0100011**
1011	**1001011**
0111	**0010111**
1111	**1111111**

Since an (n, k) linear code C is a k-dimensional subspace of the vector space Vn of all the binary n-tuple, it is possible to find k linearly independent code word, g_0 , g_1 ,…, g_{k-1} in C

$$V = u_0 g_0 + u_1 g_1 + ... + u_{k-1} g_{k-1} \qquad (2.7)$$

Where u_i = 0 or 1 for $0 \leq i < k$

Let us arrange these k linearly independent code words as the rows of a k × n matrix as follows:

$$G = \begin{bmatrix} g_0 \\ g_1 \\ . \\ . \\ g_{k-1} \end{bmatrix} = \begin{bmatrix} g_{00} & g_{01} & \cdots\cdots & g_{0,n-1} \\ g_{10} & g_{11} & \cdots\cdots & g_{1,n-1} \\ . & . & . & . \\ . & . & . & . \\ g_{k-1,0} & g_{k-1,1} & . & g_{k-1,n-1} \end{bmatrix} \qquad (2.8)$$

Where $g_i = (g_{i0}, g_{i1},\ldots,g_{i,n-1})$ for $0 \leq i < k$

If $u = (u_0,u_1,\ldots,u_{k-1})$ is the message to be encoded, the corresponding code word can be given as follows:

$$V = u.\ G \qquad (2.9)$$

$$V = (u_0, u_1, \ldots, u_{k-1}) . \begin{bmatrix} g_0 \\ g_1 \\ \cdot \\ \cdot \\ \\ g_{k-1} \end{bmatrix} \qquad (2.10)$$

$$V = u_0 g_0 + u_1 g_1 + \ldots + u_{k-1} g_{k-1} \qquad (2.11)$$

Because the rows of G generate the (n, k) linear code C, the matrix G is called a generator matrix for C

- Note that any k linearly independent code words of an (n, k) linear code can be used to form a generator matrix for the code.

A desirable property for a linear block code is the systematic structure of the code words as shown in Figure (4.2) where a code word is divided into two parts:

- The message part consists of k information digits
- The redundant checking part consists of n − k parity-check digits.

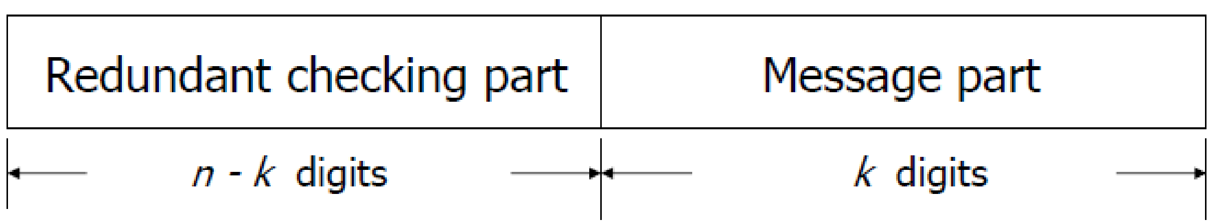


Figure (2.12): Systematic format of a code word

Let u = (u_0, u_1, … , u_{k-1}) be the message to be encoded.

The corresponding code word is:

$$\begin{aligned} V &= (v_0, v_1, v_2, \ldots, v_{n-1}) \\ V &= (u_0, u_1, \ldots, u_{k-1}).G \end{aligned} \qquad (2.13)$$

For any (n, k) linear block code C, there exists a k × n matrix G whose row space given C.There exist an (n – k) × n matrix H such that an n-tuple v is a code word in C if and only if v • H^T = 0.

The encoding circuit for (n, k) code shown in figure (4.3).

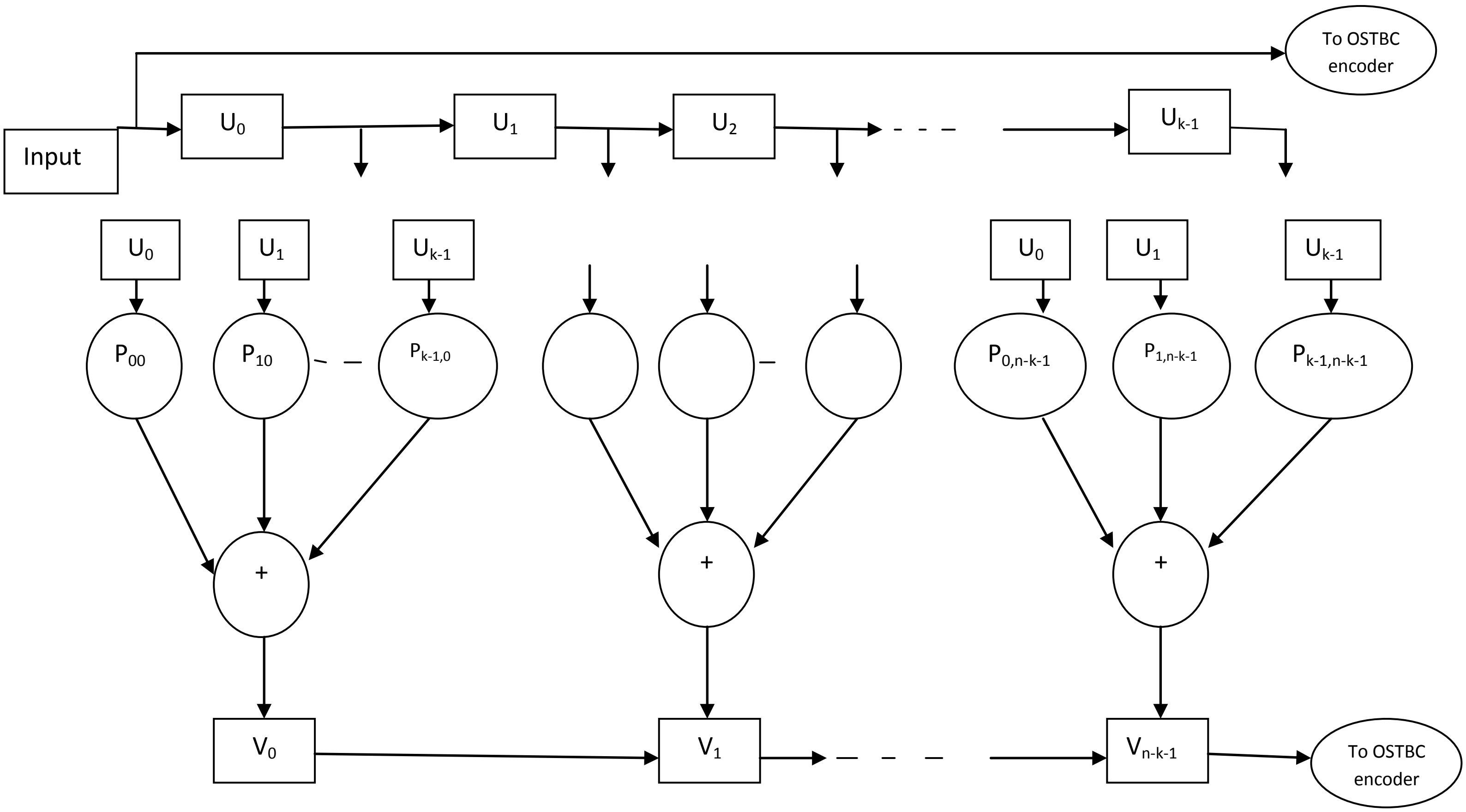
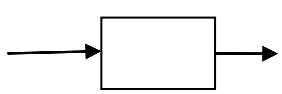
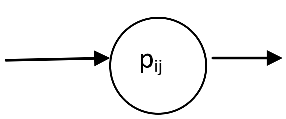


Figure (2.13): encoding circuit for (n, k) code

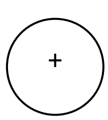
Where:



Denotes shift register stage (flip-flop)



Denotes a connection if p_{ij} =1 and no connection if p_{ij}= 0

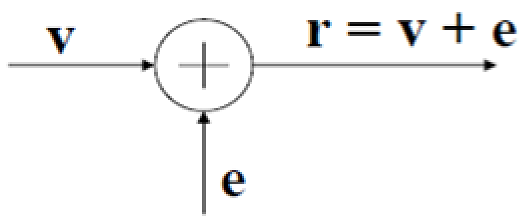


Denotes a modulo-2 adder

As soon as the entire message has entered the message register, the n-k parity-check digits are formed at the outputs of the n-k module-2 adders.

2.6.1 Error Detection:

- Let v = (v_0, v_1, …, v_{n-1}) be a code word that was transmitted over a noisy channel.
- Let r = (r_0, r_1, …, r_{n-1}) be the received vector at the output of the channel.



2.14

e = r + v = (e_0, e_1, …, e_{n-1}) is an n-tuple

$e_i = 1$ for $r_i \neq v_i$ (2.15)

$e_i = 0$ for $r_i = v_i$ (2.16)

The n-tuple e is called the error vector (or error pattern).

Upon receiving r, the decoder must first determine whether r contains transmission errors. If the presence of errors is detected, the decoder will take actions to locate the errors:

- Correct errors.
- Request for a retransmission of v.

When r is received, the decoder computes the following (n – k)-tuple:

$$\begin{aligned} S &= r.H \\ &= (S_0, S_1, \ldots, S_{n-k-1}) \end{aligned} \tag{2.17}$$

This is called the syndrome of r.

s = 0 if and only if r is a code word and receiver accepts r as the transmitted code word.

s≠0 if and only if r is not a code word and the presence of errors has been detected.

When the error pattern e is identical to a nonzero code word (i.e., r contain errors but $s = r \bullet H^T = 0$), error patterns of this kind are called undetectable error patterns. Since there is $(2^k - 1)$ nonzero code words, there are $(2^k - 1)$ undetectable error patterns.

Since r is the vector sum of v and e: $r = v + e$

$$s = r \bullet H^T = (v + e) \bullet H^T = v \bullet H^T + e \bullet H^T \qquad (2.18)$$

However,

$$v \bullet H^T = 0 \qquad (2.19)$$

Consequently, we obtain the following relation between the syndrome and the error pattern:

$$s = e \bullet H^T \qquad (2.20)$$

2.6.2 The Minimum Distance of a Block Code:

Let $v = (v_0, v_1, \ldots, v_{n-1})$ be a binary n-tuple, the Hamming weight (or simply weight) of v, denote by w(v), is defined as the number of nonzero components of v

- For example, the Hamming weight of v = (1 0 0 0 1 1 0) is 3

Let v and w be two n-tuple, the Hamming distance between v and w, denoted d(v,w), is defined as the number of places where they differ.

- For example, the Hamming distance between v = (1 0 0 1 0 1 1) and w = (0 1 0 0 0 1 1) is 3.

The Hamming distance is a metric function that satisfied the triangle inequality

$$d(v, w) + d(w, x) \geq d(v, x) \qquad (2.21)$$

From the definition of Hamming distance and the definition of module-2 addition that the Hamming distance between two n-tuple, v and w, is equal to the Hamming weight of the sum of v and w, that is [22]:

$$d(v, w) = w(v + w) \qquad (2.22)$$

2.7 Related works:

There are many research efforts on performance analysis and implementing of STC in MIMO systems. Most of this research provides a partial solution to the problem of multipath fading, So take one side without the other aspects arising from such cost, complexity, BER and the SNR, In many cases, the study provides a viable solution for one of the variables affecting the performance of communications systems, but does not represent the best solution because it often requires a lot of studies and analyzes the complex that are difficult to cover the whole by one researcher or group . But requires a series of studies and each one takes the side of the aspects are grouped in the end all those solutions discussion so that we take its beauty as much as possible and try to avoid the disadvantages thereof. There are different research efforts to overcome this problem; list here a brief for some of them.

Rafik Ahmad et al. [23] presented a Comparison of Wireless MIMO System Under Alamouti‘s Scheme and Maximum Ratio Combining Technique Basic idea in these schemes is to transmit and receive more than one copy of the original signals. Using two transmitter antennas and one receiver antenna, the scheme provides the nearly same diversity order as the maximal-ratio receiver combining (MRRC) with one transmitter antenna, and two receiver antennas.

That is, branches with strong signal are further amplified, while weak signals are attenuated. In general,

1) The signals from each channel are added together.

2) The gain of each channel is made proportional to the rms signal level and inversely proportional to the mean square noise level in that channel.

3) Different proportionality constants are used for each channel.

Maximal-ratio combining is the optimum combiner for independent AWGN channels. Maximum ratio combining is a linear combining method, where various signal inputs are individually weighted and added together to get an output signal. A block diagram of a maximum ratio combining diversity is shown in Figure (2.14).

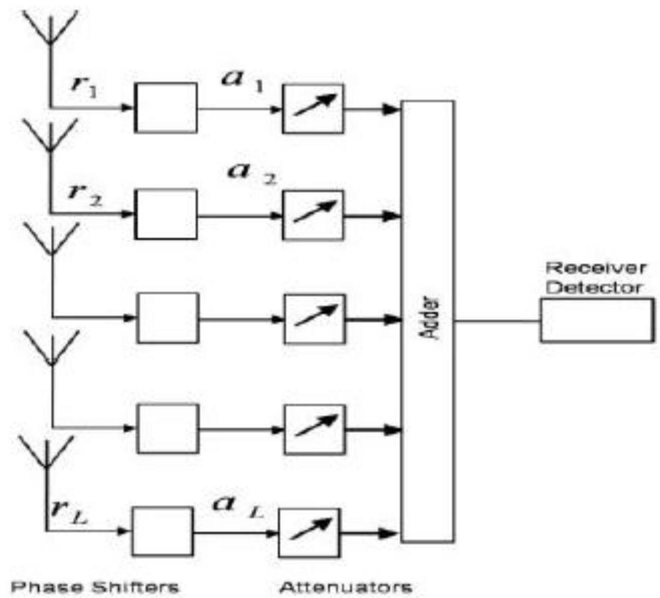


Figure (2.14): block diagram of a maximum ratio combining diversity.

The output signal is a linear combination of a weighted replica of all of the received signals. It is given by:

$$r = \sum_{i=1}^{L} a_i r_i \tag{2.23}$$

Where, r_i is the received signal at receive antenna i, and a_i is the weighting factor for receiver antenna. In maximum ratio combining, the weighting factor of each receive antenna is chosen to be in proportion to its own signal voltage to noise power ratio.

