Space-Time Codes for Wireless Communication

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology

by

Trilochan Behera

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Under the guidance of

Prof. Upendra Kumar Sahoo

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Dedicated to.......

My parents and my younger brothers and sisters.

Abstract

With an increasing demand for high data rate, there has been a lot of research in the field of wireless communication. This paper deals with the fundamentals of space-time coding for wireless communication systems. A well-known technique known as Space-Time Coding has been adopted in the systems using multiple antennas for high speed and reliable communication. The basic idea of space-time coding deals with the designing of two-dimensional signal matrix that is to be transmitted over an interval of time from a number of transmitting antennas. High data rate and improved bit error performance can be achieved by exploiting diversity in the spatial dimensions by designing appropriate signal structure. Space-Time Block Coding is a MIMO transmit strategy which exploits transmit diversity and high reliability. We analyze the basic design structure of the space- time codes and summarize their relative performances.

Declaration

I hereby declare that the work presented in the thesis entitled Space Time Codes for Wireless Communication is a bonafide record of the research work done by me under the supervision of Prof. Upendra Kumar Sahoo, Department of Electronics & Communication Engg., National Institute Of Technology, Rourkela, India and that no part thereof has been presented for the award of any other degree.

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Certificate

I certify that this thesis entitled **Space- Time Codes for Wireless Communication** is a bonafide record of the research work carried by Mr. Trilochan Behera under my supervision in the Digital Signal Processing Lab, Department of Electronics & Communication, National Institute of Technology, and Rourkela, India. The results presented in this thesis or part of it has not been presented for the award of any other degree.

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List of Symbols

N : Number of transmit antennas

M : Number of receive antennas

N_o : Noise power spectral density

$s[l]$: Transmitted signal (scalar)

$r[l]$: Received signal (scalar)

$n[l]$: Additive noise (scalar)

$\overline{s}[l]$: Detected signal (scalar, soft decision)

H : Channel coefficient matrix

$h[l]$: Channel fading coefficient (scalar)

Chapter1#

Introduction

Wireless communication is one of the biggest and most rapidly growing sectors of the communication industry due to an increasing demand in sophisticated communication services.. In late 1800s Hertz and Marconi started experiments on study of radio waves and its propagation in free space which shows that electrical signals can be transmitted into free space via EM waves travelling at the speed of light. We can define a SISO channel model through which we can transmit EM waves to the desired destination. We go for appropriate design of the signal structure and the algorithm called space time codding for improving the data rate and the quality of transmission. Highly spectrally efficient wirelesses transmissions can be achieved using multiple transmit and receive antennas. Multiple antennas are deployed in a MIMO system both at the transmitter and receiver. The specialty of MIMO technology is that it offers benefits they can attain the above requirements without the need for additional bandwidth, which is a major challenge in wireless communication. Unlike the Gaussian channel, the wireless channel suffers from attenuation due to multi path fading in the propagating medium and due to interference from other sources. Due to this attenuation it becomes impossible for the receiver to determine the transmitted signal unless some replica of the transmitted signal is transmitted. This can be achieved using a technique called diversity, where replica of the signal is transmitted in addition to the original signal Diversity is the single most important contributor to reliable wireless communications.

Fading is an important challenge in wireless communication that arises due to multipath propagation. It is defined as rapid fluctuation in the signal strength due to constructive or destructive of the signal. Fading can be of two types known as large scale fading and small scale fading. Large scale fading is due to the tall buildings, terrain or mountains that decrease the signal strength over a distance and small scale fading arises due to the scattering of the signal at the transmitter by small near by objects. Small scale fading has been considered in his paper. We go for MIMO system which includes multiple transmit and receive antennas, in order to exploit spatial diversity for improving the data rate and providing reliable communication over a Rayleigh fading channel.

Chapter 2 #

Signal structures and fading

In wireless communication the transmitted signal suffers attenuation due to multi path propagation and hence we cannot get the true replica of the transmitted signal at the receiver. Fading is defined as rapid fluctuation in the the power of transmitted signal due to destructive interference. Fading can be categorized as large and small scale signal fading. Large scale fading is due to surrounding elements such as tall buildings, mountains or natural processes like rainfall.

Large-scale fading is the result of signal attenuation due to signal propagation over large distances and diffraction around large objects in the propagation path .But our focus is on small scale fading which occurs due to scattering off objects in the propagating medium. Multipath is a phenomena in wireless propagation of radio waves that results in radio waves reaching the receiver by two or more propagating paths. This is due to atmospheric ducting ionospheric reflection and refraction from terrestrial objects such as mountain and tall buildings. It also arises due to scattering of radio waves that gives rise to receiving multiple constructively and destructively interfering copies of the transmitted signal. Each copy experiences different phase shifts and attenuation since the behavior of the transmission channel varies from path to path.

At a particular instant of time and frequency response of the channel exhibits its effects on the transmitted signal at different harmonics. The channel impulse response may vary over time, giving rise to a linear time-variant system model. The impulse response of the channels in a

MIMO transmission system may also be different between each transmit-receive antenna pair. A more detailed study can be found in [1].

2.1 Channel parameters

Here we will define three basic channel parameters which is the channel impulse response function, coherence band width and selectivity .The channel impulse response of a MIMIO system generally expressed as $h_{ij}(t,\tau)$ is a function of time, delay and position of both transmitting and receiving antenna. The impulse response of a SISO channel is generally expressed by the input delay-spread function. The variable t represents the time domain and the variable τ represents the frequency domain. The indices j and i represent the spatial domains captured at the transmitting and receiving arrays. The fading channel in each of this domain is represented by the coherence interval. The channel is assumes to be flat over the interval. The channel response may vary abruptly outside the defined interval. Coherence is a feature of the channel not the transmitted signal. More detailed information about channel coefficient can be found in [3].

The properties of the transmitted signal play a vital role in estimating the effect of the channel on the signal being transmitted. Thus selectivity is defined by the relationship between the coherence band width of the channel and the properties of the transmitted signal. If the coherence band width of the channel is greater than the signal bandwidth then the channel is assumed to be a flat fading channel and if the coherence bandwidth of the channel is smaller than the signal bandwidth then the channel is known frequency selective channel.

2.2 Statistical models for fading signals

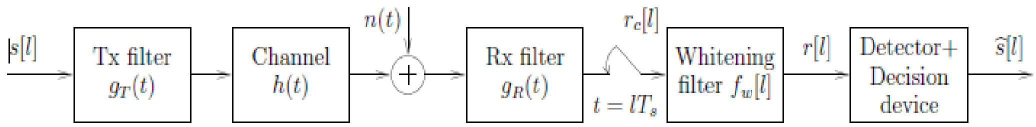
Since a transmitted signal is affected by both the phenomena of scattering and multipath, hence it cannot be expressed easily by a closed form. Based on the nature of signal propagation in the wireless channel the statistical descriptions of the channel fading coefficients are derived. The magnitude of the channel is described by the Rayleigh distribution and its phase is uniformly distribute in the interval (0, 2π].The Rayleigh probability density function is defined by a parameter $\sigma > 0$,which represents the standard deviation of the Gaussian variable.

$$f(\propto) = \begin{cases} \frac{\propto}{\sigma^2} e^{\frac{-\alpha^2}{\sigma^2}}, \alpha \geq 0 \\ 0, \propto < 0 \end{cases} \tag{2.1}$$

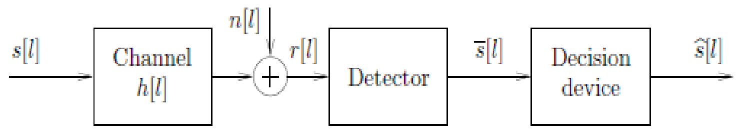
The mean value is $E(\propto) = \sqrt{\frac{\pi}{2}}\sigma$ and the average power is $E(\propto^2) = 2\sigma^2$.A more detailed study can be found in [2].

2.3 System models for fading channels

This section deals with important characteristics of wireless channel and their mathematical models. We will first discuss about the flat fading channel and then we will go for the frequency selective fading channel which is more practical in broadband systems. Three assumptions were considered like wide sense stationary, uncorrelated scattering and analogous correlation between two transmitting and receiving antenna depends only on the relative position of the antennas in spatial domain. Here a complex baseband signal is represented by its complex baseband representation. Fig 1 exhibits a complex baseband communication system.



(a) Full system diagram, continuous time.



(b) Simplified system diagram, discrete time.

Figure 1 Block diagram of baseband communication system

The samples received signal can be expressed as

$$r_c[l] = \int_{-\infty}^{\infty}\left[\int_{-\infty}^{\infty} h(\tau)\sum_{k=-\infty}^{\infty} s[k]gT(\theta-\tau-kT_s)d\tau + n(\theta)\right] gR(lT_s-\theta)d\theta$$

$$=\sum_{k=-\infty}^{\infty} h_c[l-k]s[k] + n[l]_c \qquad (2.2)$$

$$r[l] = \sum_{p=0}^{P_W-1} f_W[p]Z^{-p}\left(\sum_{k=-\infty}^{\infty} h_c[l-k]s[k] + n[l]_c\right)$$

$$= \sum_{k=-\infty}^{\infty} s[k]\sum_{p=0}^{P_W-1} f_W[p]h_c[l-p-k] + \sum_{p=0}^{P-1} f_W[p]n_c[l-p] \qquad (2.3)$$

Chapter 3 #

Diversity

The degradations in time, frequency and spatial domain caused by signal fading are major problems in wireless communication. These problems are not necessarily harmful and we can take the variations in the channel's responses as an advantage in order to improve the received Signal-to-Noise ratio. A more detailed information on bit error curve can be found in [4].Let two identical signals are transmitted over two distinct frequency channels in parallel such that they experience independent fading effects in the propagating channel. At the receiver we will receive these two copies and under such scenario there is low probability that both these copies are severely degraded than the case when only the single transmitted signal is received. Hence by combining these two copies of the received signal we can get better result than the previous case.

Diversity is defined as the process of obtaining different copies of the same signal. We go for diversity to have reliable communication in wireless fading channel.Altough there are various means of achieving diversity but the aim of all these techniques remains the same that is to obtain a more exact copy of the transmitted signal by combining various copies of the signal. We prefer diversity technique where the channel is highly selective. There are many diversity techniques of which we go for spatial diversity in this report. We consider the following assumption throughout the paper for wireless communication system under fading environment:

1. *Limited transmitter power:* The total transmitted power is restricted to be less than P, regardless of the number of transmitting antenna.

2. *Rayleigh fading channel:* The channel coefficients $h[l]$ are assumed to be follow Gaussian distribution with zero mean and unit variance.

3. *Spatially independent fading*: The channel coefficients $h_{ij}[l]$ at any given instant of time are independent of each other.

4. *Perfect CSI at the receiver*: The channel coefficients are known at the receiver side. In order to estimate the channel state with minimum error we consider this assumption under slow fading condition.

