COMPARATIVE ANALYSIS OF BER AND SNR BY USING MULTIPLE CHANNELS AND STBC CODE FOR MIMO

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Abstract—The paper presents the comparative analysis of Space-Time Block Codes (STBC) used in Multiple-Input Multiple-Output (MIMO) systems to assure transmit diversity. The receive diversity is resolved with a Maximum Ratio Combining technique. For a fixed number of transmit antennas, the performances of different STBC codes are analyzed in terms of Bit Error Rate (BER) and SNR for a quasi-static Rayleigh flat fading channel. Finally, it is shown that by increasing the number of transmit/receive antennas, the system performances increase, and also error performance analysis of multiple rate space-time-block code (STBC) for MIMO wireless network. The design aspect of wireless system aims at improvement in spectral efficiency and coverage area with reliable performance. This necessitates that the MIMO system must be capable to overcome data rate limitation and there must have options open for future improvement. Error performance and spectral efficiency can further be improved by incorporating STBC with MIMO system. Recently many researchers have been working on MIMO systems with STBC to improve the performance of system without additional bandwidth or transmit power requirements. We have considered here the STBC schemes in Rayleigh fading environment using various combinations of numbers of transmit and receive antennas. The simulations results have been obtained in MATLAB platform.

I. INTRODUCTION

In modern wireless communication systems like 3G, 4G, WLAN and Wi-MAX, the multipath propagation channels modeled as a Multiple-Input Multiple-Output (MIMO) system. In order to combat the effects of multipath fading and to increase the capacity and reliability of the wireless channel, a practical solution is the spatial diversity, using multiple antennas at one or both sides of the link. For MIMO systems, the knowledge of channel State Information (CSI) at the transmitter (CSIT) and at the receiver(CSIR) is the primordial criterion for choosing a diversity technique. At the receiver, if the channel is unknown it can be estimated using different techniques sowed suppose that we always have CSIR. At the transmitter, if the channel is known (with CSIT) then beam forming techniques are used to assure both the diversity gain and the array gain; if the channel is not known (without CSIT) then Space-Time (ST) codes are used to assure only the diversity gain. The ST codes are a more general class of error correcting codes, with a spatial-temporal structure, the control symbols being inserted in both spatial and Foschini introduces the multi-layered space-time architecture, known as Bell Labs Layered Space-Time (BLAST). Later, in [6] are proposed the Space-Time Trellis Codes (STTrC) which provide the best tradeoff between constellation size, data rate, diversity gain and trellis complexity, but with a greater decoding complexity. Addressing the last issue, Alamouti introduced in [10] a simple diversity scheme for two transmit antennas, which provides a maximum diversity gain and no coding gain for a minimum decoding complexity. Later, the Alamouti code was generalized for an arbitrary number of transmit antennas by Tarokh et al.as the Space-Time Block Code (STBC) [7].

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. Over 700 million people around the world subscribe to existing second and third generation cellular systems supporting data rates of 9.6 kbps to 2Mbps. More recently, IEEE 802.11 wireless LAN networks enable communication at rates of around 54Mbps and have attracted more than 1.6 billion USD in equipment sales. Over the next ten years, the capabilities of these technologies are expected to move towards the 100 Mbps - 1 Gbps range and to subscriber numbers of over two billion. At the present time, the wireless communication research community and industry discuss standardizations for the fourth mobile generation (4G). 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.

MIMO stands for multiple-input multiple-output and means multiple antennas at both antenna ends of a communication system, i.e., at the transmitter and at the receiver side. The multiple-antennas at the transmitter and/or at the receiver in a wireless communication link open a new dimension in reliable communication, which can improve the system performance substantially. 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 [5], [7]. One essential problem of the wireless channel is fading, which occurs as the signal follows multiple paths between the transmitter 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.