In Figure (2.15), the simulation results are presented along with the theoretical results. The theoretical results are presented while considering the 1 T_{xx} and 1 R_{xx}, 1 T_{xx} and 2 R_{xx} using maximum ratio combining technique. As shown in the Figure (2.15), the performance in term of BER improves significantly for example for

Eb/N0 equals to 10 db the BER improves by a factor of 10. Hence, MRC schemes provide very good results; this is also an agreement with theoretical results. However, in MRC scheme, to receive better signal quality more than two receivers may require. To counteract this Alamouti proposed a scheme in which more than one transmitter can be used to transmit signals, as signal generated from these antenna‘s will travel different path, hence may provide better quality signal at the receiver. As this scheme is somewhat compromising scheme, therefore results may not be up to the level of MRC. However, this scheme is very simple and has potential to combat with fading of the channel.

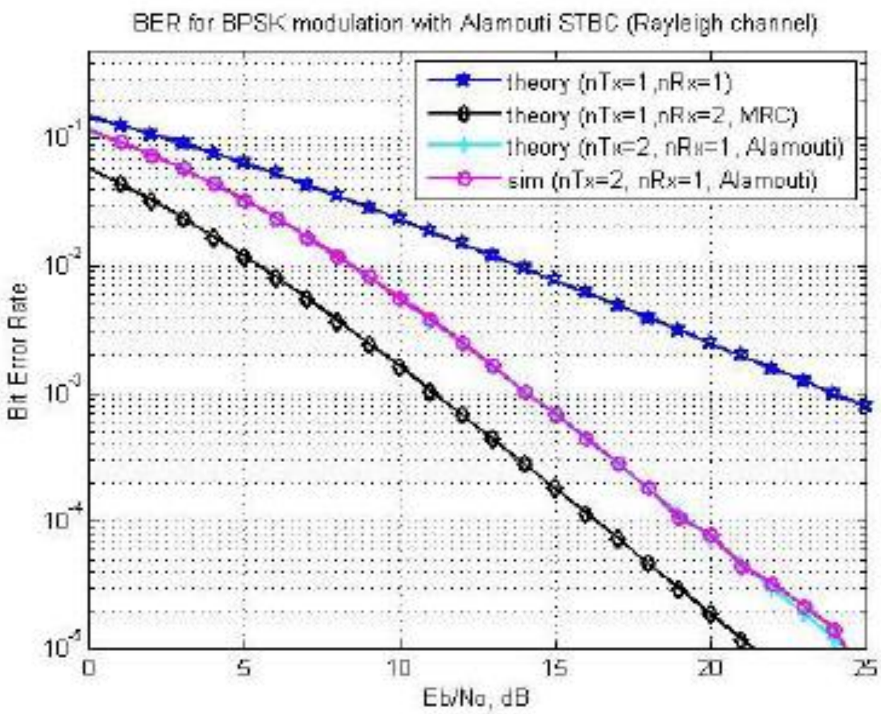


Figure (2.15): Performance analysis of SISO theoretical (1Tx,1Rx), SIMO Maximum ratio combining theoretical (1Tx, 2 Rx), MISO Alamouti theoretical (2Tx, 1Rx) and Alamouti simulation (2Tx, 1Rx) system.

Also comparison of diversity technique for estimating the channel performance of mobile communication signals affected by Rayleigh multipath fading phenomena is discussed. The performance of Alamouti scheme and Maximum ratio combining techniques are evaluated under the assumption of BPSK signals affected by reflection, diffraction and scattering environment. It is shown that in wireless MIMO, system based on Alamouti diversity technique and Maximum ratio combining a technique can help to combat and mitigate against Rayleigh fading channel and approach AWGN channel performance with constant transmits power. While the results are equally applicable if the average transmitted power varies. However there are limitations in this study because it relied on the system only two antennas and neglected the possibility of increasing the antennas in the transmitter and receiver in addition to the value of high SNR used to achieve this.

Shreedhar A Joshi et al. [24] studied Space Time Block Coding for MIMO Systems using Alamouti Method with Digital Modulation Techniques BPSK and QAM Modulation Scheme with channel state information (CSI) at the transmitter.

The performance of the Alamouti scheme using BPSK symbols with realizations obtained by simulations of slow Rayleigh fading channels is shown in Figure (3.8). It is assumed that the total transmit power from the two antennas used with the

Alamouti scheme is the same as the transmit power sent from a single transmit antenna to two receive antennas and applying an MRC at the receiver. It is also assumed that the amplitudes with fading from each transmit antenna to each receive antenna are mutually uncorrelated and Rayleigh distributed such that the average signal powers at each receive antenna from each transmit antenna are the same. shows the SER performance with alamouti and without Alamouti technique for BPSK. Figure (2.16). shows the performance of the Alamouti scheme using QPSK constellations. Here the BER performance of the Alamouti scheme is compared with a (1 × 1) system scheme (no diversity or STC) and with a (1 × 2)

MRC scheme. The simulation results show that the Alamouti (2×1) scheme achieves the same diversity as the (1×2) scheme using MRC. However, the performance of Alamouti scheme is 3 dB worse due to the fact that the power radiated from each transmit antenna in the Alamouti scheme is half of that radiated from the single antenna and sent to two receive antennas and using MRC. In this way, the two schemes have the same total transmit power. The other digital modulation technique employed in this proposed work is QAM which compares the Symbol error rate (SER) performance of Alamouti space-time coding with 2 transmitting antennas and 1 receive antenna. The SER performance is done for different orders of QAM is shown from figures (2.17) and (2.18) respectively.

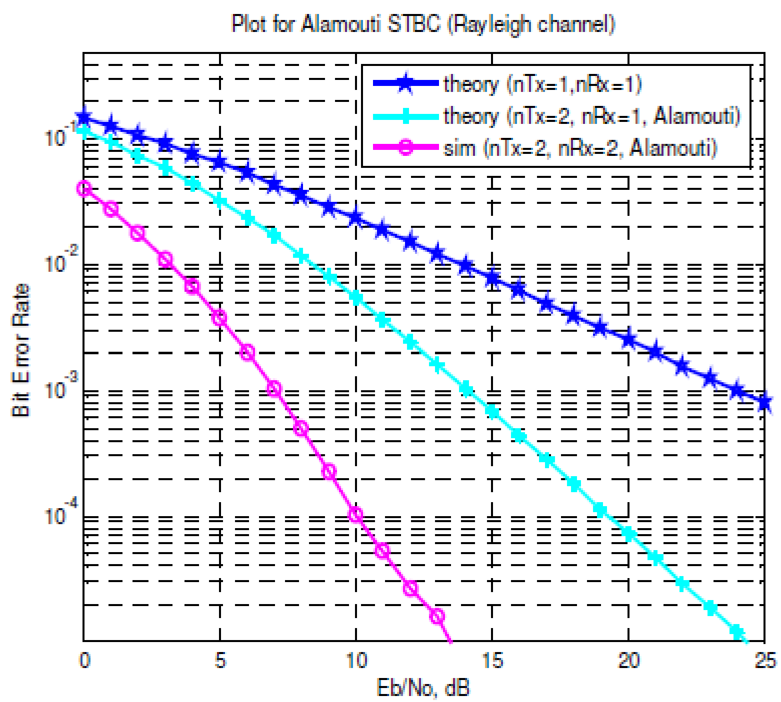


Figure (2.16):The BER performance of the BPSK Alamouti Scheme, nt = 2, nr = 1,2

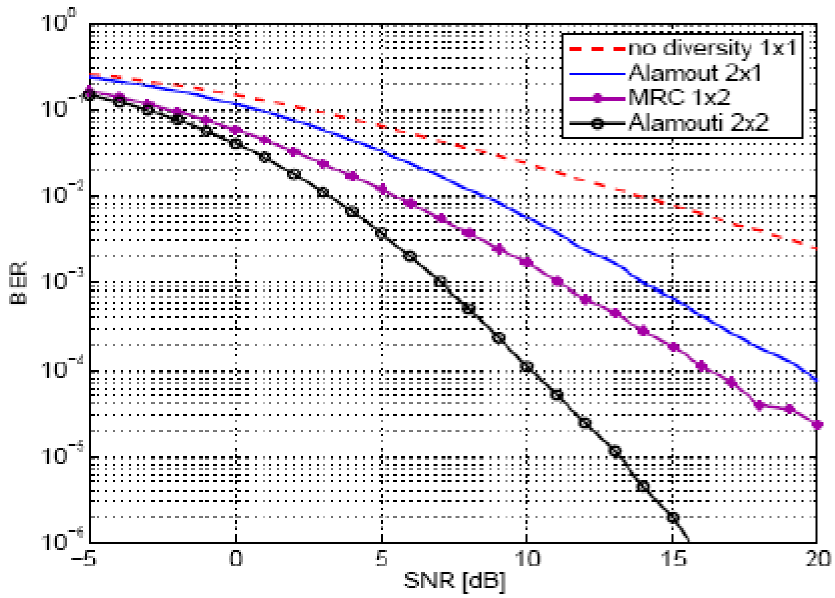


Figure (2.17):The BER performance of the QPSK Alamouti Scheme, nt = 2, nr = 1,2

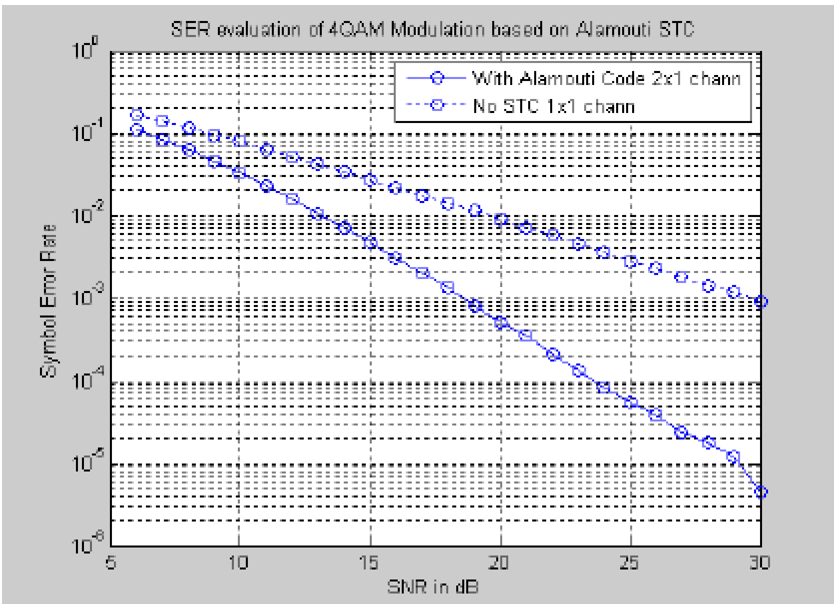


Figure (2.18):The SER performance of the 4 QAM Alamouti Scheme, nt = 2,nr = 1

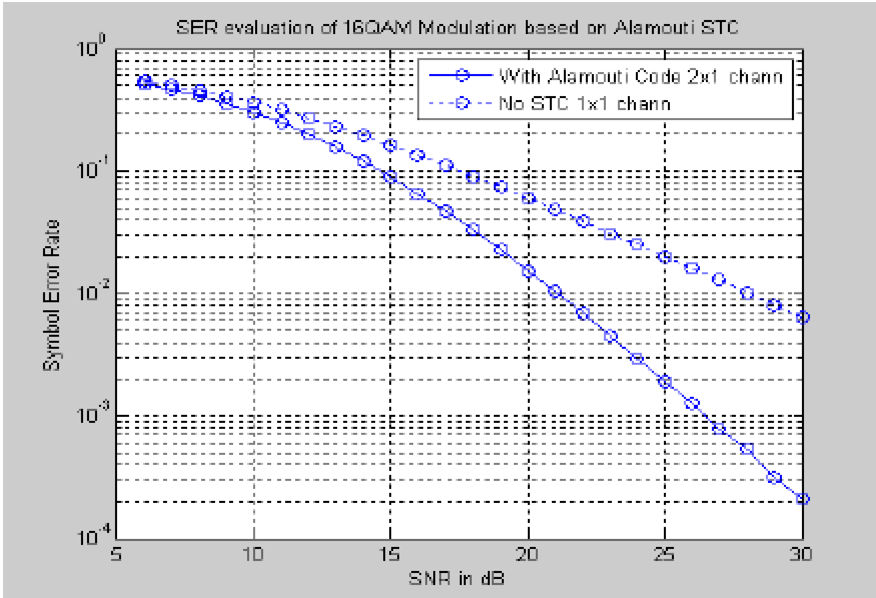


Figure (2.19):The SER performance of the 16 QAM Alamouti Scheme, nt =2,nr= 1

This work is devoted to space-time coding for multiple- input/multiple-output (MIMO) systems. The concept of space-time coding is explained in a systematic way. The performance of space-time codes for wireless multiple-antenna systems with channel state information (CSI) at the transmitter has been also studied. Alamouti code is the only OSTBC that provides full diversity at full data rate (1 symbol/time slot) for two transmit antennas. But they used a large SNR to achieve this.

Another study also presented by Martin Svirak [25], presented to Simulation of Space-Time Block Coding in Broadband Indoor Fading Channel Using Matlab.

Fading channels are commonly used in wireless communications. New applications such as wireless local area networks (LANs) require very high data rate transmissions. These applications are usually used in indoor environments. The result of radio signal multipath propagation in real environment is signal spread in time and it leads to the frequency selectivity of the channel. Indoor fading channels are usually frequency selective for data rates over roughly several Mbps. Frequency selectivity of the fading radio channel depends on the multipath delay spread. It can be described by average root-mean-square (rms) delay spread $\bar{\tau}_{rms}$. Fading channel is frequency selective if approximately:

$$S = \frac{T_s}{\bar{\tau}_{rms}} \tag{2.24}$$

When Ts denotes symbol interval.

The channel with constant $\bar{\tau}_{rms}$ and variable Ts (bit rate) is considered. According equation (3.13), if s >10, channel is frequency non-selective and if s < 10, channel is regarded as a frequency selective. BER performance of the system might be improved by using some type of equalization but in this work, the radio system with no equalization is assumed. Now we can consider that data are transfered in frames with length l. Simply the FER (Frame Error Rate) can be defined as probability, that there is at least one error in the frame, which can be detected. Than the retransmission of the frame is needed. So that FER as a function of the parameter s can be simply calculated for specific frame length l. Results for example l = 128 are shown in figure (2.20) for several SNR (Signal to Noise Ratio) conditions.