5. *Circularly symmetric complex Gaussian noise*. The signals are also corrupted by additive white Gaussian noise components $n_i[l]$ which are modelled as independent random variable of zero mean and variance of N_o in addition to fading.

3.1 Brief introduction

Multiple antennas are used at both the transmitter and receiver to improve the system performance in Rayleigh fading channel. This chapter deals with the technique of designing multiple antenna systems to exploring spatial diversity in order to improve the system performance by increasing the signal to noise ratio. Spatial diversity primarily focusses on the modification techniques in the receive side, with the aim of overcoming fading caused by multipath propagation.

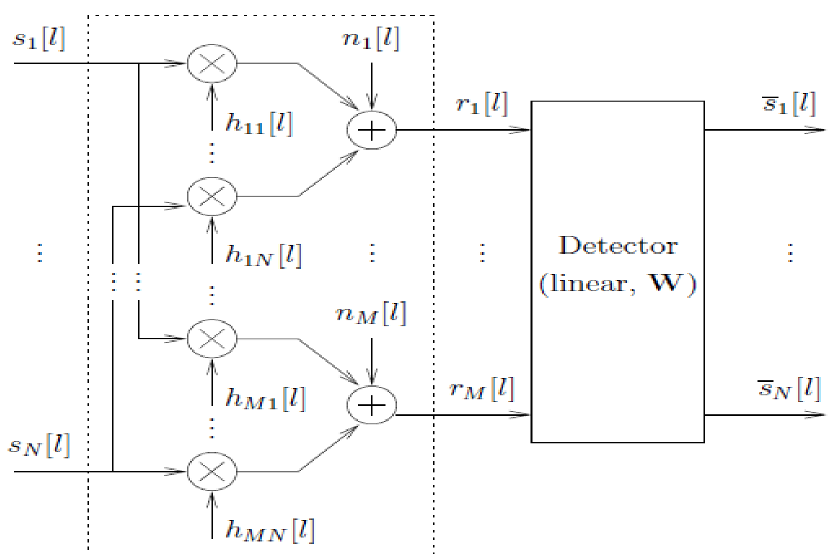


Figure 2 Block diagram of MIMO system

The above diagram represents a complex baseband communication system. We will have M receiving antennas and N transmitting antennas in MIMO systems which is defined by the following equation:

$$r = Hs + n \tag{3.1}$$

where s represents a N x1 vector of transmitted signal , r is a M x 1 vector of received signal and n represents Additive white Gaussian noise of dimension M x 1 . H is the channel matrix of order M x N, whose elements h_{ij} represents the complex fading coefficients. Depending on the applications being considered the broadband wireless channel can be categorized as frequency selective fading channel undergoing medium to high spatial correlation.

3.2 Spatial diversity

The variation in time, frequency or space results in signal fading in the channel which is a major challenge to a communication engineer. However these impairments are not necessarily harmful and we can take these variations in the channel impulse response as an advantage to increase the overall signal to noise ratio. For example, we transmit two identical signals into two different channels experiencing independent fading effects. The two copies of the same signal are received at the receiver and there is low probability that both these copies are severely affected than the case when only one copy of the signal is transmitted over the fading channel. Hence a better estimation of the transmitted signal can be done by combining both the copies of the received signal.

Thus the ides of diversity can be exploited to obtain reliable communication over a deep fading channel. Although diversity can be obtained in different ways but the desired result will be the same i., e to obtain reliable communication over fading channels.

The following standard assumptions were considered in this report as stated below for wireless communication channels:

1. Limited transmitter power: The total transmitted power is limited to be less than P, regardless of the number of transmitting antennas.

2. Rayleigh fading channel: The channel coefficients $h[l]$ follows Gaussian distribution with zero mean and unit variance.

3. Spatially independent fading: The coefficients $h_{ij}[l]$ are independent at any given instant of time.

4 Perfect CSI at the receiver: The receiver has perfect knowledge of the channel coefficients. Multiple antenna systems were deployed in wireless systems at the expense of processing complexity both at the transmitter and receiver in order to improve the system performance.

Spatial diversity deals with the receiver techniques in order to overcome fluctuations in the signal due to multipath propagation. Each copy of the given transmitted signal is transmitted into independent paths that results in statistically independent fading effects. We can obtain an improved signal by considering a weighted combination of the received copies.

3.2.1 Receive only diversity

We illustrate with a small example the advantage of receive diversity by taking into consideration a receiver employing Maximum ratio combining technique. Let us begin with a system having no diversity and then compare its performance with another system adopting the diversity technique in order to improve result without increasing transmitted power or bandwidth.

Figure 2 shows a SISO flat fading system with N = 1, M = 1 and an optimal SNR detector is shown. We apply Schwarz' Inequality to check the optimality of this detector. The received signal is given by

$$r[l] = h[l]s[l] + n[l] \tag{3.2}$$

and the detected signal is given by

$$r[l] \quad = h^{*}[l]s[l] + n[l];$$

$$= |h[l]|^{2}s[l] + n[l]; \tag{3.3}$$

where $|h[l]|^{2}|$ represents the magnitude of the channel. We can improve the performance of the detector by matching the channel response with the input signal to give maximum SNR.

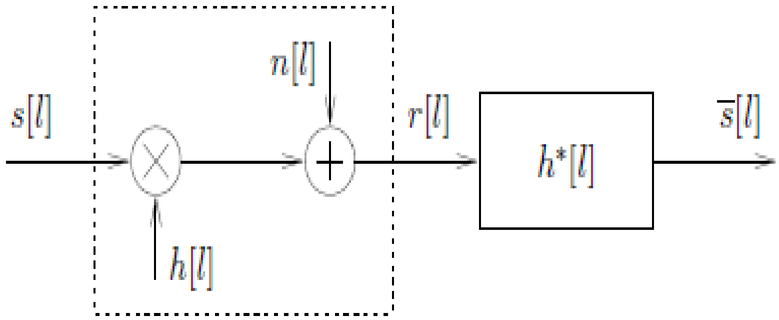


Figure 3. Optimal SNR detector in a SISO system

The conditional SNR of the SISO is given by

$$SNR = \frac{|\propto[l]s[l]|^2}{E|n[l]|^2}$$

$$= \rho|\propto[l]|^2 \quad (3.4)$$

where $\propto[l]$ is the magnitude of channel coefficients and $E|n[l]|^2$ is noise power and $\rho = \frac{P}{N}$ is SNR of the channel without fading. For a system employing Binary Phase Shift Keying modulation technique, the instantaneous bit error rate is given by

$$\text{BER (bpsk)} = Q\,(\sqrt{2\rho}\propto[l]) \quad (3.5)$$

The average bit error rate can be calculated as given below

$$<\text{BER}> = \int_0^\infty (BER)f(\alpha)d\alpha$$

$$=\int_0^{\infty} Q\,(\sqrt{2\rho} \propto [l])\; 2 \propto e^{-\propto^2}\, d\alpha$$

$$= \frac{1}{2}\left(1 - \sqrt{\left(\frac{\rho}{\rho+1}\right)}\right) \qquad (3.6)$$

At high SNR the above equation reduces to $\frac{1}{4\rho}$. We can say from the above equation that the SISO system has a diversity order of 1. Now considering the case of a Single input multiple output channels as shown in Figure 4 .The received signal along the i^{th} branch can be written as

$$r_i[l] = h_i[l]s[l] + n[l]; \qquad (3.7)$$

The SNR of each branch along the transmission path can be defined in a similar manner as

$$SNR_i = \rho\, \alpha_i^2[l] \qquad (3.8)$$

where $\rho = \frac{P}{N}$ is the SNR of the channel without fading and $\propto_i[l]$ is the magnitude of the channel coefficient $h_i[l]$.

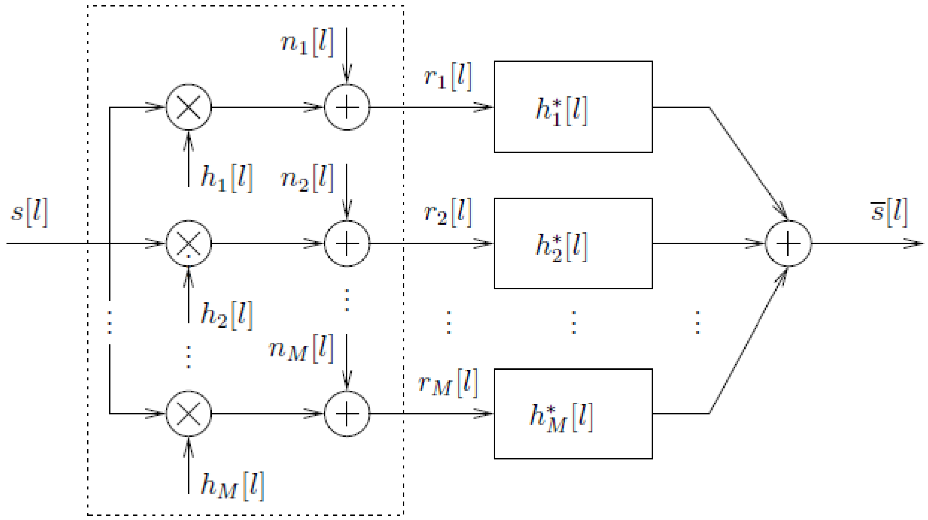


Figure 4. SIMO system with optimal MRC receiver

The received signal from each antenna can be linearly combined at the receiver to obtain the estimated signal which is given by

$$\overline{s}[l] = \sum_{i=1}^{M} c_i[l] r_i[l]$$

$$= \sum_{i=1}^{M} c_i[l] h_i[l] s_i[l] + n_i[l] \tag{3.9}$$

Given the channel coefficients $h_1[l], \ldots . h_M[l]$,the conditional SNR of the combined signal is given by

$$\text{SNR (SIMO)}, \propto_i [l] = 1, 2\ldots, \text{M} \quad = \frac{\left|\sum_{i=1}^{M} c_i[l] h_i[l] s_i[l]\ \right|^2}{E(\ \left|\sum_{i=1}^{M} c_i\ [l] n_i\ [l]\right|^2\ )}$$

$$= \rho \sum_{i=1}^{M} \alpha_i^2 [\text{l}]$$

$$= \mathrm{M}\,\overline{\rho}_{i|\alpha_{i(l)}} \tag{3.10}$$

where $\overline{\rho}_i$ represents the average branch. By setting the combining weights $c_i[\mathrm{l}] = h_i^*[\mathrm{l}]$ we can obtain an optimal SNR using the MRC technique.

The estimated signal is given by

$$\bar{s}[l] = \sum_{i=1}^{M} h_i^*\,[l]h_i[l]s[l] + \; n_i[l]$$

$$= \; s[l]\sum_{i=1}^{M} \propto_i^2\,[l] + \;\sum_{i=1}^{M} \propto [l]n_{i[l]} \tag{3.11}$$

and decoding will be done from this form.