Several transmission schemes have been proposed that utilize the MIMO channel in different ways, e.g., spatial multiplexing, space-time coding or beam forming. Space-time coding (STC), introduced first by Tarokh at el. [6], is a promising method where the number of the transmitted code symbols per time slot are equal to the number of transmit antennas. These code symbols are generated by the space-time encoder in such a way that diversity gain, coding gain, as well as high spectral efficiency are achieved. 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), space-time turbo trellis codes and layered space-time (LST) codes. A main issue in all these schemes is the exploitation of redundancy to achieve high reliability, high spectral efficiency and high performance gain. The design of STC amounts to find code matrices that satisfy certain optimality criteria. In particular, STC schemes optimize a trade-off between the three conflicting goals of maintaining a simple decoding algorithm, obtaining low error probability, and maximizing the information rate. In the last few years the research community has made an enormous effort to understand space-time codes, their performance and their limits. The purpose of this work is to explain the concept of space-time block coding in a systematic way. This thesis provides an overview of STBC design principles performance. The main focus is devoted the comparisons of BER Vs SNR for QPSK & QAM-16. Our goal is to provide a unified theory of STBCs for different transmit antennas and different receive antenna and to analyze their performance on different MIMO channels, using multiple channels i.e. AWGN and Rayleigh flat fading channels.
II. OBJECTIVE

Finding BER for STBC system for different Modulations, different channels and for number of transceivers.

a) BER for QPSK and QAM-16.
b) SNR Vs BER for AWGN and Rayleigh flat fading channel.
c) SNR Vs BER for different number of transmitter and receivers.

III. BLOCK DIAGRAM

3.1 Transmitter
3.1.1 Inter-leaving

Inter-leavers are designed and used in the context of characteristics of the errors that might occur when the message bits are transmitted through a noisy channel. To understand the functions of an inter-leaver understanding of error characteristics is essential. Two types are errors concern communication system design engineer. They are burst error and random error. Interleaving is a technique for making forward error correction more robust with respect to burst errors.

An interleaver permutes symbols according to a mapping. Interleaving can be useful for reducing errors caused by burst errors in a communication system.

a) Random Errors:
Error locations are independent of each other. Error on one location will not affect the errors on other locations. Channels that introduce these types of errors are called channels without memory (since the channel has no knowledge of error locations since the error on location does not affect the error on another location)

b) Burst Errors:
Errors are depended on each other. For example, in channels with deep fading characteristics, errors often occur in bursts (affecting consecutive bits). That is, error in one location has a contagious effect
on other bits. In general, these errors are considered to be dependent and such channels are considered to be channels with memory.

One of the most popular ways to correct burst errors is to take a code that works well on random errors and interleave the bursts to “spread out” the errors so that they appear random to the decoder. There are two types of interleavers commonly in use today, block interleavers and convolution interleavers.

The block interleaver is loaded row by row with L code words, each of length n bits. These L codeword’s are then transmitted column by column until the interleaver is emptied. Then the interleaver is loaded again and the cycle repeats. At the receiver, the code words are deinterleaved before they are decoded. A burst of length L bits or less will cause no more than 1 bit error in any one codeword. The random error decoder is much more likely to correct this single error than the entire burst. The parameter L is called the interleavers degree, or interleavers depth. The interleavers depth is chosen based on worst case channel conditions. It must be large enough so that the interleaved code can handle the longest error bursts expected on the channel. The main drawback of block interleavers is the delay introduced with each row-by-row fill of the interleavers.

In practice, interleaving is one of the best burst-error correcting techniques. In theory, it is the worst way to handle burst errors. Why? From a strict probabilistic sense, we are converting “good” errors into “bad” errors. Burst errors have structure and that structure can be exploited. Interleavers “randomize” the errors and destroy the structure. Theory differs from reality, however. Interleaving may be the only technique available to handle burst errors successfully.

For example, Viterbi showed that, for a channel impaired by a pulse jammer, exploiting the burst structure is not enough. Interleaving is still required. This does not mean that we should be careless about our choice of code and take up the slack with long interleavers. Codes designed to correct burst errors can achieve the same performance with much shorter interleavers. Until the coding theorists discover a better way, interleaving will be an essential error control coding technique for bursty channels.

3.1.2 Error Correcting Codes
An error-correcting code is an algorithm for expressing a sequence of numbers such that any errors which are introduced can be detected and corrected (within certain limitations) based on the remaining numbers. The study of error-correcting codes and the associated mathematics is known as coding theory.