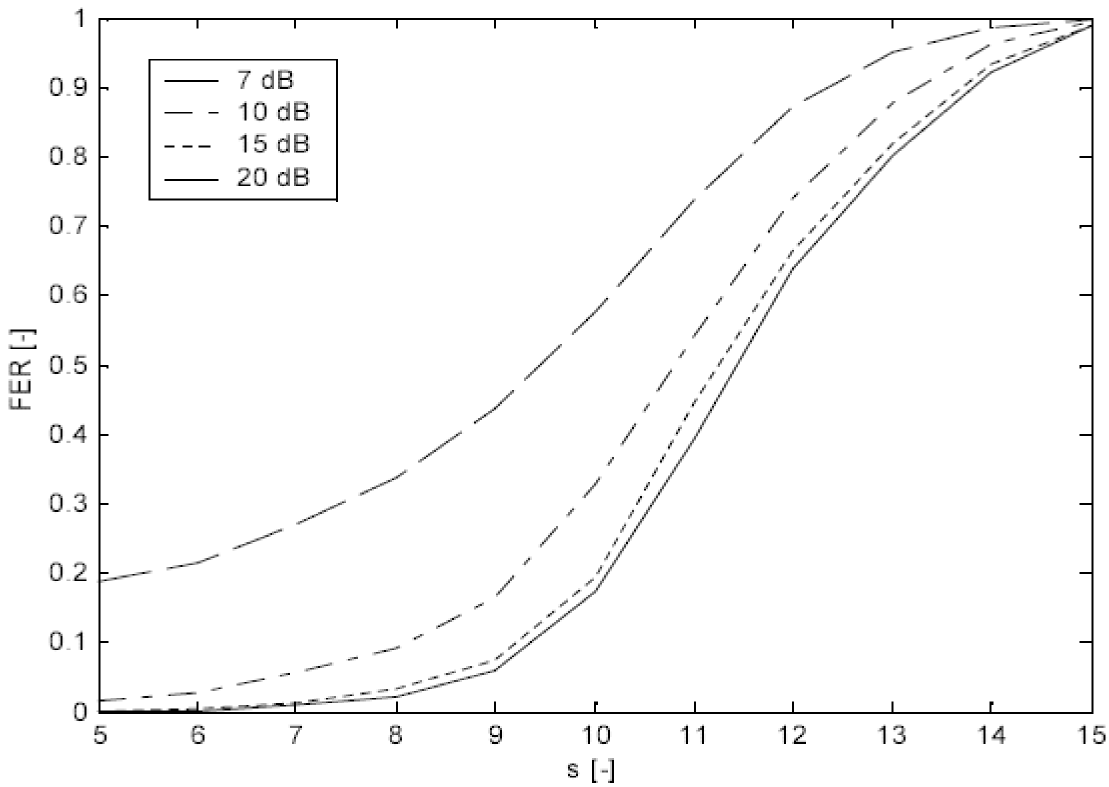


Figure (2.20): FER performance vs. frequency selectivity

It is evident, that FER grows with increasing parameter s and converges to unity. It is possible, that higher bit rate with worse FER can transfer more data in the same time with suitable transfer protocol. For double bit rate (s = 10), the FER increses by 15 percent, but it is obvious that double bits are transfered at the same time. Conclusion is, that it depends on the concrete system, if it is advantageous or not to increase bit rate with increasing FER. This is applicable for better SNR conditions, because for s = 10, the FER is roughly 20 percent for SNR = 7 dB and this value may be unusable for some systems.

In this work the effect of the frequency selectivity on the STBC performance is studied. Indoor fading channel model with exponential power-delay profile is used to evaluate the system performance. Quasi-static Rayleigh fading channel is modeled as a hundreds of statistically generated impulse responses. Frequency selectivity of the channel is expressed by ratio of the symbol interval and average RMS delay spread. Frame error rate is increasing with frequency selectivity of the channel, but at the same time, bit rate of the system is improving. Application depends on the required performance of the used radio system and transfer protocol. But the main drawback of this method is that it is used inside buildings did not provide out door free space channels.

Sachin Chourasia, Prabhat Patel [26] presented A Comparative analysis of orthogonal space time block code with trellis coded modulation (TCM) over Rayleigh and Rician fading channel. In this paper, our main aim is analysis the performance of OSTBC with TCM over the Rayleigh fading channel and Rician fading channel and compare the performance of this technique over the Rayleigh fading channel and Rician fading channel. Where this scheme provides a significant diversity gain over the TCM scheme and about 2 dB coding gain over the Alamouti code. And this proposed technique for OSTBC with TCM shows the better performance around 3 dB over Rician fading channel when the line of sight (LOS) path is considered. While with no line of sight (NLOS) path is considered, this technique gives better result of about 1dB over Rayleigh fading channel as compare to the Rician fading channel. The disadvantages of this work that he must first determine the type of transmitter LOS or NLOS and the main drawback is the high value of SNR used.

2.8 Chapter Summary

Multiple Antenna Systems and some background knowledge deals with space-time coding techniques and their performance in slow and fast fading MIMO channels and provide a more systematic discussion of space-time block coding (STBC). Also in this chapter, the concept of diversity techniques has been considered; then they generalized to introduce the concept of space time block coding which explore the diversity of both the time and the space. More details in block coding are analyzed. Displays the previous studies on this subject, so that deals with the method and techniques used by each researcher and the steps followed by the discussion of the findings and then mentioned shortcomings in this way until it is avoided in the proposed method.

Chapter Three

Design of Orthogonal STBC

3.1 Overview:

STBC basically it forms combination of two words space diversity and time diversity. In orthogonal STBC, any two pairs of columns of the coding matrix result to be orthogonal. The pioneering work of Alamouti has been a basis to create OSTBCs for more than two transmit antennas. First of all, Tarokh studied the error performance associated with unitary signal matrices [27]. Sometime later, Ganesan at al. streamlined the derivations of many of the results associated with OSTBC and established an important link to the theory of the orthogonal and amicable orthogonal designs [28].

Orthogonal STBCs are an important subclass of linear STBCs that guarantee that the ML detection of different symbols $\{s_n\}$ is decoupled and at the same time the transmission scheme achieves a diversity order equal to n_t , n_r. Next, we will give a general survey on orthogonal design and various properties of OSTBCs [29].

3.2 Design of Orthogonal Space Time Block Code:

Now after converting each message information to the codewords C in a block code is:

$$C = (C_1^1 , \ldots, C_L^1, C_1^2, \ldots, C_L^2, \ldots , C_1^n, \ldots, C_L^n) \qquad (3.1)$$

Here will be the representation of codewords by symbol:

$$S=(S_1^1, \ldots, S_t^1, S_1^2, \ldots, S_t^2, S_1^i, \ldots, S_t^i) \qquad (3.2)$$

Where S_t^i : transmitted signal at time t by transmit antenna i, $1 \leq t \leq L$, $1 \leq i \leq n$.

Where:

n: number of transmit antenna.

m: number of receive antenna.

L: length of block codes.

An OSTBC represented by a matrix, each row represents a time slot and each column represents one antenna's transmissions over time [30].

<u>Over the T_x antenna</u>

$$\text{Over the time slots } n_T \downarrow \begin{bmatrix} S_{11} & S_{12} & \ldots\ldots & S_{1n_{Tx}} \\ S_{21} & S_{22} & \ldots\ldots & S_{2n_{Tx}} \\ . & \ldots\ldots & \ldots\ldots & . \\ . & \ldots\ldots & \ldots\ldots & . \\ S_{n_T 1} & S_{n_t 2} & \ldots\ldots & S_{n_T n_{Tx}} \end{bmatrix} \tag{3.3}$$

According to the columns of the transmission matrix S are orthogonal to each other. That means that in each block, the signal sequences from any two transmit antennas are orthogonal. The orthogonality enables us to achieve full transmit diversity and at the same time, it allows the receiver by means of simple MRC to decouple the signals transmitted from different antennas and consequently, it allows a simple ML decoding.

The Alamouti code matrix is a code from the complex orthogonal design type (Hadamard complex matrices). The symbols s_1 and s_2 are arranged in the transmit code matrix S. s_1 and s_2 can be arranged in many ways, such that 16 variants of code matrix can be obtained table (3.1).

Table (3.1): Alamouti-type code matrices:

$\mathbf{S}$	$-\mathbf{S}$	$\mathbf{S}^*$	$-\mathbf{S}^*$
$\begin{matrix} -s_1 & s_2 \\ s_2^* & s_1^* \end{matrix}$	$\begin{matrix} s_1 & -s_2 \\ -s_2^* & -s_1^* \end{matrix}$	$\begin{matrix} -s_1^* & s_2^* \\ s_2 & s_1 \end{matrix}$	$\begin{matrix} s_1^* & -s_2^* \\ -s_2 & -s_1 \end{matrix}$
$\begin{matrix} s_1 & -s_2 \\ s_2^* & s_1^* \end{matrix}$	$\begin{matrix} -s_1 & s_2 \\ -s_2^* & -s_1^* \end{matrix}$	$\begin{matrix} s_1^* & -s_2^* \\ s_2 & s_1 \end{matrix}$	$\begin{matrix} -s_1^* & s_2^* \\ -s_2 & -s_1 \end{matrix}$
$\begin{matrix} s_1 & s_2 \\ s_2^* & -s_1^* \end{matrix}$	$\begin{matrix} -s_1 & -s_2 \\ -s_2^* & s_1^* \end{matrix}$	$\begin{matrix} s_1^* & s_2^* \\ s_2 & -s_1 \end{matrix}$	$\begin{matrix} -s_1^* & -s_2^* \\ -s_2 & s_1 \end{matrix}$
$\begin{matrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{matrix}$	$\begin{matrix} -s_1 & -s_2 \\ s_2^* & -s_1^* \end{matrix}$	$\begin{matrix} s_1^* & s_2^* \\ -s_2 & s_1 \end{matrix}$	$\begin{matrix} -s_1^* & -s_2^* \\ s_2 & -s_1 \end{matrix}$

All this matrices have equivalent properties, since we know that two Hadamard matrices are equivalent. if one can be obtained from the other by a sequences of row negations, row permutations, column negations and column permutations [31]. Real orthogonal designs for n = 2 and n = 4 are:

$$S_{12} = \begin{bmatrix} S_1 & S_2 \\ -S_2^* & S_1^* \end{bmatrix} \tag{3.4}$$

And

$$S_{34} = \begin{bmatrix} S_3 & S_4 \\ -S_4^* & S_3^* \end{bmatrix} \tag{3.5}$$

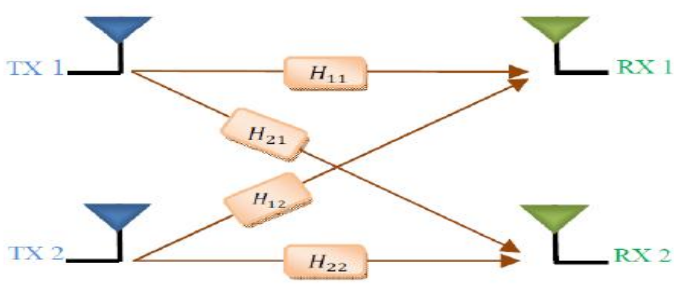


Figure (3.1): 2X2 OSTBC system

Are used in a block structure resulting in the so called extended Alamouti S_{EA}, for four transmit antennas:

$$S_{EA} = \begin{bmatrix} S_{12} & S_{34} \\ -S_{34}^{*} & S_{12}^{*} \end{bmatrix} = \begin{bmatrix} S_1 & S_2 & S_3 & S_4 \\ -S_2^{*} & S_1^{*} & -S_4^{*} & S_3^{*} \\ -S_3^{*} & -S_4^{*} & S_1^{*} & S_2^{*} \\ S_4 & -S_3 & -S_2 & S_1 \end{bmatrix} \qquad (3.6)$$

Where: S_{EA}:extended Alamouti.

Table (3.2): all possibilities to generate a coding matrix’s:

Design I				Design II			
s_1	s_2	s_4	s_3	s_1	s_2	s_4	s_3
$-s_2^*$	s_1^*	$-s_3^*$	s_4^*	$-s_2^*$	s_1^*	$-s_3^*$	s_4^*
$-s_4$	s_3	s_1	$-s_2$	$-s_4^*$	s_3^*	s_1^*	$-s_2^*$
s_3^*	s_4^*	$-s_2^*$	$-s_1^*$	s_3	s_4	$-s_2$	$-s_1$
s_1	$-s_2$	s_3	s_4	s_1	$-s_2$	s_4	s_3
s_2^*	s_1^*	$-s_4^*$	s_3^*	s_2^*	s_1^*	$-s_3^*$	s_4^*
$-s_3$	s_4	s_1	s_2	$-s_4^*$	s_3^*	s_1^*	s_2^*
$-s_4^*$	$-s_3^*$	$-s_2^*$	s_1^*	s_3	s_4	s_2	$-s_1$
s_1	s_3	s_2	s_4	s_1	$-s_4$	s_3	s_2
$-s_3^*$	s_1^*	$-s_4^*$	s_2^*	s_4^*	s_1^*	$-s_2^*$	s_3^*
$-s_2$	s_4	s_1	$-s_3$	$-s_3^*$	s_2^*	s_1^*	s_4^*
$-s_4^*$	$-s_2^*$	s_3^*	s_1^*	s_2	s_3	s_4	$-s_1$
s_1	$-s_3$	s_2	s_4	s_1	s_4	s_3	s_2
s_3^*	s_1^*	$-s_4^*$	s_2^*	$-s_4^*$	s_1^*	$-s_2^*$	s_3^*
$-s_2$	s_4	s_1	s_3	$-s_3^*$	s_2^*	s_1^*	$-s_4^*$
$-s_4^*$	$-s_2^*$	$-s_3^*$	s_1^*	s_2	s_3	$-s_4$	$-s_1$
s_1	s_2	s_4	s_3	s_1	$-s_2$	s_4	s_3
$-s_2^*$	s_1^*	$-s_3^*$	s_4^*	s_2^*	s_1^*	$-s_3^*$	s_4^*
$-s_4$	s_3	s_1	$-s_2$	$-s_4^*$	s_3^*	s_1^*	s_2^*
$-s_4^*$	$-s_3^*$	s_2^*	s_1^*	s_3	s_4	s_2	$-s_1$
s_1	$-s_2$	s_4	s_3	s_1	s_2	s_4	s_3
s_2^*	s_1^*	$-s_3^*$	s_4^*	$-s_2^*$	s_1^*	$-s_3^*$	s_4^*
$-s_4$	s_3	s_1	s_2	$-s_4^*$	s_3^*	s_1^*	$-s_2^*$
$-s_4^*$	$-s_3^*$	$-s_2^*$	s_1^*	s_3	s_4	$-s_2$	$-s_1$

Code Rate (R) : ratio between the number of symbol the encoder takes as the input (k) and the total time consumed in transmitted the entire symbol (T) [32].

$$R = \frac{K}{T} \tag{3.7}$$

After the completion of each of these processes the signals are sent using a suitable method such BPSK and antennas by using coding matrix.