With M = 2 and 4 , the bit error probabilities using MRC is given by the expression below

$$p_{M=2}, \rho = \frac{1}{2} - \frac{1}{2}\sqrt{\left(\frac{\rho}{\rho+1}\right)} - \frac{1}{4}\sqrt{}\left(\frac{\rho}{(\rho+1)^2}\right) \approx \frac{1}{8\rho^2} \tag{3.12}$$

$$p_{M=4}, \rho = \frac{1}{2} - \frac{1}{2}\sqrt{\left(\frac{\rho}{\rho+1}\right)} - \frac{1}{4}\sqrt{\left(\frac{\rho}{(\rho+1)^2}\right)} - \frac{3}{16}\sqrt{\left(\frac{\rho}{(\rho+1)^5}\right)} - \frac{15}{96}\sqrt{}\left(\frac{\rho}{(\rho+1)^7}\right) \approx \frac{1}{32\rho^4} \tag{3.14}$$

As $M \rightarrow \infty$ the performance of MRC approaches as that of the AWGN response.

3.2.2 Transmit only diversity

We go for receive diversity to improve the performance of wireless communication systems by deploying multiple antenna arrays at the base station where hardware size and cost are less important factors. The receive diversity could be used to enhance the uplink channel from the subscriber unit to the base station. A recent survey on signal processing operations on this subject can be found in [5].

Receive diversity is quite simpler than transmit diversity where copies of independently fading signals are obtained which are combined optimally in order to extract the originally transmitted signal. The major difference between transmit and receive diversity is that in the former case the signals are already combined when they reach the receiver and separating this mixture of signal at the receiver in an optimal way is a major challenge. Figure 5 shows a MISO system where we have multiple transmit antenna and single receive antenna.

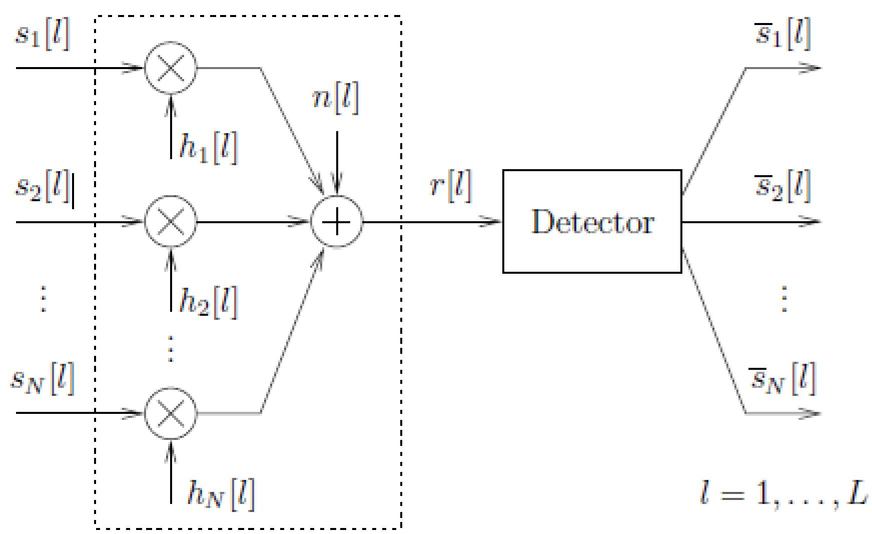


Figure 5 System diagram of a MISO channel

The received signal, assuming flat fading is given by

$$r[l] = \sum_{j=1}^{N} h_j\,[l]s_j\,[l] + n[l] \quad ,$$

Alamouti Space time block code is a fundamental transmit diversity technique which implements two transmit antenna and one receive antenna having the following code as described below[3] :

$$S = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}$$

$$\begin{bmatrix} r[1] \\ r[2] \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n[2] \end{bmatrix}$$

$$= \begin{bmatrix} x_1 h_1 + x_2 h_2 \\ -x_2^* h_1 + x_1^* h_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n[2] \end{bmatrix} \tag{3.15}$$

$$\begin{bmatrix} r[1] \\ r^*[2] \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n^*[2] \end{bmatrix} \tag{3.16}$$

The estimate of the transmitted symbol is calculated by considering the pseudo matrix of H defined as $H^{+} = (H^H H)^{-1} H^H$

The estimate of the transmitted signal is given by

$$\begin{bmatrix} \overline{x_1} \\ \overline{x_2} \end{bmatrix} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} r[1] \\ r^*[2] \end{bmatrix}$$

$$= (\propto_1^2+\propto_2^2)\begin{bmatrix}x_1\\x_2\end{bmatrix} + \begin{bmatrix}h_1^* & h_2\\h_2^* & -h_1\end{bmatrix} + \begin{bmatrix}n[1]\\n^*[2]\end{bmatrix}$$

$$= (\propto_1^2+\propto_2^2)\begin{bmatrix}x_1\\x_2\end{bmatrix} + \begin{bmatrix}\overline{n_1}[1] & \overline{n_2}[2]\\\overline{n_2}[1] & \overline{n_1}[2]\end{bmatrix} \quad (3.17)$$

where $\propto_1$ and $\propto_2$ are the magnitude of the first and second channel coefficients respectively. In this code two signals are transmitted using two transmitting antenna that is N=2 and $s_1[1] = x_1$,$s_1[2] = -x_2^*$, $s_2[1] = x_2$, $s_2[2] = x_1^*$, hence $|x_1|^2 + |x_2|^2 = |s_1|^2 + |s_2|^2$. The conditional SNR of space time Alamouti code given perfect knowledge about channel coefficient is known is given by

$$\text{SNR (Alamouti code)} = \frac{|(\propto_1^2+\propto_2^2)x|^2}{E(|\propto_{1n}+\propto_2 n\prime|)^2}$$

$$= \rho(\alpha_1^2 + \alpha_2^2) \quad (3.18)$$

where “n” and “n’ ” are independent random noise term .

3.2.3 Combined transmit and receive diversity

We can have both multiple antennas at the transmitting and receiving end in order to exploit the spatial diversity and such systems are called multiple input multiple output system abbreviated as MIMO systems. A MIMO system is as shown below with N transmit antenna and M receive antennas.

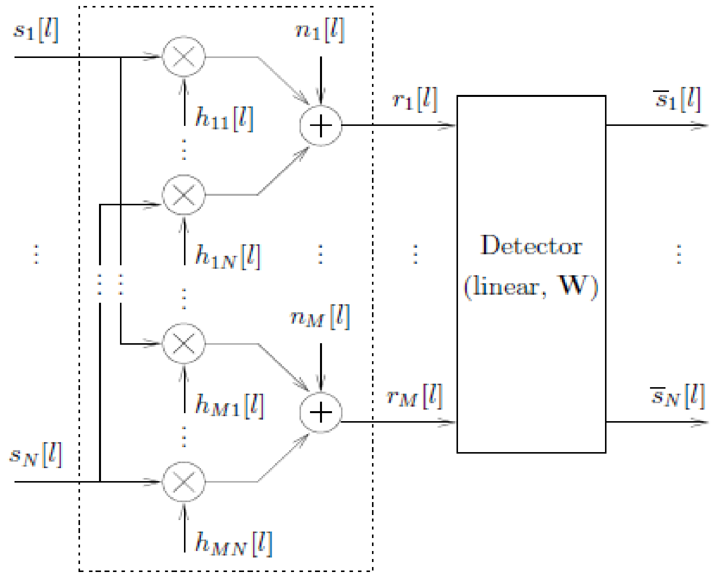


Figure 6 A MIMO system with N transmit antenna and M receive antenna

The received signal is given by$r = Hs + n$ where H is an M x N channel coefficient matrix. Here we assume the channel matrix H to be of full rank. We can extend Alamouti space time coding for two transmitter and two receiver system as given below:

$$S = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}$$

$$\begin{bmatrix} r_1[1] & r_2[1] \\ r_2[2] & r_2[2 \end{bmatrix} = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \end{bmatrix} + \begin{bmatrix} n[1] \\ n[2] \end{bmatrix}$$

$$\begin{bmatrix} r_1[1] \\ r_1^*[2] \\ r_2[1] \\ r_2^*[2] \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{12}^* & -h_{11}^* \\ h_{21} & h_{22} \\ h_{22}^* & -h_{21}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n^*[2] \\ n[1] \\ n^*[2] \end{bmatrix} \quad (3.19)$$

The decoded signal at the receiver is given by

$$\begin{bmatrix}\overline{x_1}\\\overline{x_2}\end{bmatrix} = \begin{bmatrix}h_{11}^* & h_{12} & h_{21}^* & h_{22}\\ h_{12}^* & -h_{11} & h_{22}^* & -h_{21}\end{bmatrix}\begin{bmatrix}r_1[1]\\ r_1^*[2]\\ r_2[1]\\ r_2^*[2]\end{bmatrix}$$

$$\begin{bmatrix}\overline{x_1}\\\overline{x_2}\end{bmatrix} = (\propto_{11}^2+\propto_{12}^2+\propto_{21}^2+\propto_{22}^2)\begin{bmatrix}x_1\\x_2\end{bmatrix} + \begin{bmatrix}\overline{n_{11}}[1] & \overline{n_{12}}[2] & \overline{n_{21}}[1] & \overline{n_{22}}[2]\\ \overline{n_{12}}[2] & \overline{n_{11}}[1] & \overline{n_{22}}[2 & \overline{n_{21}}[1]\end{bmatrix}\begin{bmatrix}\propto_{11}\\\propto_{12}\\\propto_{21}\\\propto_{22}\end{bmatrix} \tag{3.20}$$

We will see that with multiple diversity the performance in terms in terms of BER verses SNR ration give better result than that of either transmit or receive diversity I addition to increasing the diversity order which is 4 in this case. The optimal solution is achieved by applying the ordering given in [6].

Chapter 4#

Space-time coding

We can employ space-time coding in MIMO system in order to enhance the performance of the system. Initially we will study the relationship between different codes and then we will give a system based outlook of space-time transmission through common transmitter and receiver model.