Error detection is much simpler than error correction and one or more "check" digits are commonly embedded in credit card numbers in order to detect mistakes. Early space probes like Mariner used a type of error-correcting code called a block code, and more recent space probes use convolution codes. Error-correcting codes are also used in CD players, high speed modems, and cellular phones. Modems use error detection when they compute checksums, which are sums of the digits in a given transmission modulo some number. The ISBN used to identify books also incorporates a check digit.

3.1.3 Modulation:
Modulation is a process of mixing a signal with a sinusoid to produce a new signal. This new signal, conceivably, will have certain benefits over an un-modulated signal.

\[ f(t) = A \sin(\omega t + \varphi) \]

We can see that this sinusoid has 3 parameters that can be altered, to affect the shape of the graph. The first term, A, is called the magnitude, or amplitude of the sinusoid. The next term, \( \omega \) is known as
the frequency, and the last term, $\phi$ is known as the phase angle. All 3 parameters can be altered to transmit data.

The sinusoidal signal that is used in the modulation is known as the carrier signal, or simply "the carrier". The signal that is used in modulating the carrier signal(or sinusoidal signal) is known as the "data signal" or the "message signal". It is important to notice that a simple sinusoidal carrier contains no information of its own.

In other words we can say that modulation is used because some data signals are not always suitable for direct transmission, but the modulated signal may be more suitable.

a) QPSK Modulation
b) QAM-16

3.1.4 Space–time block coding (STBC)

Space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the assorted received versions of the data to improve the reliability of data-transfer.

The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact, space–time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.

Space-time block codes (STBC) are a generalized version of Alamouti scheme, but have the same key features. These codes are orthogonal and can achieve full transmit diversity specified by the number of transmit antennas. In other words, space-time block codes are a complex version of Alamouti’s space-time code, where the encoding and decoding schemes are the same as there in the Alamouti space-time code on both the transmitter and receiver sides. The data are constructed as a matrix which has its columns equal to the number of the transmit antennas and its rows equal to the number of the time slots required to transmit the data. At the receiver side, the signals received are first combined using maximum ratio combiner and the send to MMSE and the demodulation of QPSK and QAM-16.

Space-time block codes were designed to achieve the maximum diversity order for the given number of transmit and receive antennas subject to the constraint of having a simple linear decoding algorithm. This has made space-time block codes a very popular and most widely used scheme. Training-based methods [4] seem to give very good results on the performance of channel estimation at the receiver. The comparison have been referred to SNR is high than the BER and result is very clearly getting. Pure training-based schemes can be considered as an advantage when an accurate and reliable MIMO channel needs to be obtained. However, this could also be a disadvantage when bandwidth efficiency is required. This is because pure training-based schemes reduce the bandwidth efficiency considerably due to the use of a long training sequence which is necessarily needed in order to obtain a reliable MIMO channel estimate. Because of the computation complexity of blind and semi-blind methods, many wireless communication systems still use pilot sequences to estimate the channel parameters at the receiver side.

We consider a general MIMO system with $NT$ transmits antennas and $NR$ receives antennas, employing a space-time encoder, a MIMO channel with $NT$ inputs and $NR$ outputs and a space-time decoder with MRC technique and MMSE.
a) The Space-Time Encoder:
The simplest transmit diversity scheme for two transmit antennas is the Alamouti code, described by the transmission matrix:

\[
G = \begin{bmatrix}
x_1 & x_2 \\
-x_2^* & x_1^*
\end{bmatrix}
\]

To transmit \(m\) bits/channel use we use a modulation that maps every \(m\) bits to one symbol from a real or complex constellation with \(M = 2^m\) symbols, for example PSK or QAM. The transmitter picks two symbols from the constellation, for example, \(x_1\) and \(x_2\). In the first time slot \(t_1\), the first antenna transmits the symbol \(x_1\) and the second antenna the symbol \(x_2\). Then, in the second time slot \(t_2\), the symbols \(-x_2^*\) and \(x_1^*\) are transmitted simultaneously from the two antennas. Both symbols \(x_1\) and \(x_2\) are spread over two transmit antennas and over two time slots (see Fig. 4). At the transmitter, we do not know the channel (without CSIT), so we suppose an equal transmit power for each antenna and a unitary total transmit power.

b) The Space-Time Coded MIMO Channel:
The transmitted symbols over the MIMO channel are affected by severe magnitude fluctuations and phase rotations.