The channel gains from the i^{th} transmit antenna to the j^{th} receiver antenna is denoted by $h_{i,j}$, and at the receiver, the signal received by the i^{th} antenna in the k^{th} time slot is given by:

$$r_t^{(j)} = \sum_{i=1}^{n} h_{ij} S_t^i + n_t^i \qquad (3.8)$$

With perfect channel state information the ML receiver compute the decision metric[2]:

$$D^2 = \sum_{i=1}^{n} \sum_{j=1}^{m} \left| r_t^j - \sum_{i=1}^{m} h_{ij} S_t^i \right|^2 \qquad (3.9)$$

Where:

$h_{i,j}$: path gain from transmit antenna i to receive antenna j , $1 \le i \le n$, $1 \le j \le m$.

r_t^j : received signal at time k by receive antenna j , $1 \le k \le L$, $1 \le j \le m$.

S_t^i : transmitted signal at time t by transmit antenna i, $1 \le t \le L$, $1 \le i \le n$.

n_t^i : Additive White Gaussian Noise (AWGN).

3.2.1 Two transmit antenna and one receive antenna system (2x1):

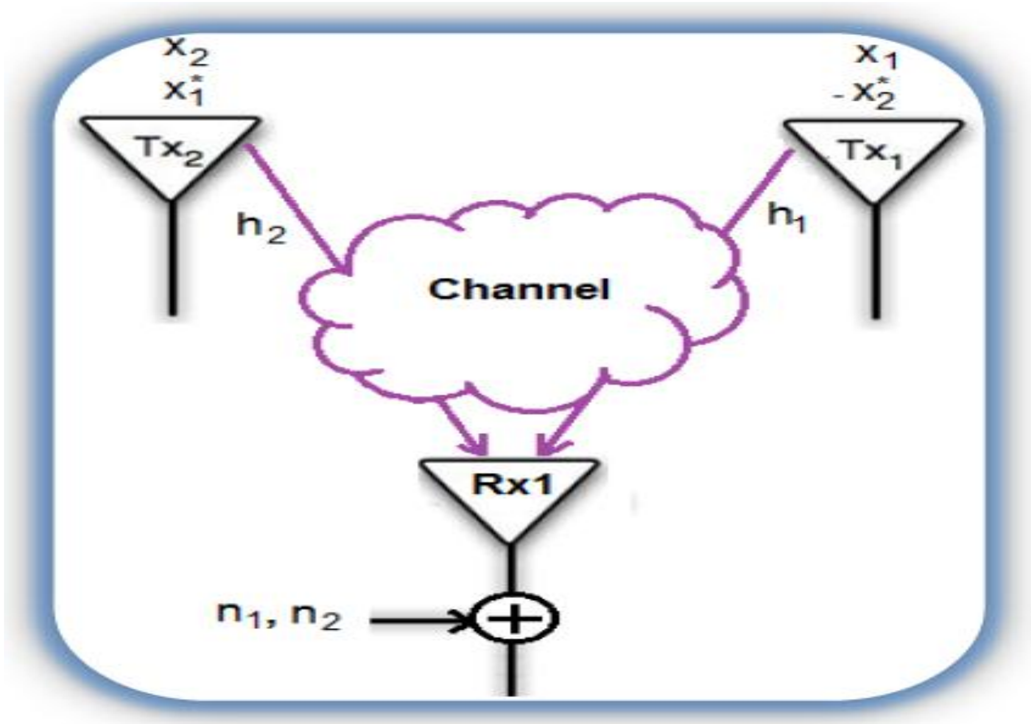


Figure (3.2):The channel effects at the 2 transmit antenna and one receive antenna.

The signal will be under the effect of Rayleigh fading channel and Additive White Gaussian noise (AWGN), Figure (3.2).The notation used in Figure (3.2) can be found in Table (3.3):

Table (3.3): Alamouti scheme-A channel model notation:

	Fading gain		**AWGN noise**
From 1st antenna to the receiver	$h_1(t)$	**Noise in 1st period**	n_1
From 2nd antenna to the receiver	$h_2(t)$	**Noise in 2nd period**	n_2

Assuming the fading will be block flat fading (constant) across the two consecutive symbol periods, so we can write:

$$h_1(t) = h_1(t+T) = h_1 = \alpha_1 e^{j\theta 1} \qquad (3.10)$$

$$h_2(t) = h_2(t+T) = h_2 = \alpha_2 e^{j\theta 2} \qquad (3.11)$$

Where T is the symbol period, α_i and θ_i are the amplitude and phase factor for the channel gain.So the received signal can be model as follow:

$$r_0 = r(t) = h_1S_1 + h_2S_2 + n_1 \qquad (3.12)$$

$$r_1 = r(t + T) = -h_1S_2^* + h_2S_1^* + n_2 \qquad (3.13)$$

Where r_0 is the received signal at time t, r_1 is the received signal at time t+T, n_1 and n_2 are random variable of AWGN noise.

At the receiver:

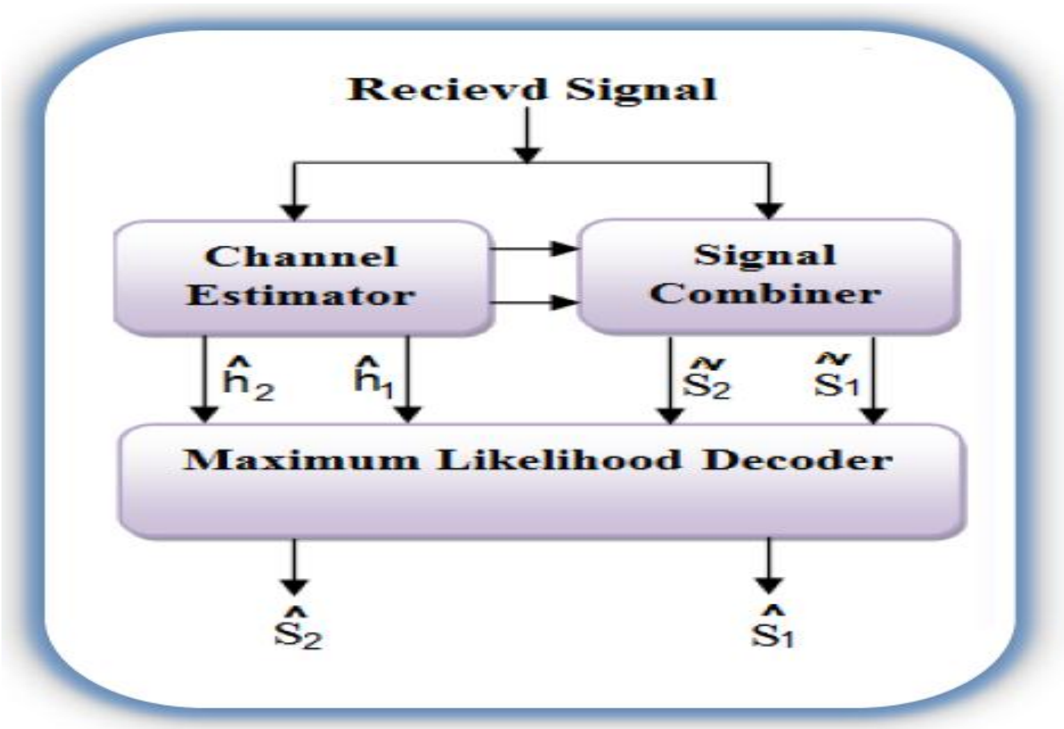


Figure (3.3): signal at the receiver

The receiver shown in Figure (3.3), and contain three basic components which are:

1. Channel estimator: which tries to find an estimation value of paths gain.

2. Signal combiner: as all diversity schemes, the basic function of combiner are to try to mitigate the fading in the signal using all the available copies of the transmitted signal.

3. ML decoder: finds out which symbol was transmitting using minimum distance. The combined signal will be then process by maximum likelihood (ML) detector to make a decision which symbol was transmit. The ML detector has a linear complexity as it relies on the following decision rule:

Choose S_i if and only if:

$$d^2(\hat{S}_1, \hat{S}_i) \leq d^2(\hat{S}_1, \hat{S}_k) \forall i \neq k \qquad (3.14)$$

3.2.2 Two transmit antennas and two receive antennas (2x2):

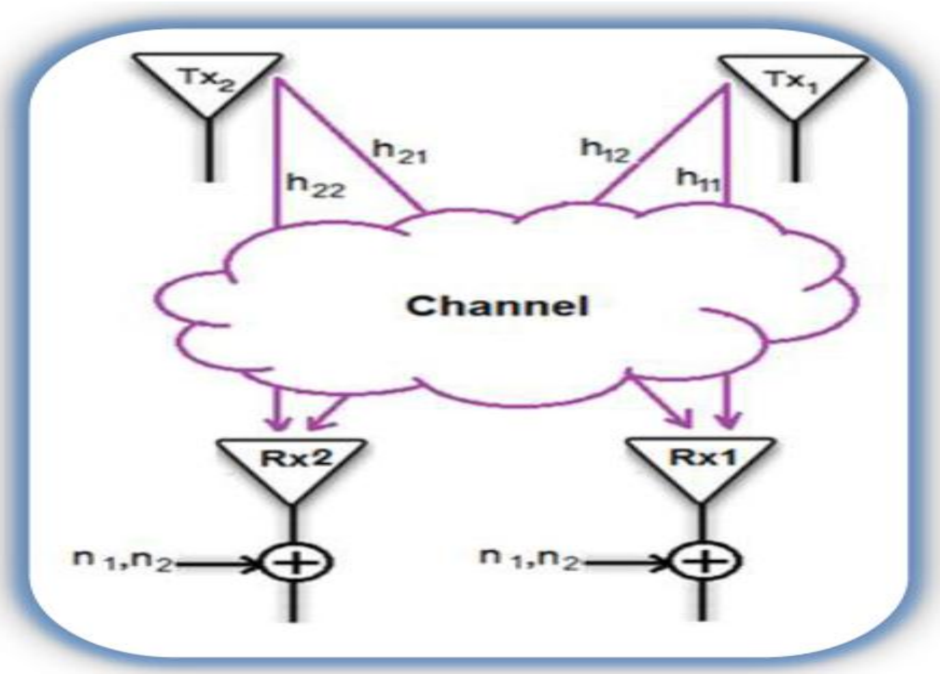


Figure (3.4): The channel effects at the (2x2) system.

The signal will be under the effect of Rayleigh fading channel and Additive White Gaussian noise (AWGN), shown here in Table (3.4).

Table (3.4): (2x2) channel model notation:

<table>
<tr><td rowspan="2">From 1st Tx antenna</td><td>To 1st Rx. antenna</td><td>To 2nd Rx. antenna</td><td></td><td>AWGN noise</td></tr>
<tr><td>$h_{11}(t)$</td><td>$h_{12}(t)$</td><td>Noise in 1st period</td><td>n_1</td></tr>
<tr><td>From 2nd Tx antenna</td><td>$h_{21}(t)$</td><td>$h_{22}(t)$</td><td>Noise in 2nd period</td><td>n_2</td></tr>
</table>

Assuming the block flat fading, so we can write:

$$h_{11}(t) = h_{11}(t + T) = h_{11} = \alpha_{11}e^{j\theta 11} \quad (3.15)$$

$$h_{12}(t) = h_{12}(t + T) = h_{12} = \alpha_{12}e^{j\theta 12} \quad (3.16)$$

$$h_{21}(t) = h_{21}(t + T) = h_{21} = \alpha_{21}e^{j\theta 21} \quad (3.17)$$

$$h_{22}(t) = h_{22}(t + T) = h_{22} = \alpha_{22}e^{j\theta 22} \quad (3.18)$$

Where α_{ij} *and* θ_{ij} are the amplitude and phase factor for the channel gain between the transmitter antenna (i) and the receiver antenna (j).

So the received signals can be modeled as the following:

$$r_0 = h_{11}S_1 + h_{12}S_2 + n_1 \quad (3.19)$$

$$r_1 = -h_{11}S_2^* + h_{12}S_1^* + n_2 \quad (3.20)$$

$$r_2 = h_{21}S_1 + h_{22}S_2 + n_1 \quad (3.21)$$

$$r_3 = -h_{21}S_2^* + h_{22}S_1^* + n_2 \quad (3.22)$$

Where r_0, r_1 , r_2, *and* r_3 as in table (3.5), n_1 *and* n_2 are the random variable of AWGN noise.

Table (3.5): Received signal notation of (2x2) system:

	At 1st Rx antenna	**At 2nd Rx antenna**
Time t	**r_0**	**r_2**
Time t+T	**r_1**	**r_3**

At the receiver:

As shown in Figure (3.5), the received signal will be combining, and then the output of the combiner will be process through ML detector to carry out the estimated transmitted symbols [33]. This can be done as follow:

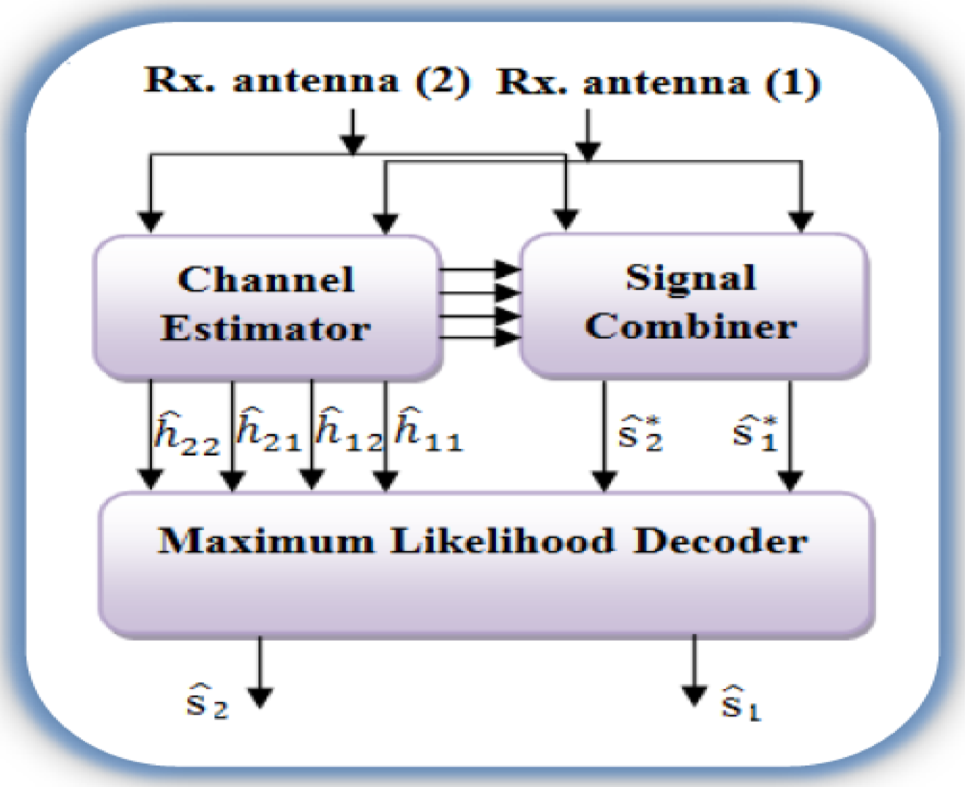


Figure (3.5): (2x2) system receiver.