A generalized system block diagram implementing space time coding is shown below:

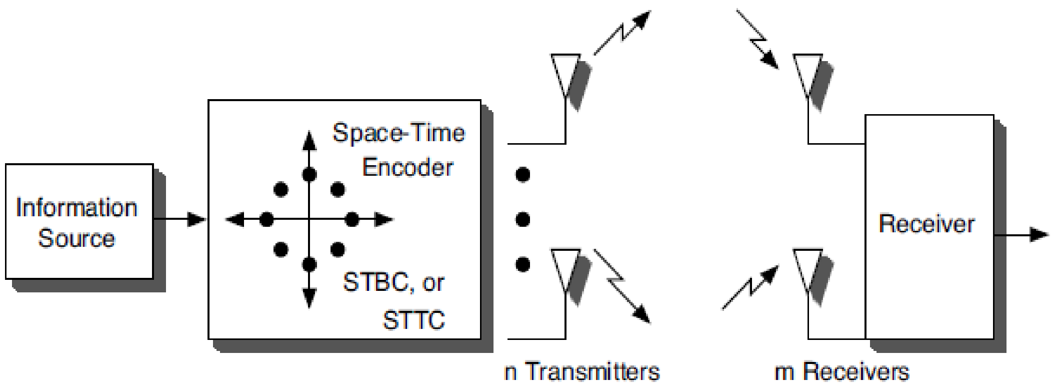


Figure 7. System block diagram

Let us consider a communications system where the base station is installed with n transmit antennas and the receiver unit is equipped with m receive antennas (see Figure (7)). At each time slot t, signals $x_t^i, i = 1, 2 \dots n$ are transmitted from n transmit antennas at the base station .At any time instant t, the signal received at antenna j that is r_t^j is given by

$$r_t^j = \sum_{i=1}^{n} h_{ij} x_t^i + n_t^j$$

Our aim is to improve the system performance by lowering the bit error rate at desired signal to noise ratio.in the following classes we will have a detailed study of the space tome coding.

4.1 Transmitter and receiver system models

Before going to space-time coding first of all we will express a clear mathematical framework, by presenting common system models for the space-time transmitter as shown in Figure 8.

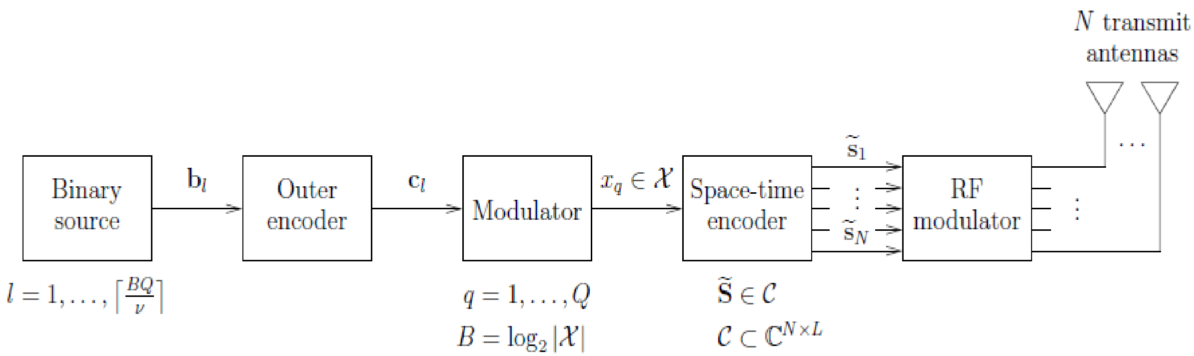


Figure 8 Space time transmitter

The space time transmitter includes a binary source, an outer encoder followed by a modulator whose output is given to the space time encoder. The output of the encoder is then RF modulated for transmission. The source generates $K\ bits$ data vectors. The function of the outer encoder is to carry out traditional error correction at a certain rate. The modulator is a bit-to-symbol mapper The output of the modulator is then fed to the space time encoder which converts the modulated symbols into vectors of certain length to be transmitted by the antennas.

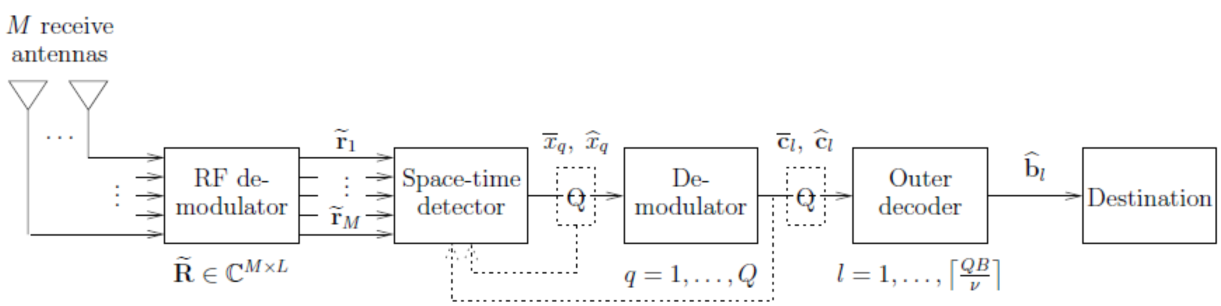


Figure 9 Space time receiver

Figure 9 represents a space time receiver which consists of a RF demodulator followed by a space time detector .The output of the detector is demodulated which is then decoded to give the estimated signal at the destination.

4.2 Overview of existing space-time techniques

Here we will focus on the important developments that have been done in space-time coding. Figure 10 exhibits various space time coding techniques with their application and area of research. The space time coding includes both transmit diversity and spatial multiplexing techniques. The transmit diversity includes space time block codes and space time trellis codes as shown in above figure. The spatial multiplexing technique involves layered architecture and threaded architecture. In this paper we will be working with space time block codes.

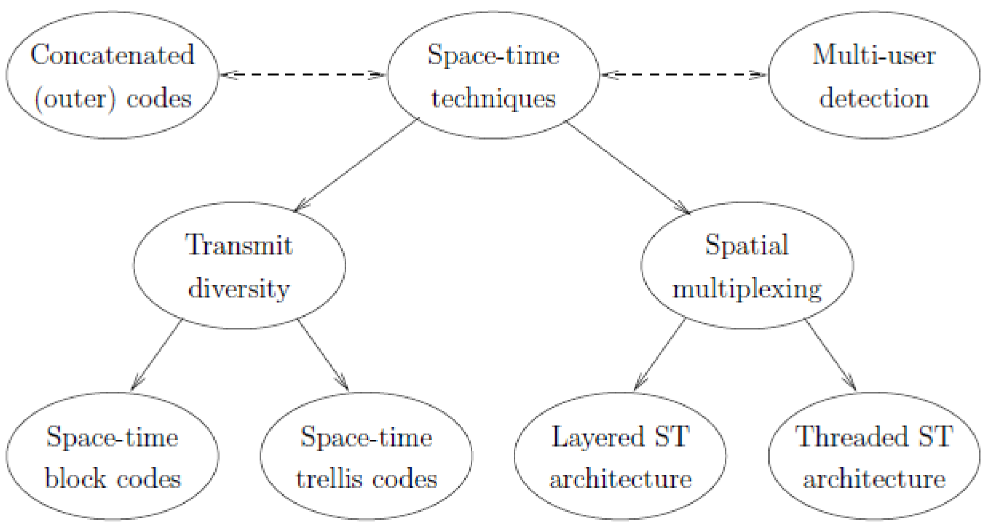


Figure 10 Classification of space-time coding techniques

4.3 Space-time block codes [8 , 9]

In space time block code we will be assuming flat fading channel where the coherence bandwidth of the channel is greater than the transmitted signal bandwidth. The Alamouti space time block code[7] is a simple coding scheme designs for a two antenna system. It further extended this coding scheme to the case of 2 transmit antennas and m receive antennas, and provides a diversity order of 2m. The Alamouti space time coding has following features:

1. There is no feedback from the receiver to the transmitter.
2. No extra bandwidth is required because redundancy is applied in space across multiple antennas, not in frequency or time domain.
3. The decoding at the receiver is simple

The following diagram represents a simple communication system implementing Alamouti space time coding.

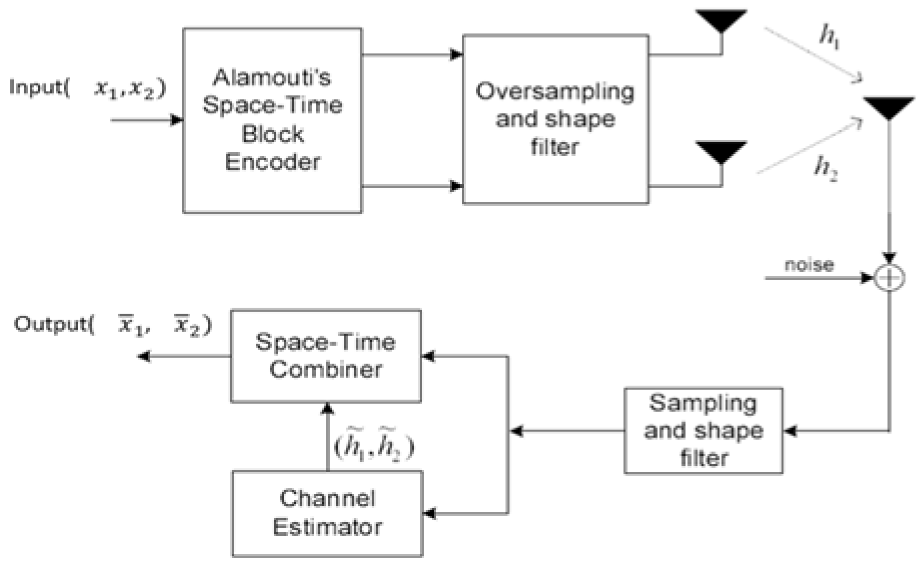


Figure 11 Block diagram of Alamouti STBC

Figure 11 represents the Aamouti space time coding where we have two inputs symbols x_1 , x_2 which are encoded and then oversampled. The over sampled symbols are further transmitted by two transmitting antennas into independent channels having channel response function $h_1 and$ h_2 .In addition to fading, the transmitted signals also get contaminated by additive white Gaussian noise. The received signal is first sampled and then the estimated signal is obtained.

Alamouti space time coding is a simple transmit diversity technique for wireless communication that offers a simple method for achieving spatial diversity with two transmit antennas. The scheme is as follows:

Consider that we have a transmission sequence, for example$\{x_1, x_2, x_3 \ldots . x_n\}$. In normal transmission, we will be sending $x_1$in the first time slot, x_2 in the second time slot, x_3 and so on. However, in Alamouti coding we group the symbols into groups of two. In the first time slot, send x_1 and x_2 from the first and second antenna. In second time slot send $-x_2{}^*$ and $x_1{}^*$ from the first and second antenna. In the third time slot send x_3 and $x_4$from the first and second antenna. In fourth time slot, send $-x_4{}^*$ and $x_3{}^*$ from the first and second antenna and so on. Though we are grouping two symbols, we still need two time slots to send two symbols. Hence, there is no change in the data rate.

Table 0-1

Time slot	Antenna 1	Antenna **2**
First time slot (t_1)	x_1	x_2
Second time slot (t_2)	$-x_2{}^*$	$x_1{}^*$
Third time slot(t_3)	x_3	x_4
Fourth time slot(t_4)	$-x_4{}^*$	$x_3{}^*$

Though we are grouping two symbols, we still need two time slots to send two symbols and hence there is no change in the data rate. We have considered the following assumption in Alamouti space time coding.