\[
y_{11} = h_{11} x_1 + h_{12} x_2 + n_{11}, \\
y_{12} = -h_{11} x_2^* + h_{12} x_1^* + n_{12}, \\
y_{21} = h_{21} x_1 + h_{22} x_2 + n_{21}, \\
y_{22} = -h_{21} x_2^* + h_{22} x_1^* + n_{22},
\]

\[\text{Figure 2.5 A particular MIMO 2x2 system with Alamouti coding and MRC&MMSE}\]

Where \(h_{ij}\) is the path gain between the \(j^{th}\) transmit antenna and the \(i^{th}\) receive antenna. The term \(n_{ij}\) is the additive noise for the \(i^{th}\) receive antenna at the \(j^{th}\) time slot, modeled as independent complex Gaussian random variables with zero-mean and variance \(1/(2\text{SNR})\) per complex dimension, where \(\text{SNR}\) is the signal to noise ratio of the channel.

3.2 Channel

3.2.1 Rayleigh fading channel
The delays connected with different signal paths in a multipath fading channel change in an unpredictable manner and can only be characterized statistically. When there are a large number of paths, the central limit theorem can be applied to model the time-variant impulse response of the
channel as a complex-valued Gaussian random process. When the impulse response is modeled as a zero mean complex-valued Gaussian process, the channel is said to be a Rayleigh fading channel.

The article gives a quick overview of a simple statistical multipath channel model called Rayleigh fading channel model.

We assume a quasi-static flat fading Rayleigh channel, with coherence time $T_c$. For a flat fading channel, the fading coefficients $h_{ij}$ remain constant within a frame of length $T_c$ time slots and change into new ones from frame to frame. Also, we assume uncorrelated path gains (the distance between two antennas is more than half of the wavelength) which vary independently from one frame to another. For a quasi-static channel, the path gains are constant over a frame of length multiple of $T_c$. For a Rayleigh channel, the path gains are independent complex Gaussian random variables, with zero mean and variance 0.5 per real dimension.

### 3.3 Receiver

#### 3.3.1 STBC Decoder

At the receiver, we suppose a perfect CSIR, so we use the Maximal Ratio Combining (MRC) technique, combining coefficients being optimally chosen equal with the complex conjugated equivalent channel matrix.

#### 3.3.2 MMSE Equalization

In Minimum Mean Square Error solution, for each sample time $k$ we would want to find a set of coefficients $c[k]$ which minimizes the error between the desired signal $y[k]$ and the equalized signal $c[k] \odot y[k]$, i.e.

$$E(e[k])^2 = E(s[k] - c[k] \odot y[k])^2$$

$$= E(s[k] - c_k^T s[k] - c_k^T y)^T$$

$$= E(s[k])^2 - c_k^T E(s[k]) - E(c_k^T s[k]) - E(s[k] y_k^T) + E(c^T y y^T c)$$

$$= E(s[k])^2 - c^T R y s - R s y c + c^T R y y c$$

where,

- $e[k]$ is the error at sample time $k$,
- $C$ is column vector of dimension $k \times 1$ storing the equalization coefficients,
- $K$ is column vector of dimension $k \times 1$ storing the received samples,
- $K$ is the number of taps in the equalizer,
- $R_{ys} = E(y s[l])$ is the cross correlation between received sequence and input sequence,
- $R_{yy} = E(y[l] y[l]^T)$ is the cross correlation between received sequence and input sequence and
- $R_{yy} = E(y[l] y[l]^T)$ is the auto-correlation of the received sequence.
For solving the Minimum Mean Square Error (MMSE) criterion, we need to find a set of coefficients $c$ which minimizes $\mathcal{E}(c[k])^2$.