The ML detector chooses S_i if and only if:

$$d^2(\hat{S}_1, \hat{S}_i) \leq d^2(\hat{S}_1, \hat{S}_k) \forall i \neq k \tag{3.23}$$

3.3 Proposed Method:

In view of the previous section that all thesis submitted tried to solve the problem of multipath fading and its effects on communication systems, but each thesis focused on a specific aspect and neglected the rest of the aspects affecting the performance of the system for example solve the problem of BER, but at the expense of increasing the SNR or vice versa in addition to the limitations of the system used alamouti system only.

Either ways you progress in this thesis tried as much as possible and avoid the errors mentioned obstacles and depending on the system of four antennas at the transmitter and receiver OSTBC (4x4), as shown in Figure bellow:

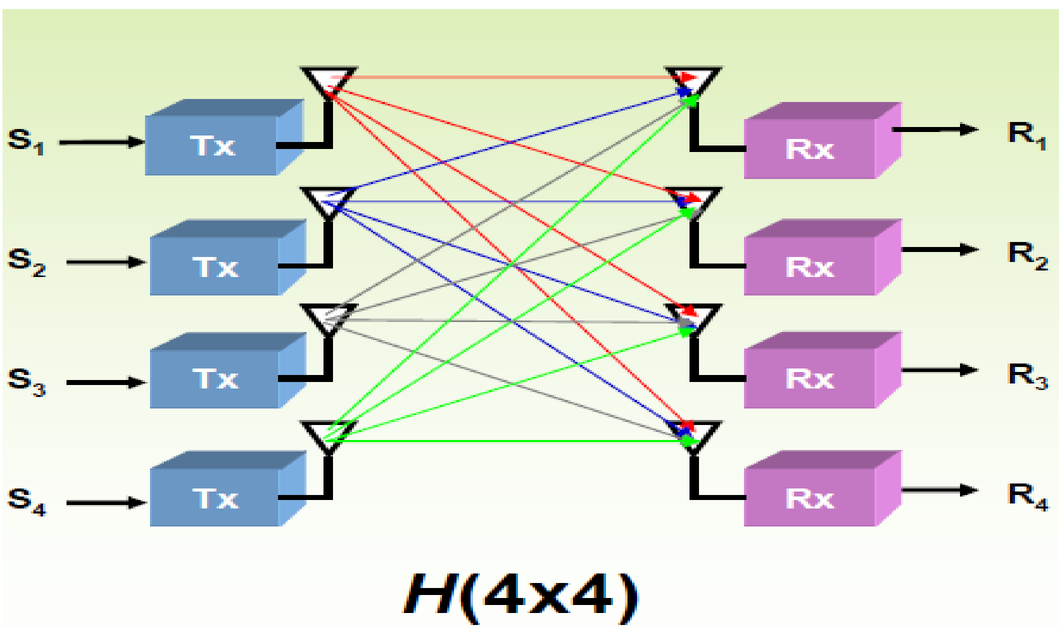


Figure (3.6): Four transmit antennas and four receive antennas (4x4) system [34]

Based on this form is mathematical analysis of the system and the conclusion of equations that can be used by the receiver and calculate BER compared with the SNR. The signal at the receiver:

$$R = H.S + n \quad (3.24)$$

Where:

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{42} & h_{43} & h_{44} \end{bmatrix} \qquad (3.25)$$

And

$$S = \begin{bmatrix} S_1 & S_2 & S_3 & S_4 \\ -S_2^* & S_1^* & -S_4^* & S_3^* \\ -S_3^* & -S_4^* & S_1^* & S_2^* \\ S_4 & -S_3 & -S_2 & S_1 \end{bmatrix} \qquad (3.26)$$

Then calculate received signals R:

$$R_1 = h_{11}S_1 - h_{21}S_2^* - h_{31}S_3^* + h_{41}S_4 + n_1 \qquad (3.27)$$

$$R_2 = h_{12}S_2 + h_{22}S_1^* - h_{32}S_4^* - h_{42}S_3 + n_2 \qquad (3.28)$$

$$R_3 = h_{13}S_3 - h_{23}S_4^* + h_{33}S_1^* - h_{43}S_2 + n_3 \qquad (3.29)$$

$$R_4 = h_{14}S_4 + h_{24}S_3^* + h_{34}S_2^* + h_{44}S_1 + n_4 \qquad (3.30)$$

The ML detector chooses S_i if and only if:

$$d^2(\hat{S}_1, \hat{S}_i) \leq d^2(\hat{S}_1, \hat{S}_k) \forall i \neq k \qquad (3.31)$$

After the simulation of this system (OSTBC 4x4) in the results that the use of two antennas at the transmitter and receiver corresponds to the use of two antennas at the transmitter and one antenna at the receiver (2x1). But if we used the one antenna to transmitter and four antennas at the receiver (1x4) there will be a big difference and clear for the performance of the system so that less errors to the extent suitable to perform Systems. At the same time, be worth less remarkable SNR. Thus, the proposed method provides the desired results of design.

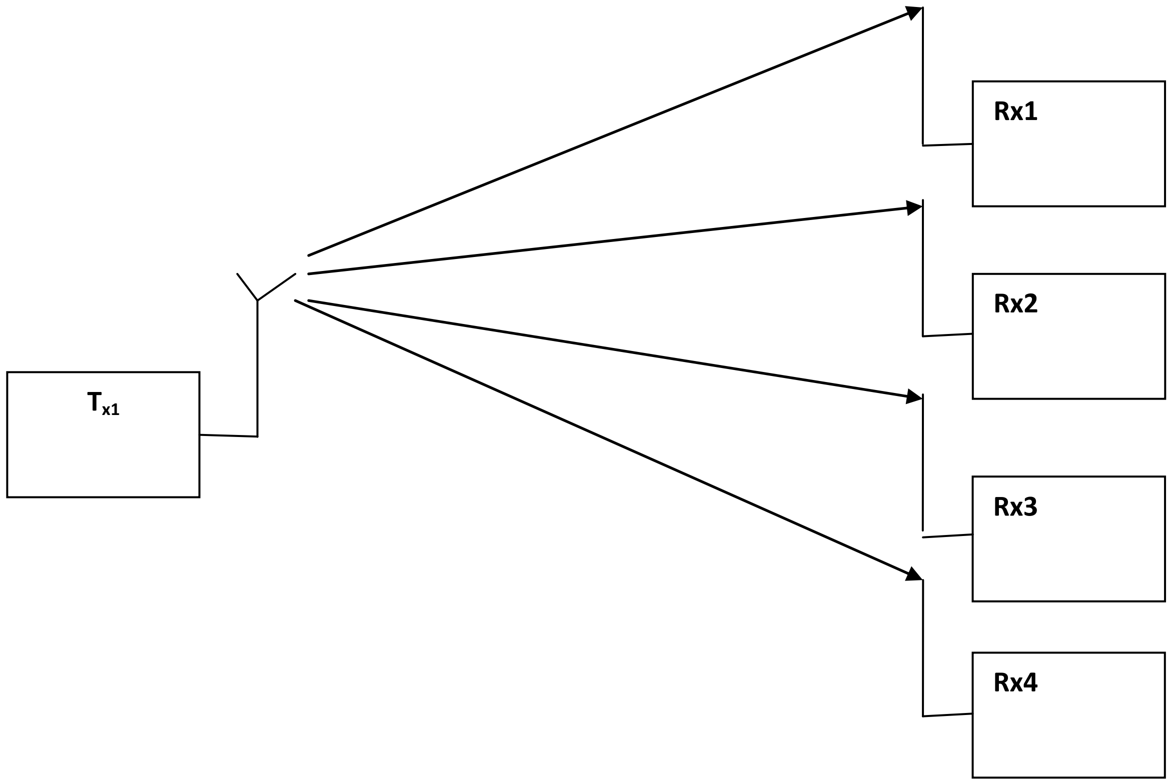


Figure (3.7): one transmit antenna and four receive antennas (1x4) system.

The signal at the receiver:

$$R = H.S + n \qquad (3.32)$$

Where:

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \end{bmatrix} \qquad (3.33)$$

And

$$S = \begin{bmatrix} S_1 \end{bmatrix} \qquad (3.34)$$

The following figure (3.8) illustrates the components of the proposed method system and how the flow of signals.

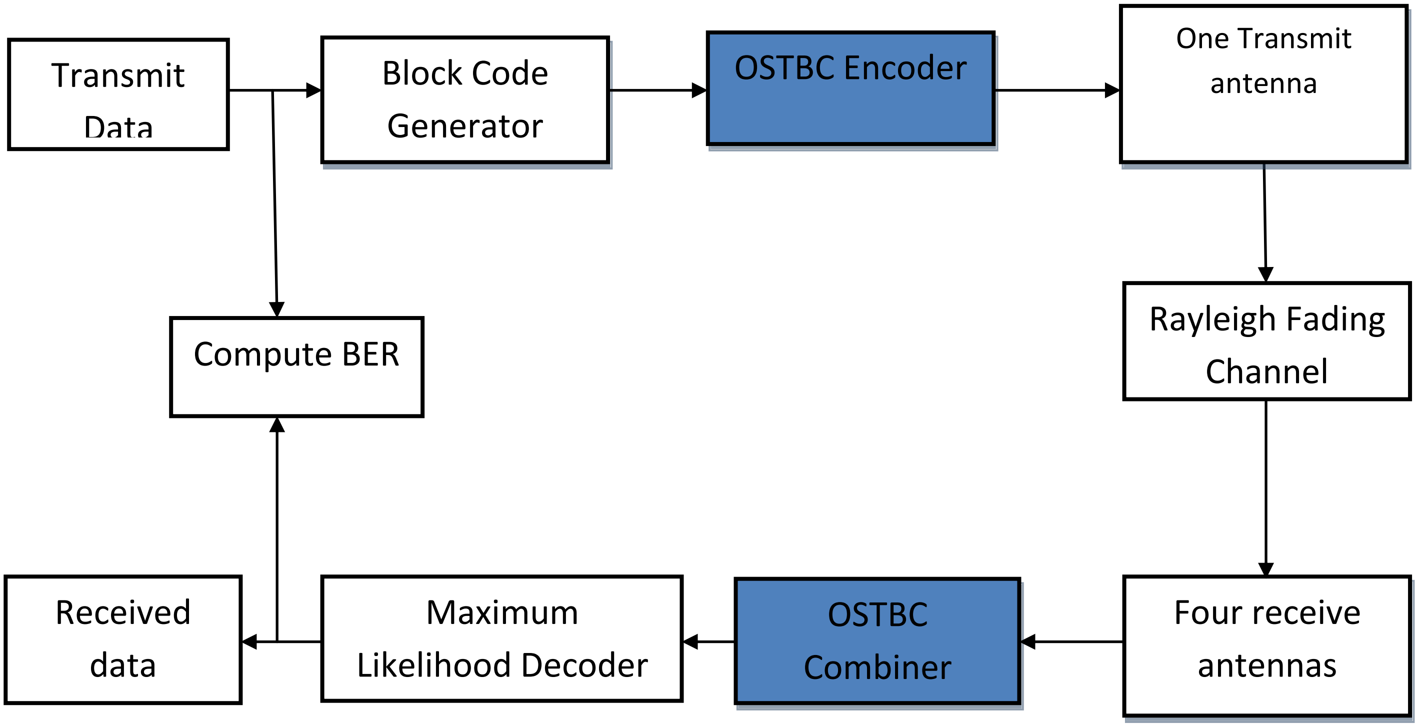


Figure (3.8): System model of proposed method (1x4)

Block code generator generate codewords by using encoding circuit show in Figure (2.13). The one transmitter antenna means reduce the cost of fixed and mobile devices connected to the network and also means that the system is simple and the process of treatment and modification of data and messages are few and this means that there is no diversity in the transmitter, either temporal or spatial.

The OSTBC Encoder block encodes an input symbol sequence using orthogonal space-time block code. The block maps the input symbols block-wise and concatenates the output codeword matrices in the time domain. The block supports time and spatial domains for OSTBC transmission. It also supports an optional dimension, over which the encoding calculation is independent. This dimension can be thought of as the frequency domain. The following illustration indicates the supported dimensions for the inputs and output of the OSTBC Encoder block.

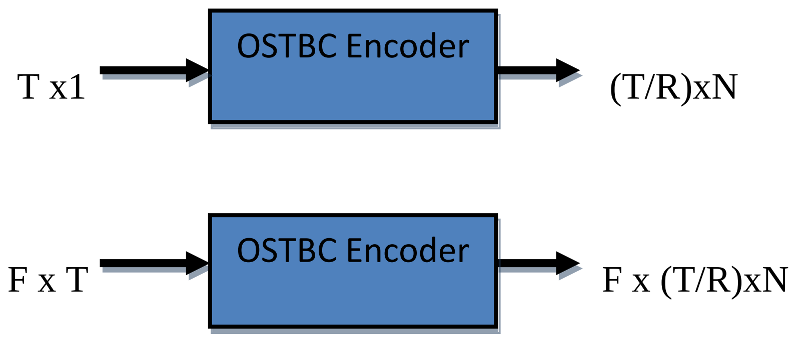


Figure (3.9): OSTBC encoder block

The following table (3.6) describes the variables.

Table (3.6): OSTBC encoder block variables:

Variable	Description
F	The additional dimension; typically the frequency domain.
T	Input symbol sequence length for the time domain.
R	symbol rate of the code
N	Number of transmit antennas

F can be any positive integer. N can be 2 or 4, indicated by Number of transmit antennas. For N = 2, R must be 1. For N = 3 or 4, R can be 3/4 or 1/2, indicated by Rate. The time domain length T must be a multiple of the number of symbols in each codeword matrix. Specifically, for N = 2 or R = 1/2, T must be a multiple of 2 and when R = 3/4, T must be a multiple of 3.

The OSTBC Encoder block supports different OSTBC encoding algorithms. Depending on the selection for Rate and Number of transmit antennas, in 2x2 system the block implements the algorithm in the following table (3.7).

Table (3.7): 2x2 encoding algorithms:

Transmit Antennas	Rate	Codeword Matrix
2	1	$H = \begin{bmatrix} S_1 & S_2 \\ -S_2^* & S_1^* \end{bmatrix}$

In each matrix, its (l, i) entry indicates the symbol transmitted from the i^{th} antenna in the l^{th} time slot of the block. The value of i can range from 1 to N (the number of transmit antennas). The value of l can range from 1 to the codeword block length.