1. The channel is flat fading
2. The channel experience by each transmit antenna is independent from the channel experienced by other transmit antennas.

3. The channel follows Rayleigh distribution.

4. The channel experienced between each transmit to the receive antenna is randomly varying in time. However, the channel is assumed to remain constant over two time slots.

5. On the receive antenna, the noise has the Gaussian probability density function with

$$P(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-\mu)^2}{2\sigma^2}} \quad \text{with } \mu = 0 \text{ and } \sigma^2 = \frac{N_0}{2}$$

The Alamouti code is a fundamental space time code designed to implement multiple antenna at the transmitter to give better performance as that of maximum ratio combiner. The space time matrix is given by

$$S = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}$$

$$\begin{bmatrix} r[1] \\ r[2] \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n[2] \end{bmatrix}$$

$$= \begin{bmatrix} x_1 h_1 + x_2 h_2 \\ -x_2^* h_1 + x_1^* h_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n[2] \end{bmatrix}$$

$$\begin{bmatrix} r[1] \\ r^*[2] \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n[1] \\ n^*[2] \end{bmatrix} \quad (4.1)$$

The estimate of the transmitted symbol is calculated by considering the pseudo matrix of H defined as $H^+ = (H^H H)^{-1} H^H$

The estimate of the transmitted signal is given by

$$\begin{bmatrix}\overline{x_1}\\\overline{x_2}\end{bmatrix} = \begin{bmatrix}h_1^* & h_2\\h_2^* & -h_1\end{bmatrix}\begin{bmatrix}r[1]\\r^*[2]\end{bmatrix}$$

$$= (\propto_1^2+\propto_2^2)\begin{bmatrix}x_1\\x_2\end{bmatrix} + \begin{bmatrix}h_1^* & h_2\\h_2^* & -h_1\end{bmatrix} + \begin{bmatrix}n[1]\\n^*[2]\end{bmatrix}$$

$$= (\propto_1^2+\propto_2^2)\begin{bmatrix}x_1\\x_2\end{bmatrix} + \begin{bmatrix}\overline{n_1}[1] & \overline{n_2}[2]\\\overline{n_2}[1] & \overline{n_1}[2]\end{bmatrix} \tag{4.2}$$

where $\propto_1$ and $\propto_2$ are the magnitude of the first and second channel coefficients respectively. In this code two signals are transmitted using two transmit antenna that is N=2 and $s_1[1] = x_1$,$s_1[2] = -x_2^*$, $s_2[1] = x_2$, $s_2[2] = x_1^*$, hence $|x_1|^2 + |x_2|^2$ =$|s_1|^2 + |s_2|^2$. The conditional SNR of space time Alamouti code given perfect knowledge about channel coefficient is known is given by

$$\text{SNR (Alamouti code)} = \frac{|(\propto_1^2+\propto_2^2)x|^2}{E(|\propto_{1n}+\propto_2 n\prime|)^2}$$

$$= \rho(\alpha_1^2 + \alpha_2^2) \tag{4.3}$$

where “n” and “n’ ” are independent random noise term .Comparing this SNR with that of the SISO system we observer that there is a full diversity of 2.A coherent BPSK system communicating over the Rayleigh fading channel contaminated by Additive white Gaussian noise has the following instantaneous bit error rate using Alamouti Space time coding

$$p_{\propto_1,\propto_2}(\rho) = Q\left(\sqrt{2}\rho(\propto_1^2+\propto_2^2)\right)$$

$$= Q\left(\sqrt{2}\rho X_4^2\right) \quad (4.4)$$

where X_4^2 is a chi-squared random variable. We have to consider the same transmitted power as that of the others systems while comparing its performance with other systems. Under such scenario the transmitted power per antenna is be reduced by a factor of 2 and is given by

$$\text{SNR (Alamouti code)} = \frac{1}{2}\rho(\alpha_1^2 + \alpha_2^2) \quad (4.5)$$

The full diversity advantage can be achieved with N=2 transmitting antenna using the Alamouti code.The Alamouti code was selected for presentation here because of its simplicity and the ideas that it gives on transmit diversity. The figure 8 shows the simulation result for Alamouti space time code with transmit diversity.

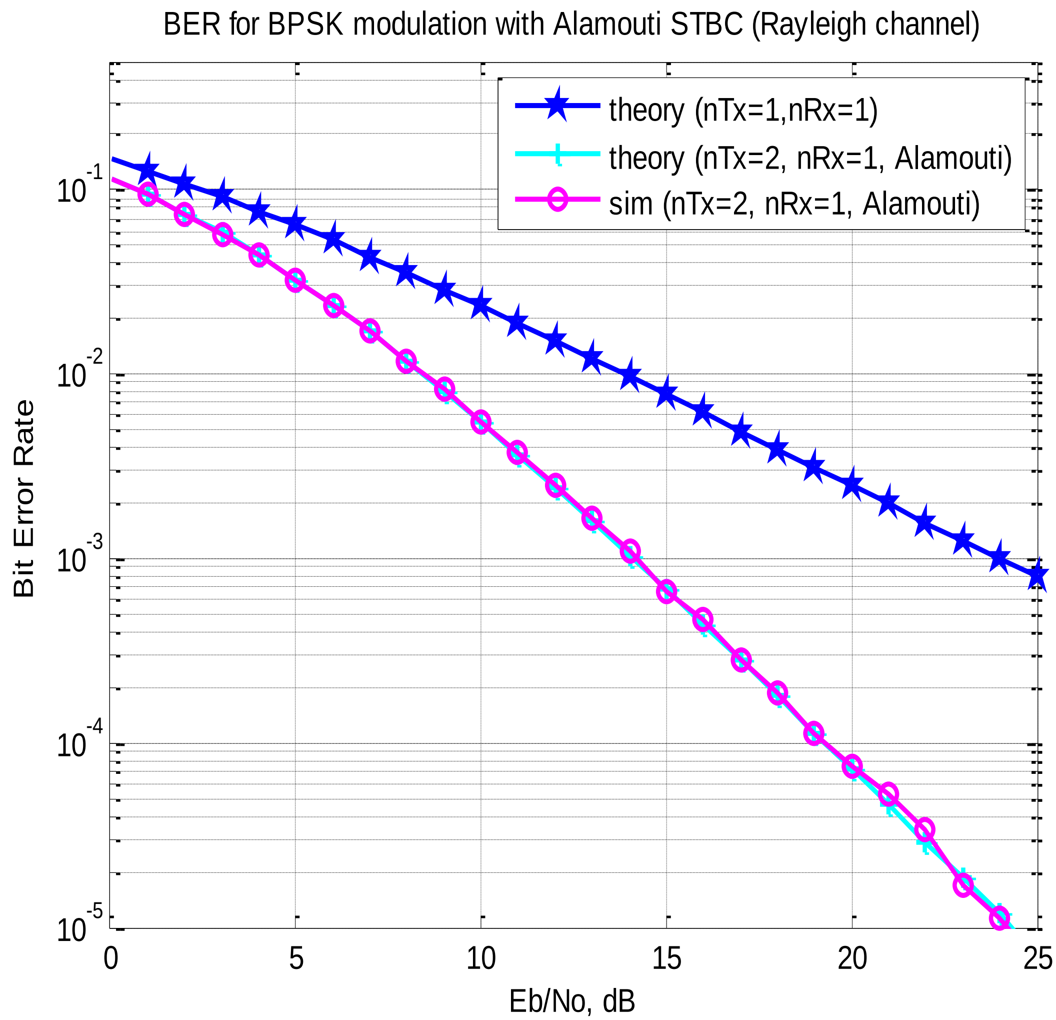


Figure 12 BER Vs SNR plot for Alamouti STBC

4.4 Maximum Ratio Combining (Receive Diversity)

Receiver diversity is another form of spatial diversity where we have multiple antennas at the receiver side. The interesting point in receive diversity is that we have to combine the signals received by different antenna and finally combing them in an efficient manner so as to get a better estimated signal. Maximum ratio combining involve receive diversity and here we have considered a Rayleigh fading channel and Binary phase shift keying (BPSK) modulation. The channel experience by each receive antenna is independent from the channel experienced by other receive antennas. On each receive antenna, the noise n has the Gaussian probability density function

$$P(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-\mu)^2}{2\sigma^2}} \quad \text{with } \mu = 0 \text{ and } \sigma^2 = \frac{N_0}{2}$$

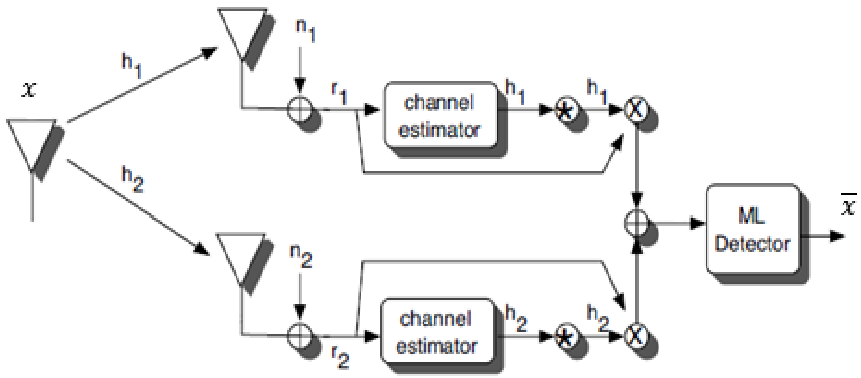


Figure 13 Maximum ratio combiner with 1Tx and 2 Rx antennas

Figure 9 shows the block diagram of a system employing Maximum ratio combining technique. Suppose we have N receive antennas and one transmit antenna in the system. The channels experienced by each receiving antenna are independent and are randomly varying in time. As the channel under consideration is a Rayleigh channel, the real and imaginary parts of are Gaussian distributed having zero mean and variance $\sigma^2 = \frac{1}{2}$. . In the presence of channel h_i , the instantaneous

$$\gamma = \frac{|h_i|^2 E_b}{N_o} \tag{4.6}$$

bit energy to noise ratio at receive antenna is given by

On the i_{th} receive antenna, the received signal is

$$y_i = h_i x + n_i \tag{4.7}$$

The received signal is in matrix form is given by,

$$y = hx + n \text{ , where} \tag{4.8}$$

$y = [y_1\, y_2 \ldots \ldots .. y_N]^T$ is the received symbol from all the receive antenna

$h = [h_1\, h_2 .... h_N]^T$ is the channel coefficient vector on all the receive antenna

x is the transmitted symbol, and

$n = [n_1\, n_2 \ldots . n_N]^T$ is the channel noise on all the receive antenna

We go for zero forcing detection to estimate the received signal and for that the equalizing symbol is taken as

$$\hat{x} = \frac{h^H y}{h^H H} = \frac{h^H hx}{h^H h} + \frac{h^H n}{h^H h} = x + \frac{h^H n}{h^H h}$$

Earlier, we noted that in the presence of channel h_i , the instantaneous bit energy to noise ratio at receive antenna is

$$\gamma_i = \frac{|h_i|^2 E}{N_o} \tag{4.9}$$

Now given that we are equalizing the channel with h^H , with the N receive antenna case, the effective bit energy to noise ratio is,

$$\gamma = \sum_{i=1}^{N} \frac{|h_i|^2 E_b}{N_o}$$

$$= \quad N\gamma_i \qquad (4.10)$$

Hence we conclude that the Effective bit energy to noise ratio in a N receive antenna case is N times the bit energy to noise ratio for single antenna case.