Differentiation with respect to $c$ and equating to 0,

$$
\frac{\partial}{\partial c} [\mathcal{E}(s[k])^2 - c^T \mathbf{R}_{y,s} - \mathbf{R}_{s,y} c + c^T \mathbf{R}_{y,y} c] = 0
$$

Simplifying,

$$
\mathbf{R}_{s,y} = \mathbf{E}(s[k]y^T)
$$

$$
= E(s[k](h^s[k] + n)^T
$$

$$
= h^T E(s^2[k]) + E(s[k]n)
$$

$$
= h,
$$

$$
\mathbf{R}_{y,y} = \mathbf{E}(y^T y)
$$

$$
= E((h^s[k] + n)(h^s[k] + n)^T
$$

$$
= E(hh^T)E(s^2[k]) + hE(s[k]n) + E(n[k]s[k])h^T + E(n^2)
$$

$$
= E(hh^T) + E(n^2)
$$

Note:

a) $\mathcal{E}(s^2[k]) = \sigma^2$ is the variance of the input signal

b) $\mathbf{E}(s[k]n[k]) = 0$ (as there is no correlation between input signal and noise)

### 3.3.3 Maximum Ratio Combing (MRC)

Combining all the signals in a co-phased and weighted manner so as to have the highest achievable SNR at the receiver at all times.

In MRC, all the branches are used simultaneously. Each of the branch signals is weighted with a gain factor proportional to its own SNR.

![Figure 2.6. Maximum Ratio Combining](image)
Derivation of Maximum Ratio combining improvement

Co-phasing and summing is done for adding up the weighted branch signals in phase. The gain associated with the ith branch is decided by the SNR of the corresponding branch. i.e., \( g_i = \frac{(S/N)_i}{(S/N)} \).

The MRC scheme requires that the signals be added up after bringing them to the same phase, if \( a_i \) is the signal envelope, in each branch then the combined signal envelope is given as,

\[
a = \sum_{i=1}^{M} a_i g_i
\]

Assuming that the noise components in the channel are independent and identically distributed in each branch, total noise power is,

\[
N_t = N_o \sum_{i=1}^{M} a_i g_i
\]

The resulting SNR is thus given by

\[
y = \frac{\alpha^2 E_b / N_o}{(\sum g_i a_i)^2 / (\sum g_i)^2} \cdot \frac{(S/N)_i}{(S/N)}
\]

The equality in this case is obtained when \( g_i = k^* a_i \), \( k \) being some constant. The maximum value of the output SNR after MRC is given by,

\[
y = \sum (E_b / N_o) (a_i^2) = \sum y_i
\]

(All summations between \( i = 1, 2 \ldots M \)). Thus we notice that the sum of the SNRs of the individual branches yields the final SNR of the output. To obtain the distribution of the combined signal, observe that,

\[
y_i = (E_b / N_o) a_i^2 = (E_b / N_o)^* (X_i^2 + \gamma_i^2)
\]

\( \gamma_i \) is \( \chi^2 \) distributed with degree 2 which is the same as an exponential distribution.

Let \( \gamma = \sum \gamma_i \). Then we can see that \( \gamma \) is \( \chi^2 \) distributed with degree 2M. Then the PDF of \( \gamma \) is given by,

\[
\rho(\gamma) = \frac{1}{(M-1)!} \gamma^{M-1} e^{-\gamma / \gamma_0} \exp(-\gamma / \gamma_0)
\]

With \( \gamma_0 = 2 \sigma^2 E_b / N_o \). The CDF of \( \gamma \) is

\[
P(\gamma) = \int_0^{\gamma} \frac{1}{(M-1)!} \gamma^{M-1} e^{-\gamma / \gamma_0} \exp(-\gamma / \gamma_0) d\gamma
\]

\[
= 1 - \exp\left(\frac{\gamma}{\gamma_0}\right) \sum_{i=0}^{M-1} \frac{1}{(i+1)!} \left(\frac{\gamma}{\gamma_0}\right)^{i+1}
\]

It can be noticed that as compared to selection combining, the fall of the probability is more rapid.

Example: at a level of 10dB below \( \gamma_0 \), M=1 Probability=0.1, M=2 Probability =0.005

The main challenge in MRC combining is the co-phasing of the incoming branches after weighting them. The expected value of the signal strength, \( E[\text{Signal Strength}] = E[\sum \gamma_i] = M \gamma_0 \).

3.3.4 Demodulation
   a) QPSK Demodulation
   b) QAM-16
3.3.5 Error Correcting Code & Correction
An error-correcting code is an algorithm for expressing a sequence of numbers such that any errors which are introduced can be detected and corrected (within certain limitations) based on the remaining numbers. The study of error-correcting codes and the associated mathematics is known as coding theory.