This data is sent through the transmitter antenna. When the receiver, there are four antennas, each of which receives the transmitted signal phase is different from the other, because the signal reaches angles and different time.

The OSTBC Combiner block combines the input signal (from all of the receive antennas) and the channel estimate signal to extract the soft information of the symbols encoded by an OSTBC. The input channel estimate may not be constant during each codeword block transmission and the combining algorithm uses only the estimate for the first symbol period per codeword block. A symbol demodulator or decoder would follow the Combiner block in a MIMO communications system. The block conducts the combining operation for each symbol independently. The combining algorithm depends on the structure of the OSTBC.

Along with the time and spatial domains for OSTBC transmission, the block supports an optional dimension, over which the combining calculation is independent. This dimension can be thought of as the frequency domain for OFDM-based applications. The following illustration indicates the supported dimensions for inputs and output of the OSTBC Combiner block.

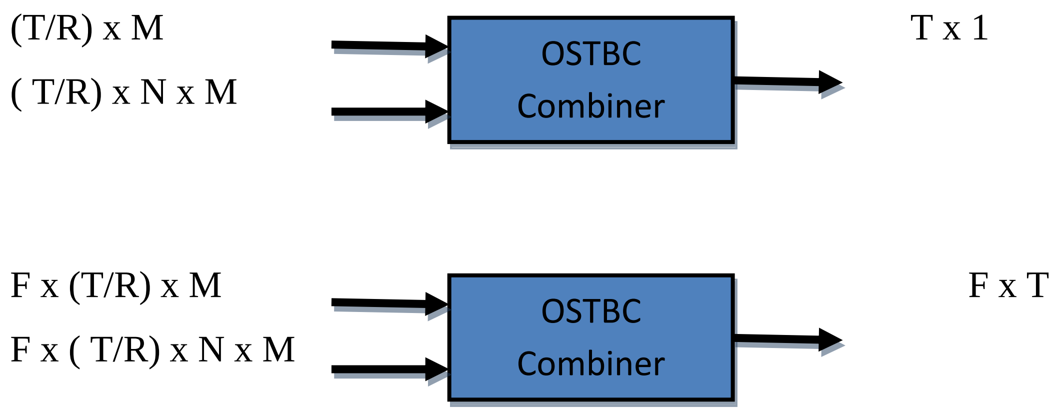


Figure (3.10): OSTBC Combiner block

The following table (3.8) describes each variable for the block.

Table (3.8): Variables of combiner block:

Variable	Description
F	The additional dimension; typically the frequency dimension..
N	Number of transmit antennas.
M	Number of receive antennas
T	Output symbol sequence length in time domain.
R	Symbol rate of the code.

F can be any positive integers. M can be 1 through 4, indicated by the Number of receive antennas parameter. N can be 2 or 4, indicated by the Number of transmit antennas parameter. The time domain length T/R must be a multiple of the codeword block length (2 for Alamouti; 4 for all other OSTBC). For N = 2, T/R must be a multiple of 2. When N > 2, T/R must be a multiple of 4. R defaults to 1 for 2 antennas. R can be either 3/4 or 1/2 for more than 2 antennas.

The OSTBC Combiner block supports different OSTBC combining computation algorithms. Depending on the selection for Rate and Number of transmit antennas, you can select algorithm shown in the following table (3.9).

Table (3.9): 2x2 combiner algorithm:

Transmit Antenna	Rate	Computational algorithm per codeword block length
2	1	$\begin{bmatrix} S_1^{\wedge} \\ S_2^{\wedge} \end{bmatrix} = \frac{1}{\lvert H^2 \rvert} \sum_{j=1}^{M} \begin{pmatrix} h_{1,j}^{*} r_{1,j} + h_{2,j} r_{2,j}^{*} \\ h_{2,j}^{*} r_{1,j} - h_{1,j} r_{2,j}^{*} \end{pmatrix}$

S_k^ represents the estimated kth symbol in the OSTBC codeword matrix. h_{ij} represents the estimate for the channel from the ith transmit antenna and the jth receive antenna. The values of i and j can range from 1 to N (the number of transmit antennas) and to M (the number of receive antennas) respectively. $r_{l,j}$ represents the lth symbol at the jth receive antenna per codeword block. The value of l can range from 1 to the codeword block length.

$$|H|^2 = \sum_{i=1}^{N} \sum_{j=1}^{M} |h_{ij}|^2 \qquad (3.35)$$

$|H|^2$ Represents the summation of channel power per link, i.e., Use the following formula for $S_1^{\wedge}$ for Alamouti code with 1 receive antenna to highlight the data types used for fixed-point signals.

$$S_1^{\wedge} = \frac{h_{1,1}^{*} r_{1,1} + h_{2,1} r_{2,1}^{*}}{|H|^2} = \frac{h_{1,1}^{*} r_{1,1} + h_{2,1} r_{2,1}^{*}}{h_{1,1} h_{1,1}^{*} + h_{2,1} h_{2,1}^{*}} \qquad (3.36)$$

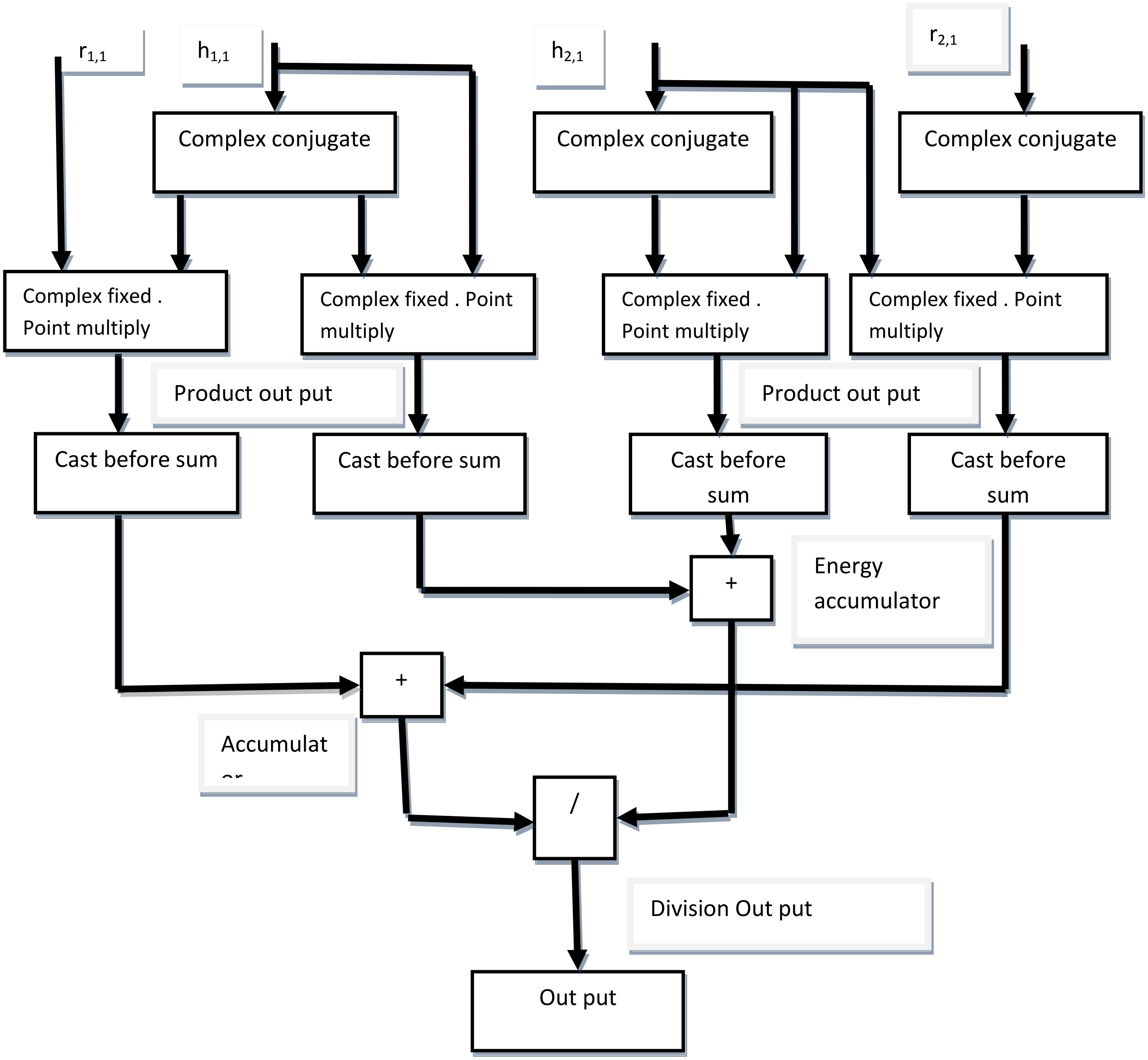


Figure (3.11): OSTBC Combiner block Components

The following formula shows the data types used within the OSTBC Combiner block for fixed-point signals for more than one receive antenna for Alamouti code, where M represents the number of receive antennas.

$$S_1^{\wedge} = \frac{h_{1,1}^{*} r_{1,1} + h_{2,1} r_{2,1}^{*} + h_{1,2}^{*} r_{1,2} + h_{2,2} r_{2,2}^{*} + \ldots + h_{1,M}^{*} r_{1,M} + h_{2,M} r_{2,M}^{*}}{h_{1,1} h_{1,1}^{*} + h_{2,1} h_{2,1}^{*} + h_{1,2} h_{1,2}^{*} + h_{2,2} h_{2,2}^{*} + \ldots + h_{1,M} h_{1,M}^{*} + h_{2,M} h_{2,M}^{*}} \quad (3.37)$$

The OSTBC combiner combines the input signals (from all of the receive antennas) in one component and then sends to the Maximal ratio decoder which is applied to the detection algorithm to determine the real data that has been sends by equations described below:

$$R_1 = h_{11}S_1 + n_1 \quad (3.38)$$

$$R_2 = h_{12}S_1 + n_2 \quad (3.39)$$

$$R_3 = h_{13}S_1 + n_3 \quad (3.40)$$

$$R_4 = h_{14}S_1 + n_4 \quad (3.41)$$

The ML detector chooses S_i if and only if:

$$d^2(\hat{S}_1, \hat{S}_i) \leq d^2(\hat{S}_1, \hat{S}_k) \forall i \neq k \quad (3.42)$$

As a result, diversity techniques have almost exclusively been applied to base stations to improve their reception quality. A base station often serves hundreds to thousands of remote units. It is therefore, more economical to add equipment to base stations rather than the remote units. For this reason, transmit diversity schemes are very attractive. For instance, four antennas put in a base station to improve the reception quality of all the remote units in that base station‘s coverage area (in fact, many cellular base stations already have two receive antennas for receiver diversity. The same antennas may be used for transmit diversity). The alternative is to add more antennas and receivers to all the remote units. The first solution is definitely more economical.

3.4 Simulation Model and Design:

Figure (3.12) is the flowchart of our simulation. First, all the parameters, which are discussed later, are initialized. Second, the data source generates a binary m-sequence in NRZ format, and delivers it to the modulator. The sequence is also stored for later use by the BER test module. Passing through the channel module, the transmitted signal at the output of the modulator is distorted by AWGN or Rayleigh fading channel. To obtain uncorrelated diversity branches, independent channel modules are employed. Subsequently, these branches are merged at the diversity combining module to construct the 'best' signal for demodulation. Next, the demodulator recovers the data sequence from the output of the diversity module. Finally, the recovered and original data sequences are compared at the BER test module to find out how many Bits were in error.

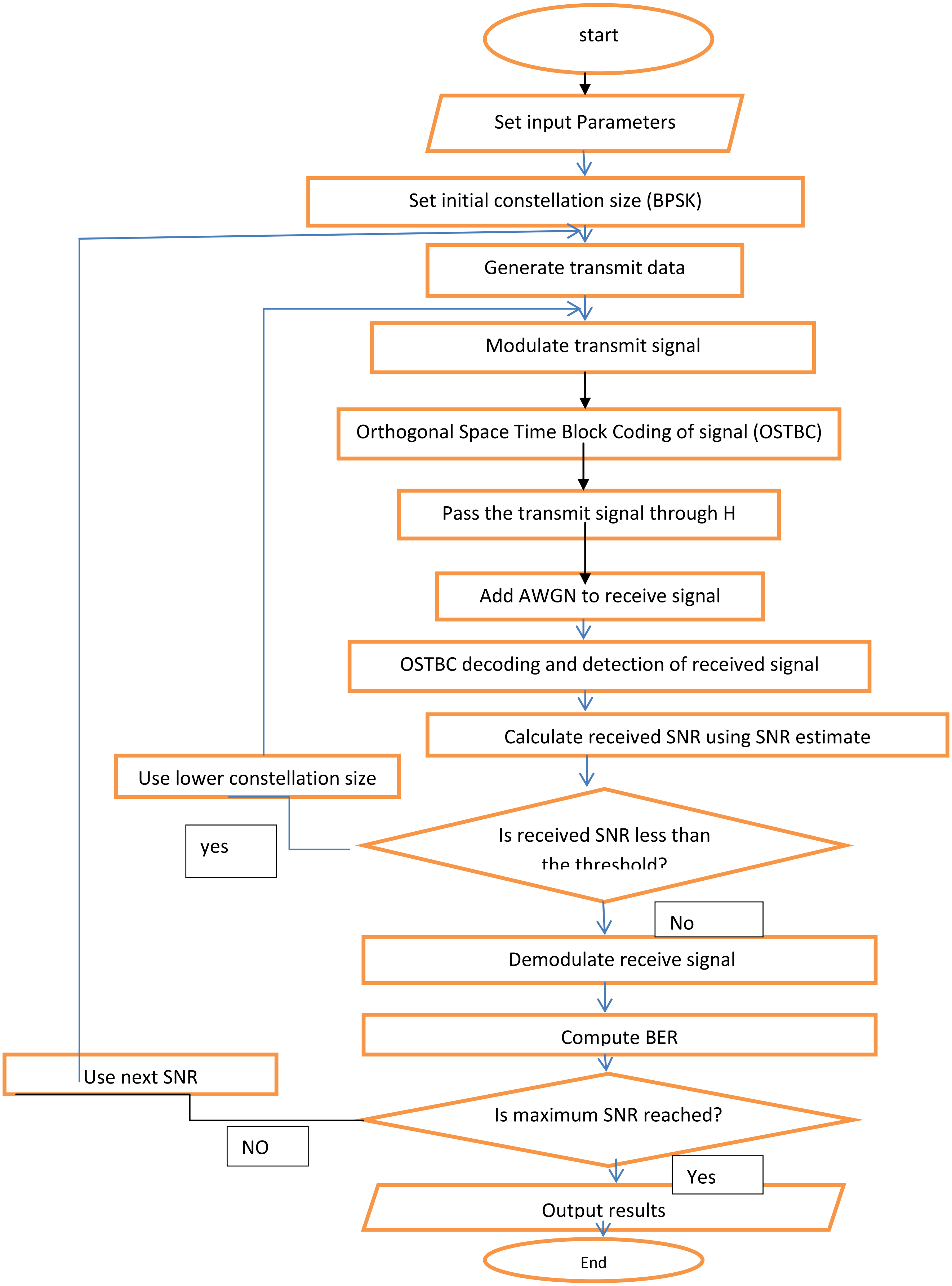


Figure (3.12): The flowchart for simulation

3.5 Simulation parameters:

The table below shows the basic variables for design.