In this paper we have considered two receiving antenna and one transmitting antenna for MRC case. With two receiving antenna the received signals are given by

$$r_1 = h_1 x + n_1 \qquad (4.11\ )$$

$$r_2 = h_2 x + n_2 \text{ , and} \qquad (4.12)$$

the combined signal is given by

$$\overline{x} = h_1^* r_1 + h_2^* r_2$$

$$=(\propto_1^2 + \propto_2^2) x + h_1^* n_1 + h_2^* n_2 \qquad (4.13)$$

The simulation result in figure 10 shows that with an increase in the number of receiving antenna the SNR increases.

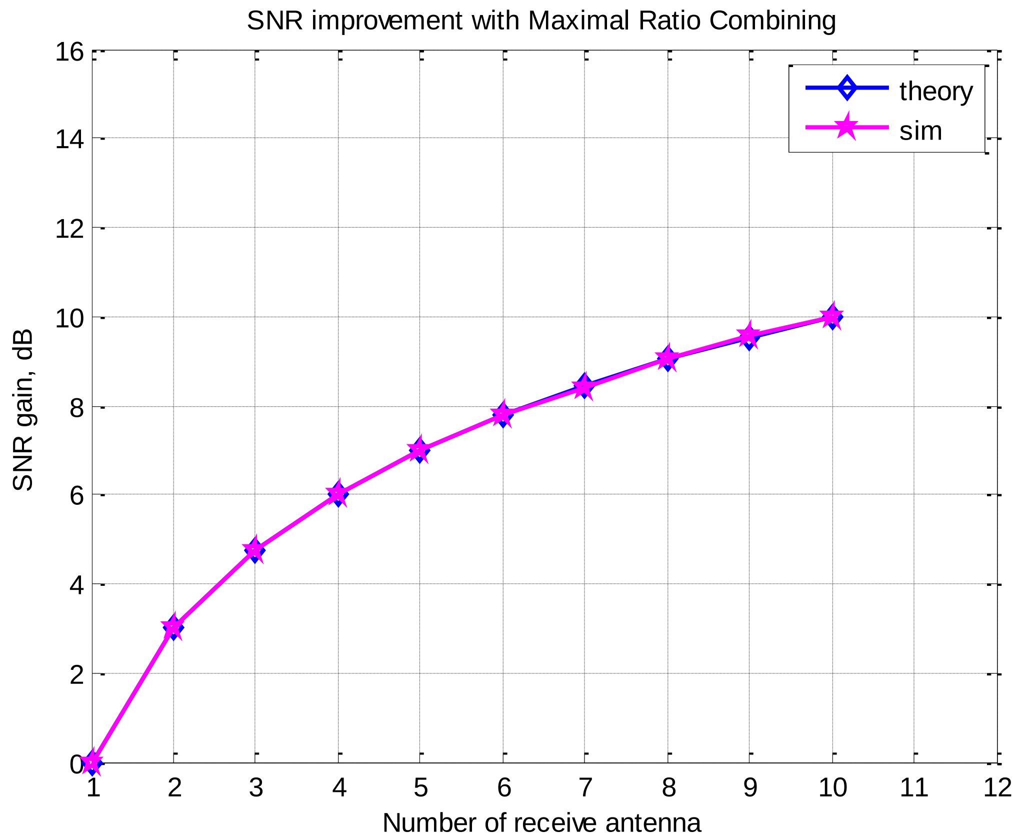


Figure 14 .SNR improvement with MRC

The simulation result shows in figure 11 plots the Bit error rate at different SNR values. If we go through the simulation we will find that the Bit error rate is 2×10^{-3} at an SNR of 10 db.

4.5 Error rate with Maximal Ratio Combining (MRC)

Let h_i be a Rayleigh distributed random variable, and then h_i^2 is a chi-squared random variable having two degrees of freedom. The pdf of γ_i is given by

$$p(\gamma_i) = \frac{1}{E_b/N_o} e^{\frac{-\gamma_i}{E_b/N_o}} \tag{4.14}$$

The effective bit energy to noise ratio γ is the sum of N random variables and is given by

$$p(\gamma) = \frac{1}{(N-1)!(E_b/N_o)^N} \gamma^{N-1} e^{\frac{-\gamma}{E_b/N_o}}, \; \gamma \geq 0 \tag{4.15}$$

If γ is effective Bit energy to noise ratio, the total Bit error rate is given by

$$P_e = \int_0^\infty \frac{1}{2} erfc(\sqrt{\gamma})\, p(\gamma) d\gamma$$

$$= \int_0^\infty \frac{1}{2} erfc(\sqrt{\gamma}) \frac{1}{(N-1)!(E_b/N_o)^N} \gamma^{N-1} e^{\frac{-\gamma}{E_b/N_o}} d\gamma \tag{4.16}$$

The above equation reduces to

$$P_e = p^N \sum_{k=0}^{N-1} \binom{N-1+k}{k} (1-p)^k, \text{ where} \tag{4.17}$$

$$p = \frac{1}{2} - \frac{1}{2}\left(1 + \frac{1}{E_b/N_o}\right)^{-1/2} \tag{4.18}$$

The simulation result for Maximum ratio combining is shown in figure 12. It can be estimated from the figure that the Bit error tare is 2×10^{-3} at an SNR of 10 dB.

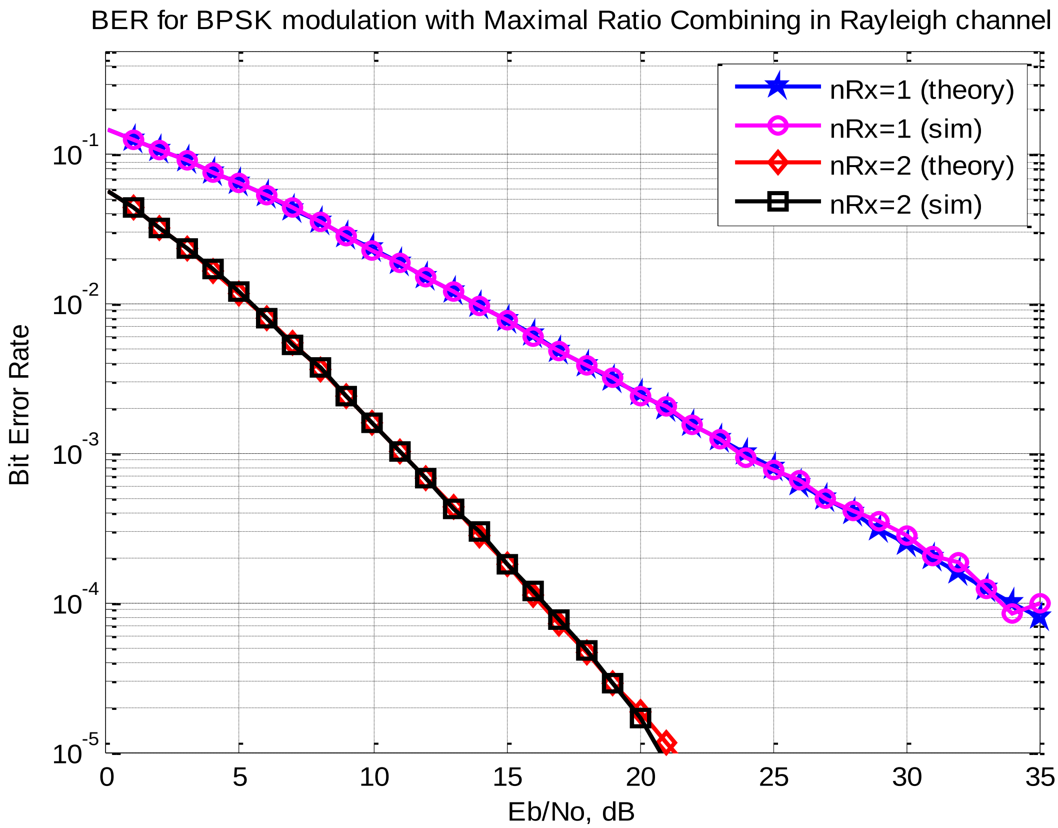


Figure 15 BER Vs SNR plot with Receive diversity

4.6 STBC with multiple diversity

So far we have considered transmit or receive diversity where we have multiple antennas either at the transmitter or receiver side. Now we will consider multiple diversity technique where we will be having multiple antennas at both the transmitter and receiver side and we will show that with multiple diversity a system gives better performance in terms of Bit error rate at a particular SNR.Figure 13 shows the block diagram of a MIMO system employing multiple antennas at the transmitter and receiver side. In this example we have taken two transmitting and receiving antennas.

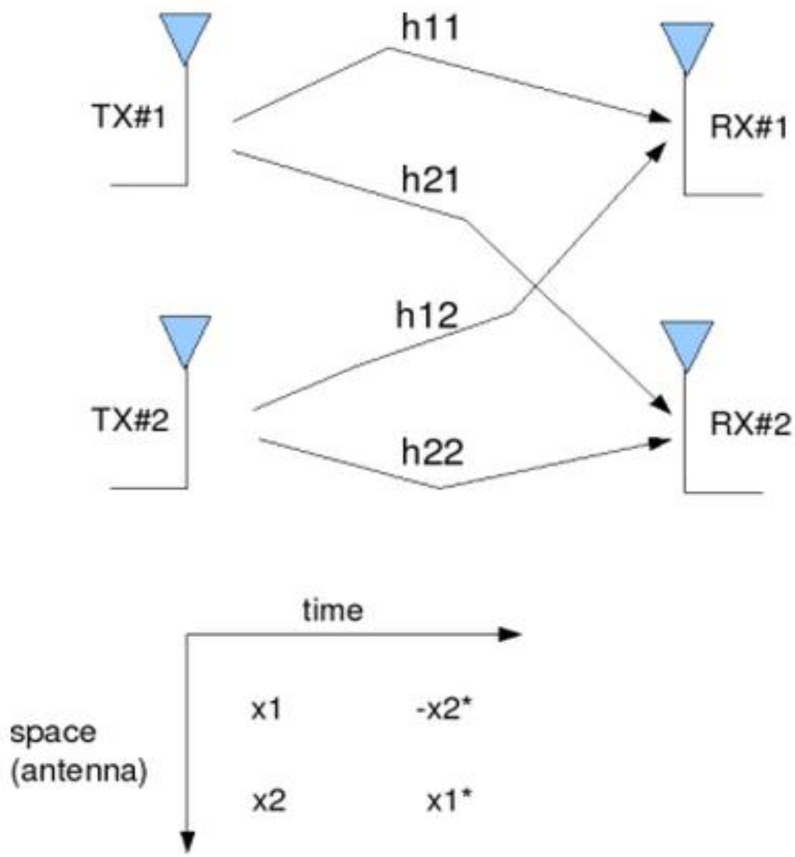


Figure 16. A MIMO system

We have taken the same assumption as in the previous. The received signal in the first time slot is given by,

$$\begin{bmatrix} {y_1}^1 \\ {y_2}^1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} {n_1}^1 \\ {n_2}^1 \end{bmatrix} \tag{4.19}$$