Error detection is much simpler than error correction and one or more "check" digits are commonly embedded in credit card numbers in order to detect mistakes. Early space probes like Mariner used a type of error-correcting code called a block code, and more recent space probes use convolution codes. Error-correcting codes are also used in CD players, high speed modems, and cellular phones. Modems use error detection when they compute checksums, which are sums of the digits in a given transmission modulo some number.

3.3.6 De-Interleaving
A corresponding deinterleaver uses the inverse mapping to restore the original sequence of symbols. It can be useful for reducing errors caused by burst errors in a communication system. Output is given to receiver message and getting the noise free receiver message, that why we calculate the BER for different Transreceiver.

IV. MIMO FOR WIRELESS NETWORKS
Digital communication using multiple-input–multiple output (MIMO) also called as “volume-to-volume” wireless link and has emerged as one of the most significant technical breakthroughs in modern communications. The technology figures prominently on the list of recent technical advances with a chance of resolving the bottleneck of traffic capacity in future Internet-intensive wireless networks. Perhaps even more surprising is that just a few years after its invention, the technology seems poised to penetrate large-scale standards-driven commercial wireless products and networks such as broadband wireless access systems, wireless local area networks (WLAN), third-generation (3G) networks and beyond.

MIMO systems can be defined as: Given an arbitrary wireless communication system, we consider a link in which the transmitting ends as well as the receiving end is equipped with multiple antenna elements as illustrated in Figure 1. The idea behind MIMO is that the signals on the transmitter (TX) antennas at one end and the receiver (RX) antennas at the other end are “combined” in such a way that the quality (bit-error rate or BER) or the data rate (bits/sec) of the communication for each MIMO user will be improved. Such an advantage can be used to increase both the network’s quality of service and the operator’s revenues significantly.

![Figure 4.1: Multiple Input Multiple Output system.](image-url)
A core idea in MIMO systems is space–time signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas. As such MIMO systems can be viewed as an extension of the so-called smart antennas, a popular technology using antenna arrays for improving wireless transmission dating back several decades.

It is important to note that each antenna element on a MIMO system operates on the same Frequency and therefore does not require extra bandwidth. Also, for fair comparison, the total power through all antenna elements is less than or equal to that of a single antenna system. i.e,

$$\sum_{k}^{N} p_k \leq P$$

Where, N is the total number of antenna elements, $p_k$ is the power allocated through the $k^{th}$ antenna element, and $P$ is the power if the system had a single antenna element. Effectively, the equation (1) ensures that a MIMO system consumes no extra power due to its multiple antenna elements.

We consider a general MIMO system with $NT$ transmit antennas and $NR$ receive antennas, employing a space-time encoder, a MIMO channel with $NT$ inputs and $NR$ outputs and a space-time decoder with MRC technique and Maximum Likelihood (ML) decoding. Fig. 1 illustrates a simple example for two transmit and two receive antennas.

**APPLICATION AND ADVANTAGES**

- **Advantages**
  1. Makes efficient use of the spectrum by allowing overlap.
  2. Eliminates ISI and IFI through use of a cyclic code.
  3. Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel.
  4. Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
  5. Is less sensitive to sample timing offsets than single carrier systems are.
  6. Provides good protection against co-channel interference and impulsive parasitic noise.

- **Applications**
  1. Wireless Local Area Networks (LANs).
  2. Digital Televisions Transmission (European and Australian standards).
  3. ADSL (asymmetric digital subscriber loop), for high speed data transmission along existing telephone lines.
  4. May be used in future Mobile communication.
V. RESULTS

Figure 5.1 Graph of QPSK modulation

Figure 5.2 Graph of QAM-16 modulation

Figure 5.3 Graph of comparison of QPSK & QAM-16 modulation
VI. FUTURE SCOPE & CONCLUSION

In this paper, we have processed for the comparison of QPSK and QAM-16. For different STBC codes from the literature, we have specified the transmission matrix and the code parameters. Then, we have provided simulation results to compare the performances of different STBC codes chosen for a different number of transmit antennas, specifying the best code that assures a maximum diversity gain and a minimum BER. However, the concatenation of STBC codes with classical channel codes like convolution or turbo codes, can offer optimal diversity and coding gain, with the expense of a decreased bit rate and an increased complexity.

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