Table (3.10): Simulation parameters:

Variable	Value
Frame length	50, 100. 500 Symbols
Number of packets	500, 1000 or 3000
Eb/No	Varying: 0 to 10 and 16 dB
Bit Error Rate (BER)	0 to 10^{-4}
Maximum number of transmit antennas (T_x) :N	2
Maximum number of receive antennas (R_x) :M	4
Modulation scheme	BPSK

3.6 Chapter Summary

In this section is to discuss the basic steps to generate OSTBC depending on the system used, whether two or four antennas at the transmitter and receiver, if used two antennas in the system is called the Alamouti and this is the foundation and is building systems, has been discussed in some detail, and then the system is built quadruple, and accompanied by mathematical equations that can be used to analyze the system and calculate the BER and their relationship to the SNR sent.

Finally discussion of the proposed method (1x4 OSTBC) of this work in solving the problem of multipath fading over Rayleigh fading channel and equations analyzed.

Chapter Four

Results and Discussions

4.1 Introduction:

In the previous chapter, built up the foundation for the simulation by analyzing the functions of each simulation block and developing the mathematical models for them. In this section, discuss and shows the simulation results from those individual blocks.

4.2 Results and Discussions:

The following graphs illustrate simulation results in terms of Bit Error Rate (BER) versus signal-to-noise ratio (SNR) for one and two transmit antennas and one, two and four receive antennas.

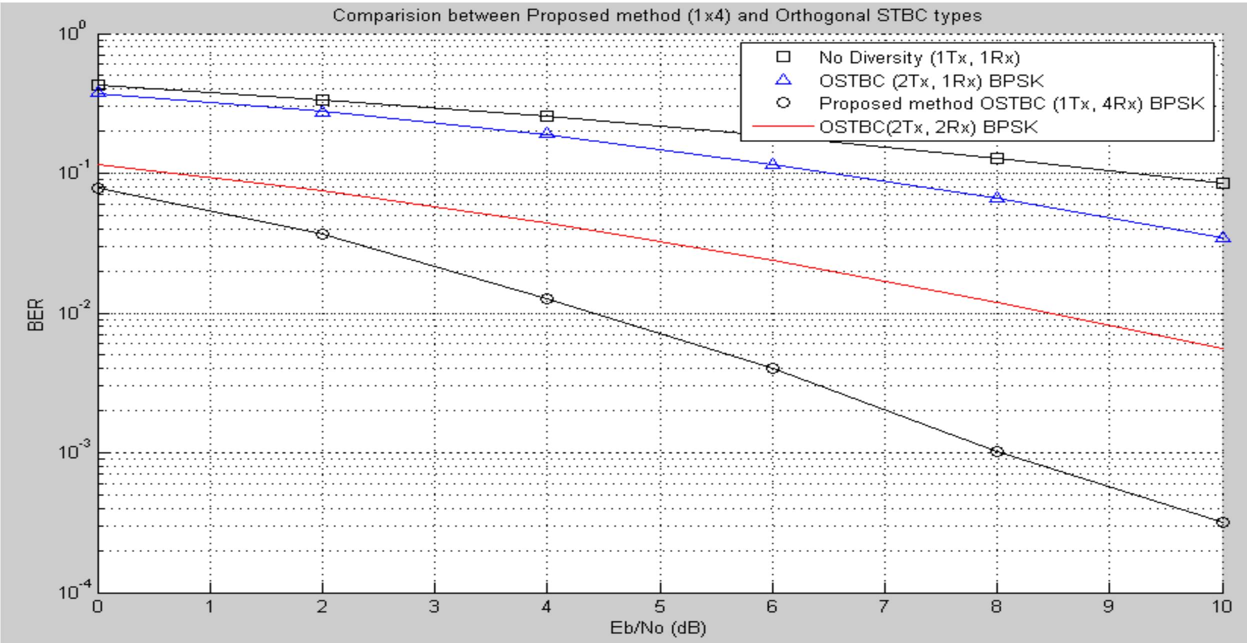


Figure (4.1): Comparison of BER Performance analysis of OSTBC in (1Tx , 1Rx), (2Tx , 2Rx – BPSK) , (1Tx , 2Rx – BPSK) and proposed method (1Tx , 4Rx –BPSK) on Rayleigh fading channel, with (number of packets =500 and frame length= 100)

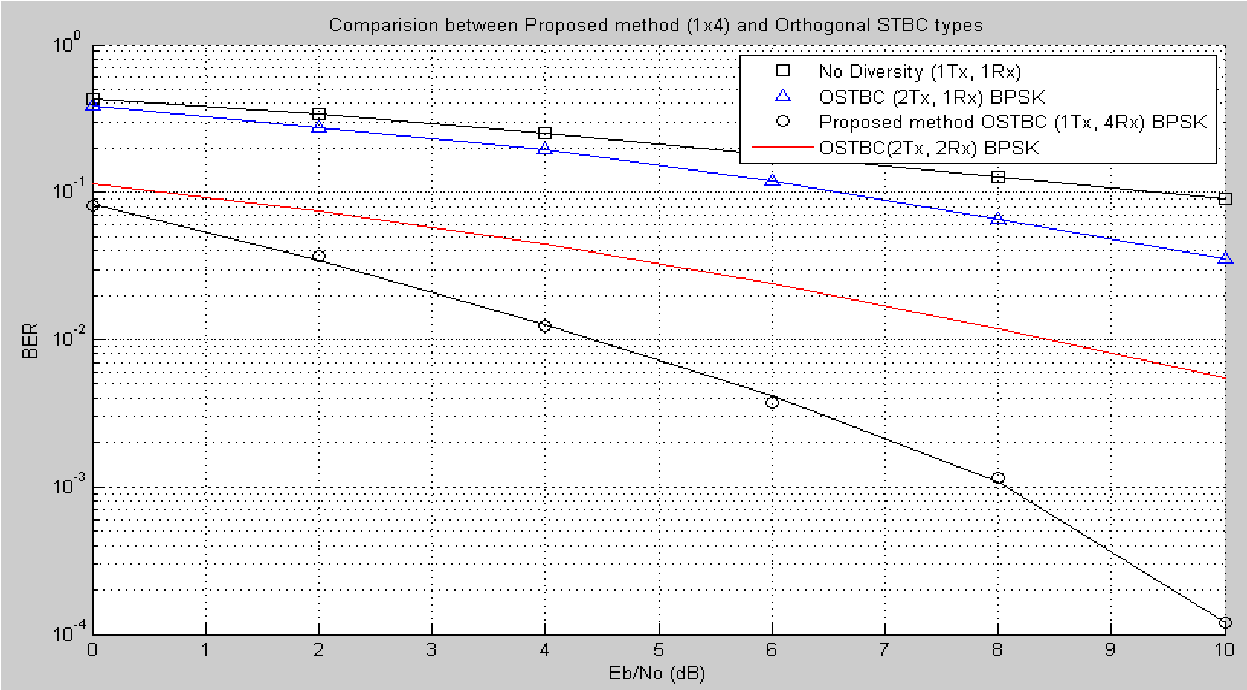


Figure (4.2): Comparison of BER Performance analysis of OSTBC in (1Tx , 1Rx), (2Tx , 2Rx – BPSK) , (1Tx , 2Rx – BPSK) and proposed method (1Tx , 4Rx –BPSK) on Rayleigh fading channel, with (number of packets =500 and frame length= 50)

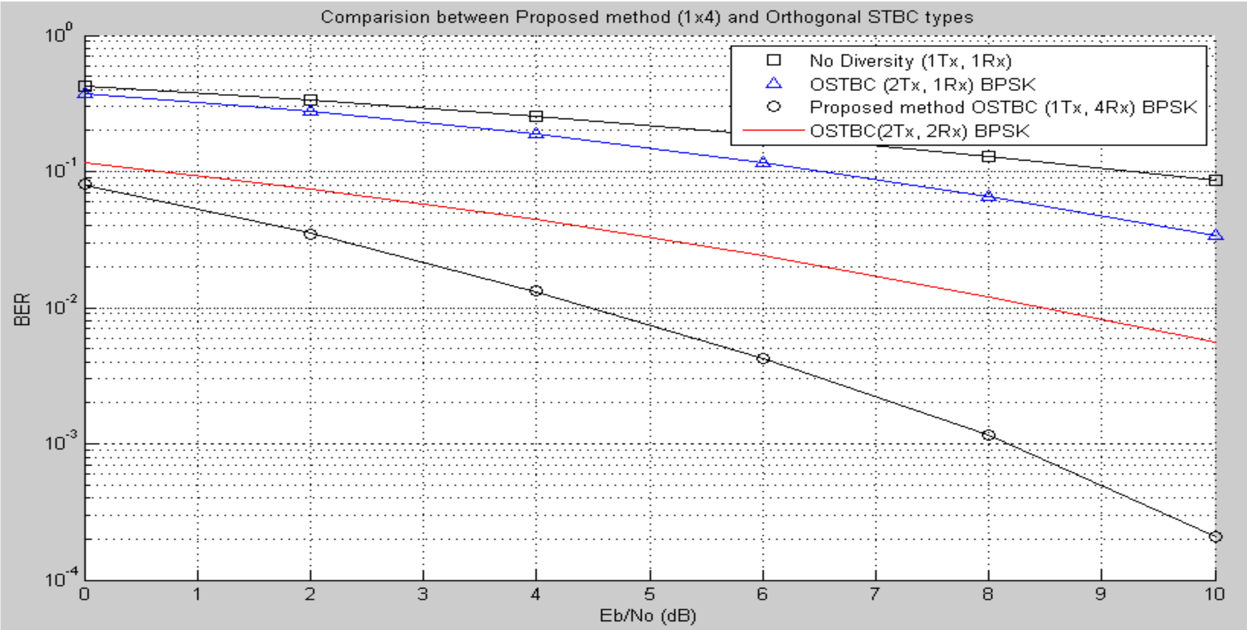


Figure (4.3): Comparison of BER Performance analysis of OSTBC in (1Tx , 1Rx), (2Tx , 2Rx – BPSK) , (1Tx , 2Rx – BPSK) and proposed method (1Tx , 4Rx –BPSK) on Rayleigh fading channel, with (number of packets =1000 and frame length= 100)

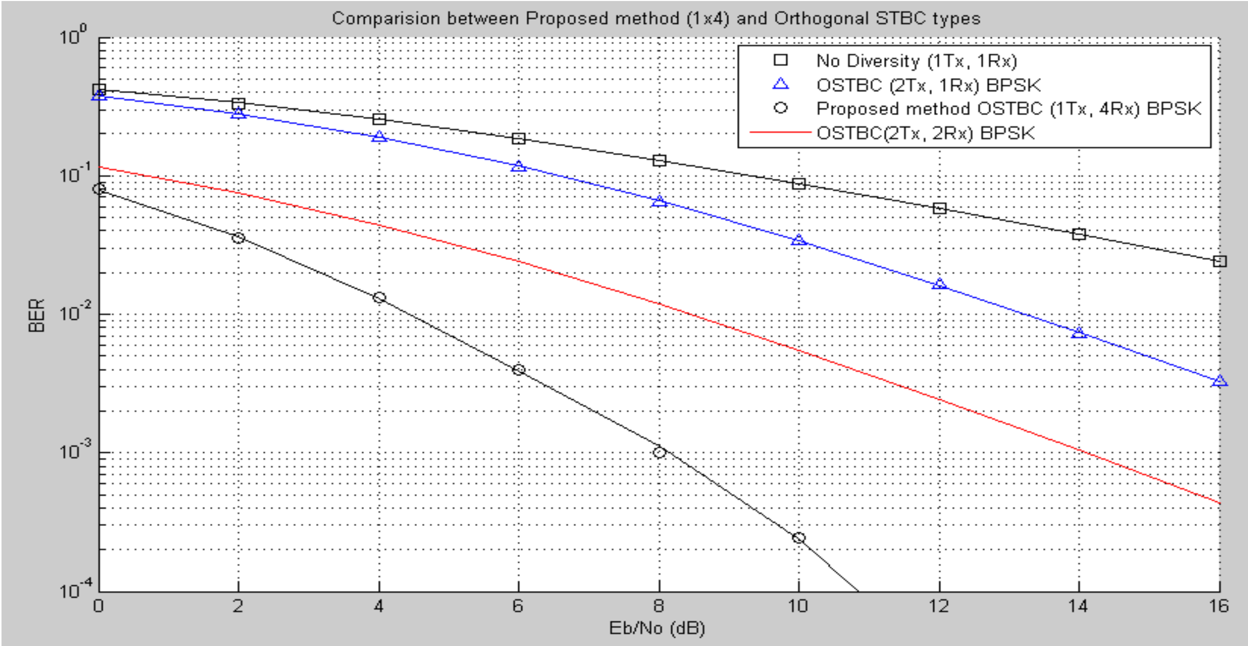


Figure (4.4): Comparison of BER Performance analysis of OSTBC in (1Tx , 1Rx), (2Tx , 2Rx – BPSK) , (1Tx , 2Rx – BPSK) and proposed method (1Tx , 4Rx –BPSK) on Rayleigh fading channel, with (number of packets =1000 and frame length= 500)