Assuming that the channel remains constant for the second time slot, the received signal is in the second time slot is given by,

$$\begin{bmatrix} {y_1}^2 \\ {y_2}^2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} -{x_2}^* \\ {x_1}^* \end{bmatrix} + \begin{bmatrix} {n_1}^2 \\ {n_2}^2 \end{bmatrix} \text{, where} \tag{4.20}$$

$\begin{bmatrix} {y_1}^1 \\ {y_2}^1 \end{bmatrix}$ is the received information at time slot 1 on receiving antenna 1, 2 respectively

$\begin{bmatrix} {y_1}^2 \\ {y_2}^2 \end{bmatrix}$ is the received information at time slot 2 on receiving antenna 1, 2 respectively

h_{ij} is the channel from i_{th} receive antenna to j_{th} transmit antenna,

$\begin{bmatrix} {n_1}^1 \\ {n_2}^1 \end{bmatrix}$ is the noise at time slot 1 on receive antenna 1, 2 respectively ,and

$\begin{bmatrix} {n_1}^2 \\ {n_2}^2 \end{bmatrix}$ is the noise at time slot 2 on receive antenna 1, 2 respectively.

Combining the equations at time slot 1 and 2 gives the following matrix equation

$$\begin{bmatrix} {y_1}^1 \\ {y_2}^1 \\ {y_1}^{2^*} \\ {y_2}^{2^*} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ {h_{12}}^* & -{h_{11}}^* \\ {h_{22}}^* & -{h_{21}}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} {n_1}^1 \\ {n_2}^1 \\ {n_1}^{2^*} \\ {n_2}^{2^*} \end{bmatrix} \text{, where} \tag{4.21}$$

the channel coefficient matrix, $H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ {h_{12}}^* & -{h_{11}}^* \\ {h_{22}}^* & -{h_{21}}^* \end{bmatrix}$

The estimate of the transmitted symbol is given by taking the pseudo inverse operation of the channel coefficient matrix, as given below

$$\begin{bmatrix} \widehat{x_1} \\ x_2 \end{bmatrix} = H^{+} \begin{bmatrix} {y_1}^{1} \\ {y_2}^{1} \\ {y_1}^{2^*} \\ {y_2}^{2^*} \end{bmatrix} \text{, where} \quad H = (H^H H)^{-1} H^H \tag{4.22}$$

The pseudo inverse matrix of the channel coefficient is defined by

$$H^{+} = (H^H H)^{-1} H^H \text{ , where}$$

$$(H^H H)^{-1} = \begin{bmatrix} \frac{1}{|h_{11}|^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2} & 0 \\ 0 & \frac{1}{|h_{11}|^2 + |h_{\frac{1}{2}}|^2 + |h_{21}|^2 + |h_{22}|^2} \end{bmatrix} \tag{4.23}$$

Now the estimate of the transmitted signal is given by

$$\begin{bmatrix} \widehat{x_1} \\ {x_2}^* \end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} {y_1}^{1} \\ {y_2}^{1} \\ {y_1}^{2^*} \\ {y_2}^{2^*} \end{bmatrix} + (H^H H)^{-1} H^H \begin{bmatrix} {n_1}^{1} \\ {n_2}^{1} \\ {n_1}^{2^*} \\ {n_2}^{2^*} \end{bmatrix} \tag{4.24}$$

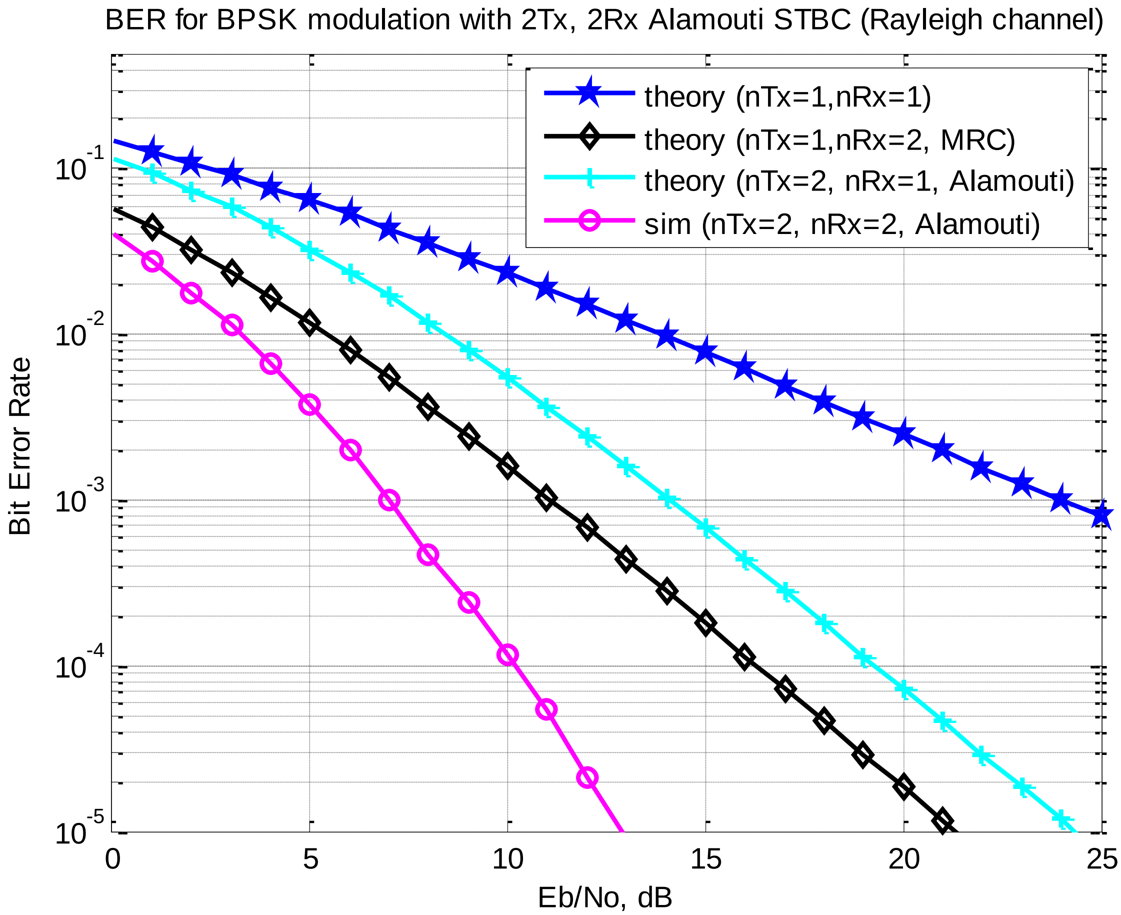


Figure 17 Simulation of a MIMO system

Figure17 shows the performance of a system involving multiple diversity and we can see from the simulation result that the Bit error is 10^{-4} at an SNR of 10 dB

Chapter 5#

Result and Analysis

5.1 Comparison of results

5.1.1 Performance of Alamouti STBC and MRC

From figure 18 and 19 we see that a system with MRC gives better performance in terms of Bit error rate than that of a system employing Alamouti space time coding . The Alamouti space time code gives a bit error rate of 5×10^{-3} whereas the MRC gives a bit error rate of 2×10^{-3} at an SNR of 10 db. We see that at low SNR a system with MRC giving low bit error rate than a system employing Alamouti space time coding, which is very important for a channel undergoing deep fading.