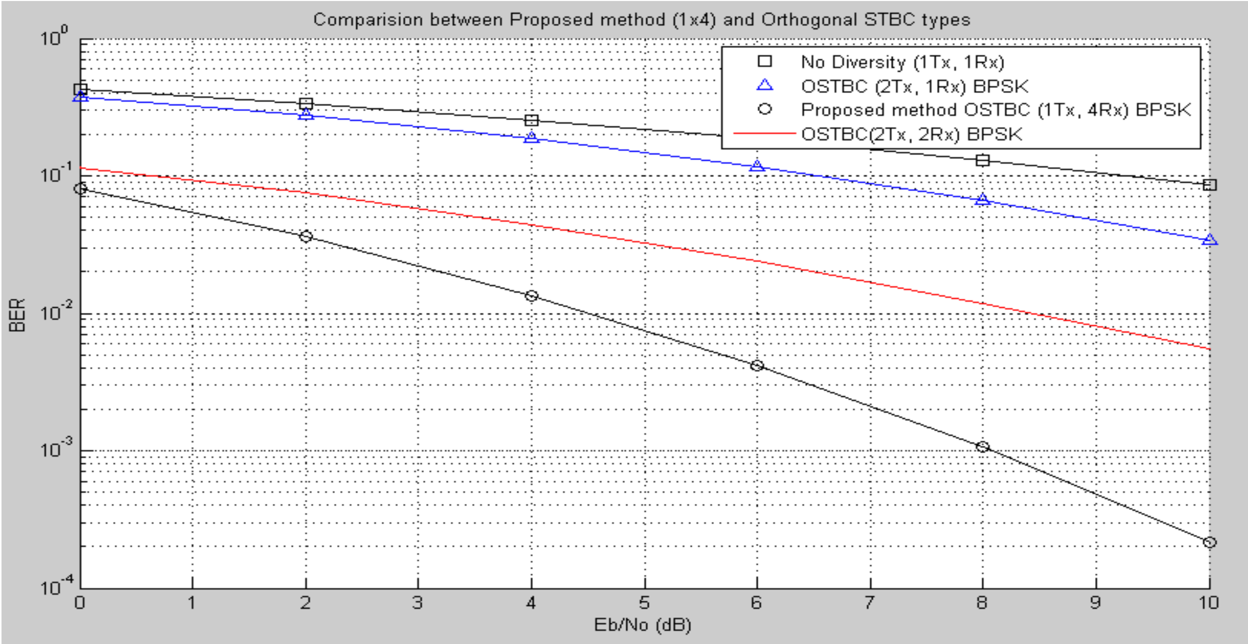


Figure (4.5): Comparison of BER Performance analysis of OSTBC in (1Tx , 1Rx), (2Tx , 2Rx – BPSK) , (1Tx , 2Rx – BPSK) and proposed method (1Tx , 4Rx –BPSK) on Rayleigh fading channel, with (number of packets =2000 and frame length= 100)

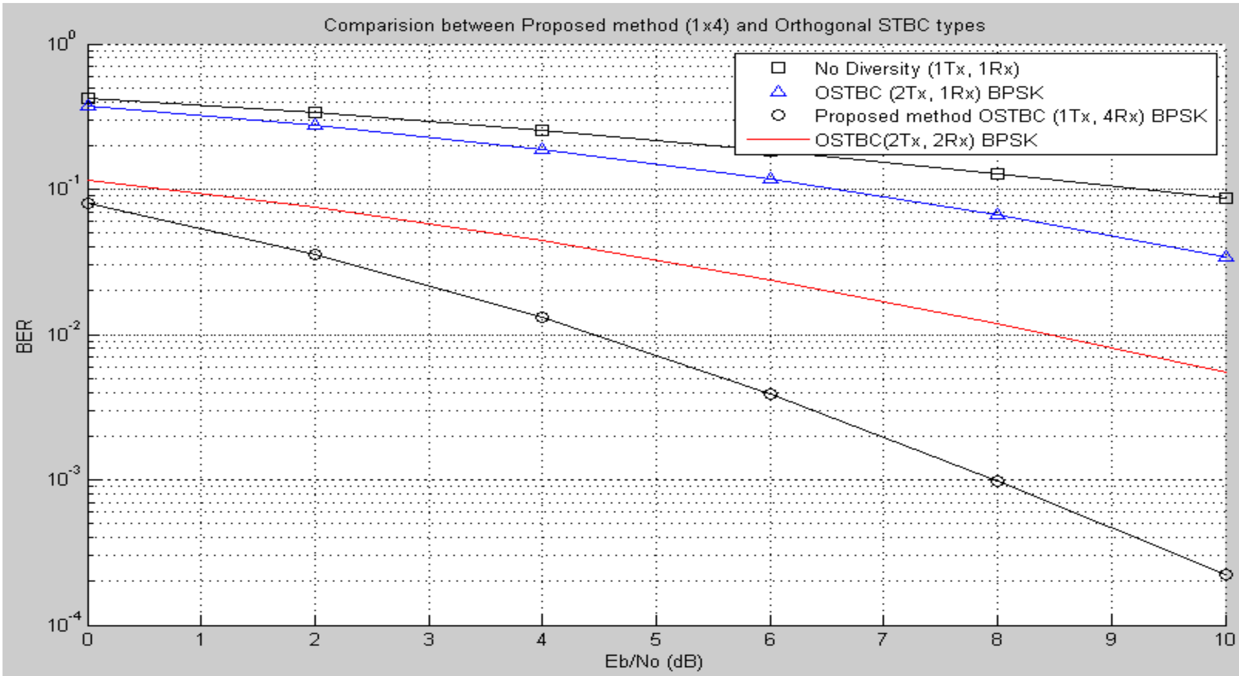


Figure (4.6): Comparison of BER Performance analysis of OSTBC in (1Tx , 1Rx), (2Tx , 2Rx – BPSK) , (1Tx , 2Rx – BPSK) and proposed method (1Tx , 4Rx –BPSK) on Rayleigh fading channel, with (number of packets =2000 and frame length= 500)

In result analysis show the comparison between SNR and BER for OSTBC which is shown in figures above, by using one and two transmit antennas and one, two and four receive antennas with BPSK modulation technique. In Figures (4.1) to (4.6) compare OSTBC using BPSK with full diversity of (1-Tx , 1-Rx) , (2-Tx , 2-Rx) , (2TX , 1-Rx) and proposed method (1-Tx , 4-Rx) with variables number of packets and frame length shows the similar slopes of the BER curves for the 2x2 and 1x4 systems indicate an identical diversity order for each system.

In figure (4.2) at 10^{-4} BER point the performance of the proposed method (1x4) BPSK system is 10 dB improvements than other OSTBC systems on Rayleigh fading channel, with (number of packets =500 and frame length= 50). Also in figure (4.4) at 10^{-4} BER point the performance of the proposed method (1x4) BPSK system is 11 dB improvements than other OSTBC systems on Rayleigh fading channel, with (number of packets =1000 and frame length= 500).

The resulting simulation results show that using one and two transmit antennas and one receive antenna (2Tx,1Rx and 1Tx, 1Rx) provides the similar diversity order for all figures. Also observe that transmit diversity of proposed method (1Tx,4Rx) system has about 1 dB variables at 10^{-4} BER point for values of packet numbers (500, 1000, 2000) and frame lengths (50, 100, 500). Finally, we conclude that the use of the proposed method reduces the value of BER and the complexity of the system compared with other methods at different values for each of the packet numbers (500, 1000, 2000) and frame length (50, 100, 500) so that a simple change in the value of the (Eb/No) of about 1dB (value oscillating between 10 and 11 dB) at 10^{-4} BER point.

Also the stability of the system at different values for each of the number of packets and frame lengths, and this gives it the flexibility to deal with changes in mobile systems and congestion so that the performance of a unified system, whatever the increase in users.

4.3 Chapter Summary:

In this chapter has been building flowchart to improve the performance of the system Orthogonal STBC and depending on the encoding matrix used by the OSTBC encoder according to the type of user modification. And using MATLAB software was designed which gave the results shown in the above figures. The results showed that the proposed method using one antenna to send and four receive antennas (1Tx to 4Rx) is the best compared with other systems. Because it gives a less BER ratio and at the same time using less signal-to-noise ratio. It is considered an economic cost as well, because in the case of use in mobile communications is the development of a single antenna in the mobile and four antennas (proposed method) at the base station, which can cover the largest number of mobile phones and thus less complexity of the system and reduce the processing time.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion:

Demand for capacity in wireless communication systems has been rapidly growing worldwide. This has been driven by the increasing data rate requirements of wireless communication systems, and increasing demand for wireless Internet and multimedia services. As the available radio spectrum is limited, higher data rates can only be achieved by designing more efficient signaling techniques. To improve spectral efficiency for future high data rate transmissions, it is desirable to construct OSTBCs with high order signal constellations. However, the design of OSTBC increasing exponentially with constellation size and the number of transmit antennas.

This Work improves OSTBC reliability and data rates, have derived Bit Error Rate of OSTBC with BPSK versus SNR over Rayleigh fading channel. And we have obtained the numerical results by numerical integral that agree with the simulation results. The simulations show that the proposed method-OSTBC (1x4-BPSK) design can efficiently reduce the BER at the small signal-to- noise ratio (SNR) region. It results shown previously to be this proposed method is useful for mobile communication systems so that the complex be few in mobile units while increasing the efficiency of the system placed four antennas in the base station so as to increase the efficiency of the reception of the signals at the same time be lower cost.

5.2 Recommendations:

This thesis only solves the problem of two and four transmit and receive antennas for OSTBC system. Expansion to general case M×N system can be considered in the future. Furthermore, other constellations can also be researched on, such as M-QAM and M-PSK. Also other channel coding types such as Reed Solomon (RS) code may be tested.

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Appendix

Simulation MATLAB Code:

compression between proposed method (1x4) and other OSTBC types with number of packets =(500, 1000, 2000) and frame length=(50, 100, 500) :

```
frmLen = 500;        % frame length (50, 100 or 500)
numPackets = 2000;  % number of packets(500, 1000, 2000)
EbNo = 0:2:16;      % Eb/No varying to 16 dB
N = 2;              % maximum number of Tx antennas
M = 4;              % maximum number of Rx antennas
% Create a local random stream to be used by random number
generators for repeatability.
hStr = RandStream('mt19937ar', 'Seed', 55408);
% Create BPSK mod-demod objects
P = 4;    % modulation order
bpskmod = modem.pskmod('M', P, 'SymbolOrder', 'Gray');
bpskdemod = modem.pskdemod(bpskmod);
tx2 = zeros(frmLen, N); H  = zeros(frmLen, N, M);
r21 = zeros(frmLen, 1); r14  = zeros(frmLen, 2);
z21 = zeros(frmLen, 1); z21_1 = zeros(frmLen/N, 1); z21_2 =
z21_1;
z14 = zeros(frmLen, M);
error11 = zeros(1, numPackets); BER11 = zeros(1, length(EbNo));
error21 = error11; BER21 = BER11; error14 = error11; BER14 =
BER11; BERthy2 = BER11;

% 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-4 1]);
xlabel('Eb/No (dB)'); ylabel('BER'); set(h,'NumberTitle','off');
set(h, 'renderer', 'zbuffer'); set(h,'Name','Orthogonal STBC
Comparision 1');
title('Comparision between Proposed method (1x4) and Orthogonal
STBC types');

% Loop over several EbNo points
for idx = 1:length(EbNo)
    % Loop over the number of packets
    for packetIdx = 1:numPackets
```

```
        data = randi(hStr, [0 P-1], frmLen, 1);   % data vector
per user
        tx = modulate(bpskmod, data);

        % OSTBC Alamouti Space-Time Block Encoder
        %   G2 = [s1 s2; -s2* s1*]
        s1 = tx(1:N:end); s2 = tx(2:N:end);
        tx2(1:N:end, :) = [s1 s2];
        tx2(2:N:end, :) = [-conj(s2) conj(s1)];

        % Create the Rayleigh channel response matrix
        H(1:N:end, :, :) = (randn(hStr, frmLen/2, N, M) + ...
                                1i*randn(hStr, frmLen/2, N,
M))/sqrt(2);
        %   assume held constant for 2 symbol periods
        H(2:N:end, :, :) = H(1:N:end, :, :);

        % Received signals
        %   for uncoded 1x1 system
        r11 = awgn(H(:, 1, 1).*tx, EbNo(idx), 0, hStr);

        %   for 2x1 system - with normalized Tx power
        r21 = awgn(sum(H(:, :, 1).*tx2, 2)/sqrt(N), EbNo(idx),
0, hStr);

        %   for Maximal-ratio combined 1x2 system
        for i = 1:M
            r14(:, i) = awgn(H(:, 1, i).*tx, EbNo(idx), 0,
hStr);
        end

        % Front-end Combiners - assume channel response known at
Rx
        %   for 2x1 system
        hidx = 1:N:length(H);
        z21_1 = r21(1:N:end).* conj(H(hidx, 1, 1)) + ...
                conj(r21(2:N:end)).* H(hidx, 2, 1);

        z21_2 = r21(1:N:end).* conj(H(hidx, 2, 1)) - ...
                conj(r21(2:N:end)).* H(hidx, 1, 1);
        z21(1:N:end) = z21_1; z21(2:N:end) = z21_2;

        %   for Maximal-ratio combined 1x4 system
        for i = 1:M
            z14(:, i) = r14(:, i).* conj(H(:, 1, i));
        end
```

```
        % ML Detector (minimum Euclidean distance)
        demod11 = demodulate(bpskdemod, r11.*conj(H(:, 1, 1)));
        demod21 = demodulate(bpskdemod, z21);
        demod14 = demodulate(bpskdemod, sum(z14, 2));

        % Determine errors
        error11(packetIdx) = biterr(demod11, data);
        error21(packetIdx) = biterr(demod21, data);
        error14(packetIdx) = biterr(demod14, data);
    end % end of FOR loop for numPackets

    % Calculate BER for current idx
    %   for uncoded 1x1 system
    BER11(idx) = sum(error11)/(numPackets*frmLen);

    %   for 2x1 system
    BER21(idx) = sum(error21)/(numPackets*frmLen);

    %   for Maximal-ratio combined 1x4 system
    BER14(idx) = sum(error14)/(numPackets*frmLen);

    %   for theoretical performance of second-order diversity
    BERthy2(idx) = berfading(EbNo(idx), 'psk', 2, 2);

    % Plot results
    semilogy(EbNo(1:idx), BER11(1:idx), 'ks', ...
             EbNo(1:idx), BER21(1:idx), 'b^', ...
             EbNo(1:idx), BER14(1:idx), 'ko', ...
             EbNo(1:idx), BERthy2(1:idx), 'r');
    legend('No Diversity (1Tx, 1Rx)', 'OSTBC (2Tx, 1Rx)
BPSK',...
           'Proposed method OSTBC (1Tx, 4Rx) BPSK', ...
           'OSTBC(2Tx, 2Rx) BPSK');

    drawnow;
end  % end of for loop for EbNo

% Perform curve fitting and replot the results
fitBER11 = berfit(EbNo, BER11);
fitBER21 = berfit(EbNo, BER21);
fitBER14 = berfit(EbNo, BER14);
semilogy(EbNo, fitBER11, 'k', EbNo, fitBER21, 'b', EbNo,
fitBER14, 'k');
hold off;
```