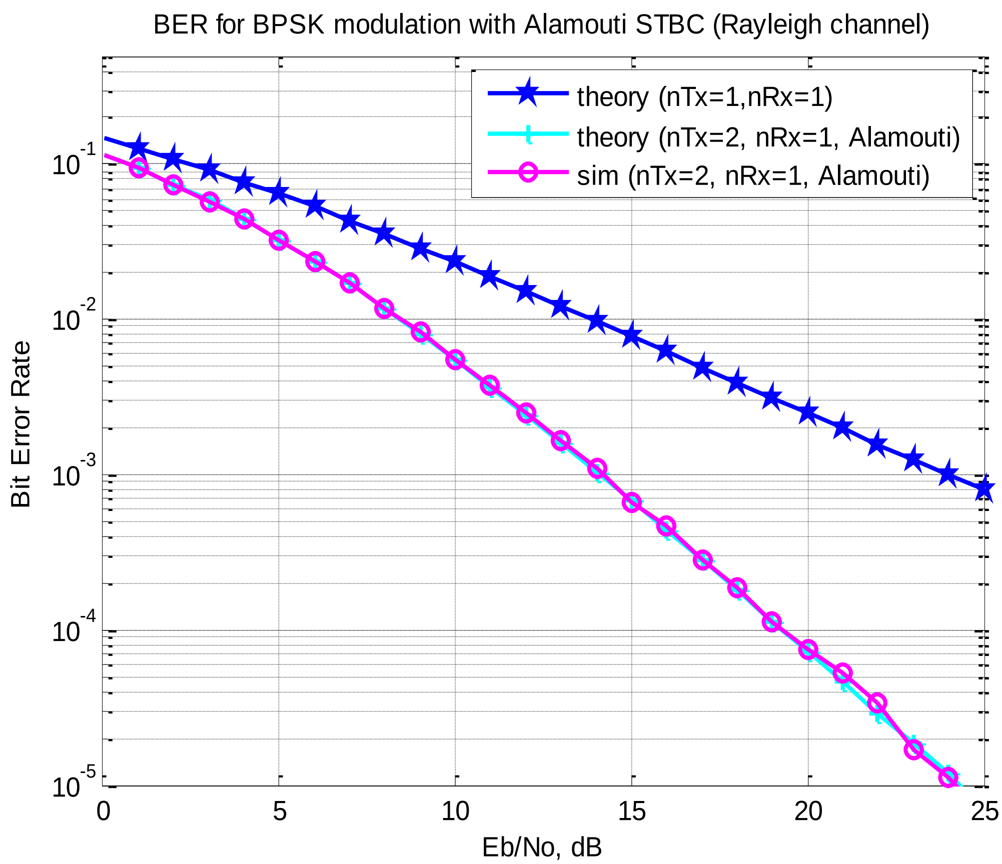


Figure 18 Alamouti STBC

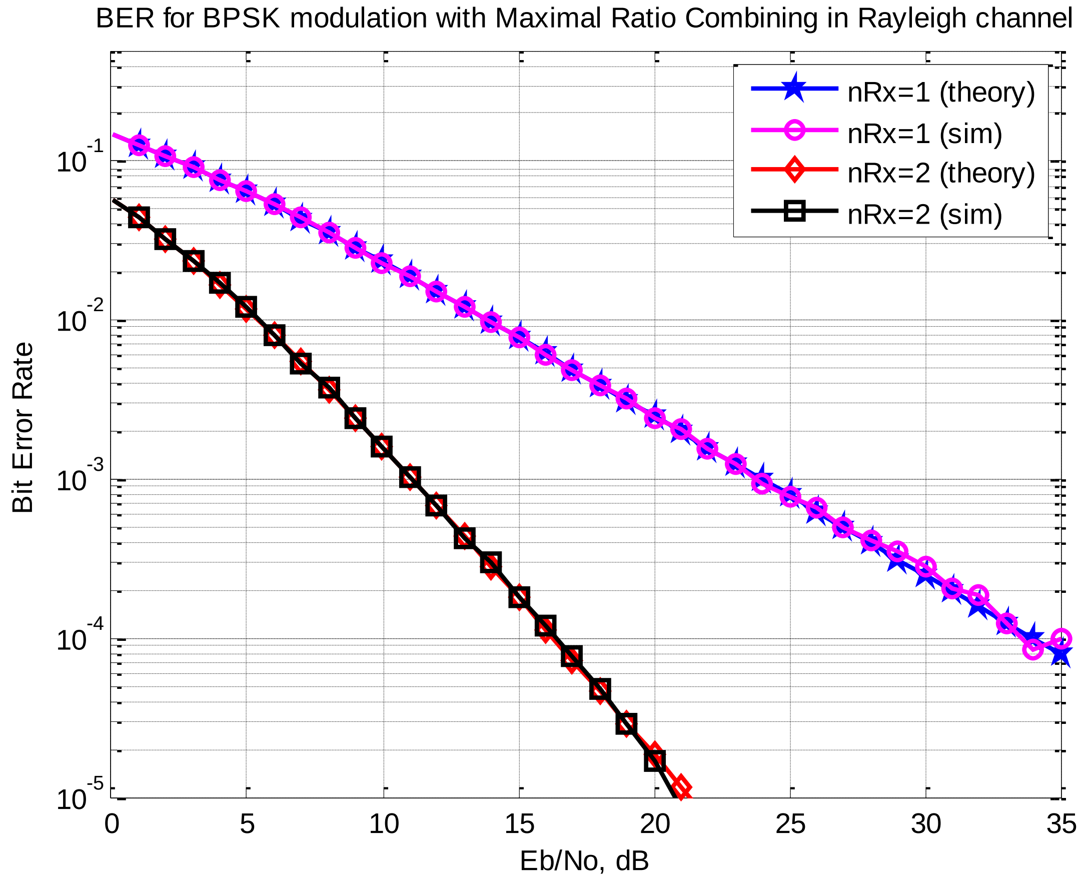


Figure 19 MRC

5.1.2 Performance of Multiple diversity system and MRC

From Figure 20 and Figure 21 we see that a system with Multiple transmit and receive antennas (MIMO) gives better performance in terms of Bit error rate than a system employing MRC technique . The MIMO system gives a bit error rate of 10^{-4} whereas the MRC case gives a bit error rate of 2×10^{-3} at an SNR of 10 db. We see that at low SNR a MIMO system gives low bit error rate than a system employing MRC, which is very important under deep fading condition We can see clearly that there is a diversity order of four instead of two in the previous case where either transmit or receive diversity is implemented. . The simulation result of both the cases is given in fig15 (a) and (b).

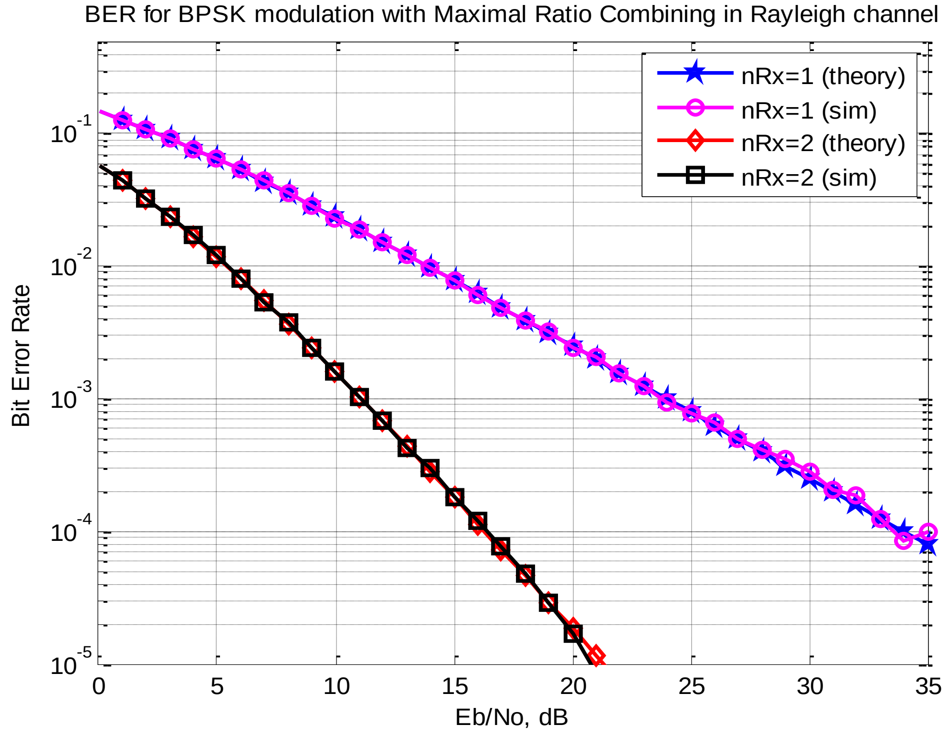


Figure 20 MRC

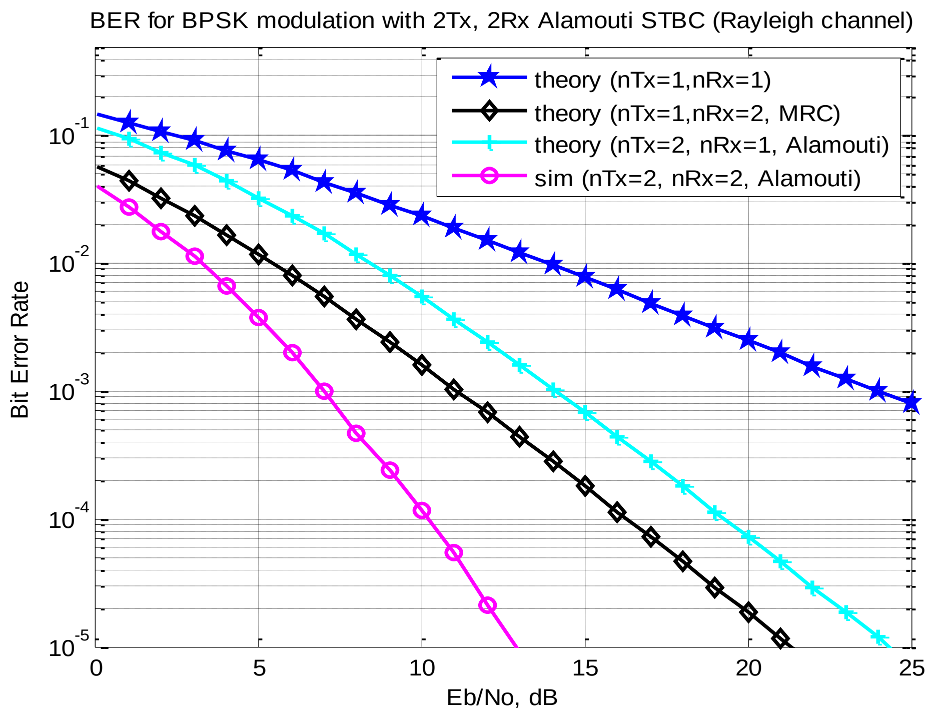


Figure 21 MIMO

A comparison between the above three cases is shown in a Tabular form as shown below.

System	BER at SNR of 10dB
Alamouti STBC (2Tx,1Rx)	5×10^{-3}
MRC (1Tx,2Rx)	2×10^{-3}
MIMO (2Tx, 2Rx)	1×10^{-4}

1. *Comparison between MRC and Alamouti STC.*

Ratio of BER of MRC and Alamouti at an SNR of 10 dB is,

$$\frac{BER_{Alamouti}}{BER_{MRC}}(SNR = 10dB) = \frac{5 \times 10^{-3}}{2 \times 10^{-3}} = 2.5\ (\approx 3.9\ dB) \tag{5.1}$$

So, with MRC we get almost 3.9 dB better performance than Alamouti STC.

2. Comparison between MIMO and MRC

Ratio of BER of MIMO and MRC at an SNR of 10 dB is,

$$\frac{BER_{MRC}}{BER_{MIMO}}(SNR = 10dB) = \frac{2 \times 10^{-3}}{1 \times 10^{-4}} = 20\ (\approx 13\ dB) \tag{5.2}$$

So, with MIMO we get almost 13 dB better performance than MRC.

Conclusion

We explored a new family of codes known as Space–Time codes for transmission in wireless Rayleigh fading channel using using multiple antennas at either the transmitter or receiver side.. Many subfamilies of space–time codes were also introduced. We analyze the performance of these codes and a comparison between them is made. Space–time codes can be readily implemented in DSP and VLSI due to their simplicity in architecture and design. In addition to the performance of these codes we have also studied the diversity feature of each code. Spatial diversity[10] is a key commodity which must be used as efficiently as possible to support reliable communicating in deep fading channels with better bandwidth efficiency and best quality of service. It has been shown that Multiple diversity performs well with low Bit error rate than either transmit or receive diversity at low Signal to Noise ratio (SNR).Further research in the field of space–time coding technology with other techniques such as orthogonal frequency division multiplexing , array processing , and numerous other topics is now being pursued.

Future work

The Space Time Coding could be implemented in distributed networks along with the Randomization technique where each node of the network transmit an independent, random linear combination of the columns of a space time code matrix, irrespective of the number of cooperative node. This approach enables a novel design of the methodology to decentralize the relay transmission and yet obtain the same diversity as that of multi antenna system. A distributed architecture is advantageous in that there is no single point of failure, with the potential for continuous operation in the presence of individual terminal or node failures. We can also apply the STC to frequency selective channels.

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