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Space-Time Block Coding

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Abstract: *The Space Time Coding has proven to be an evolved research area in wireless communications. Recently, Space-Time Block Coding (STBC) has been trying to incorporate in the forthcoming generation of mobile communication standard with aims to deliver true media capability. This paper presents the Space-Time Block Codes (STBC) for wireless networks that uses multiple number of antennas at both transmitter and receiver to transmit and receive data over various channels (Rayleigh and Rician). The simulations have been done in SIMULINK. Different modulation schemes (DPSK and BPSK) have been adopted to check the performance of the system via Bit Error Rate Vs Signal to Noise Ratio.*

Keywords: *Alamouti scheme, BER Vs SNR, BPSK, DPSK, Rayleigh, Rician.*

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I. Introduction

The demand for higher data rates over wireless channel using the spectrum allotted by the federal government is the need of the hour today. However, the wireless designers need to take care of increase in battery life by making the product small and less power consuming. The randomness of the wireless channel makes it difficult for the designers to increase data rate [1][2][9], to manage the constraints. A major problem in the wireless channel is that of fading, caused by the superposition of delayed, reflected, scattered and diffracted signal components. Another problem of the wireless channel is variation over time, due to the movements of the mobile unit and [3] [4] objects in the environment. This result into severe attenuation of the signal, referred to as deep fade. This instantaneous decrease of the signal-to-noise ratio (SNR) results in error bursts which degrades the performance significantly. In such fading environments, reliable communication is possible through the use of diversity techniques in which receiver is afforded multiple replicas of the transmitted signal under varing fading conditions. These techniques reduce the probability that all the replicas are simultaneously affected by a severe attenuation. Commonly used methods include [6] [7]:

1. Frequency Diversity, in which the signal is transmitted on multiple RF carriers.
2. Temporal Diversity, in which channel coding and inter leaving are used to replicate and distribute the signal in time.
3. Antenna/ Spatial Diversity, in which multiple antennas are used at the transmitter and/or the receiver to provide multiple replicas of the signal with uncorrelated fading characteristics.

It has been proved by the informative investigations that very high capacity can be obtained by employing multiple antenna elements at both transmitted and receiver of a wireless system. The approach of Space-Time Coding uses multiple transmit antennas and (optionally) multiple receive antennas to provide high data rates and reliable communications over fading channels by combining spatial diversity, coding and modulation. Examples of space-time coding include space-time block codes, space-time trellis codes, linear-dispersion (LD) codes and super-orthogonal space-time codes. Space-time trellis code provide full diversity and coding gain at the cost of a complex receiver. Space-time block codes provide full diversity and simple decoding without any coding gain. Like STC, Bell Laboratories Layer Space-Time (BLAST) [8][9][10] is a transceiver architecture that offers spatial multiplexing over multiple antenna wireless communication systems. Both the techniques employ the space (different antennas) and the time domain while encoding and decoding information symbols. Hence, the terms multiple-input and multiple-output (MIMO) and space time coding can be used interchangeably.

To transmit symbols from multiple antennas, a technique is used which is known as Space-time signaling. Schemes which use multiple transmit and receive antennas for communicating over a wireless channel are usually called Multiple-input multiple-output (MIMO) schemes. For effective evaluation of the performance of a MIMO transmission scheme, certain models are required in order to account for all the major effects of wireless channel on various signals. The most commonly used channel model for MIMO systems is quasi-static at Rayleigh fading [12] at all antenna elements. This was employed in where novel signal processing

schemes for MIMO systems were introduced. The simplicity of this channel model made the performance analysis of these schemes less complicated, allowing the authors to place more emphasis on introducing the transmit and receive signal processing algorithms.
The basic assumptions behind the quasi-static at Rayleigh fading channel are:

1. There are cases where the signal at any receive antenna of the MIMO system is the sum of the various multipath components. This occurs because of the presence of a large number of scatterers in the wireless channel. Here, the distribution of the received signal at each antenna will be complex Gaussian and the amplitude of such complex Gaussian distributed signals is Rayleigh distributed.
2. The channel delay spread, which is a measure of the difference in the time of arrival of various multipath components at the receiver antenna, is less than the symbol rate. This assumption guarantees at fading.
3. The channel characteristics remain constant at least for the period of transmission of an entire frame. This assumption accounts for quasi-static fading.

Thus, the quasi-static at Rayleigh fading MIMO channel for a system with η_T transmit and η_R receive antennas can be represented as:

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1\eta_T} \\ h_{21} & h_{22} & \cdots & h_{2\eta_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{\eta R_1} & h_{\eta R_2} & \cdots & h_{\eta R \eta_T} \end{bmatrix} \quad (1)$$

where h_{ij} is the path gain between the receive antennas denoted by i and the transmit antenna denoted by j. The following three techniques [16] can be used by the receiver in order to improve the quality of the received signal:
1. Selection: Received signal is selected which has the largest received power.
2. Switching: If the received power falls below a threshold level, then alternate antennas are chosen
3. Maximal Ratio Combining (MRC): The signals are combined linearly after being assigned appropriate weights. Weighted replicas of all the received signals are combined linearly. Here, it is assumed that the receiver has perfect channel side information.
If the transmitted signal at time t is s(t), the received signal at receiver i is given by:

$$r_i(t) = s(t)h_i(t) + n_i(t) \quad (2)$$

Where $n_i(t)$ is complex noise variable. Assuming that this noise is Gaussian, the receiver combining scheme is:

$$\tilde{r}(t) = \sum_{i=1}^{\eta_R} h_i^{*} r_i(t) = s(t)\sum_{i=1}^{\eta_R} |h_i|^2 + n^{'}(t) \quad (3)$$

This detected symbol is then passed through a maximum-likelihood detector to produce the estimate of transmitted signal s(t). Full diversity is obtained by Maximal Ratio Combining, but the complexity increases because of channel estimation. If same signal is transmitted from all the antennas, at the receiver the copies of this signal add incoherently, and no diversity gain can be achieved. Thus, unlike in receive diversity, in transmit diversity it is not possible to transmit the same signal from all antennas. Thus in order for transmit diversity to work, one must find a transmission scheme where replicas of the signal combine coherently at the receiver. One of the simplest and most attractive transmit diversity schemes were proposed by Alamouti, [11]:

$$G_2 = \begin{pmatrix} s_1 & s_2 \\ -s_2^{*} & s_1^{*} \end{pmatrix} \quad (4)$$

where the rows denote time instances and columns denote transmit antennas. Thus, at time t = 1, s_1 and s_2 will be transmitted from antennas 1 and 2 respectively, and at time t = 2, $-s_2^{*}$ and s_1^{*} will be transmitted from antennas 1 and 2 respectively. One can see that two symbols are transmitted over two time intervals. Hence the code is full rate. Assuming a single receiver, let h1 and h2 denote the channel coefficients for transmit antenna 1 and 2 respectively. The fading coefficients are assumed to be constant over η_T = 2 consecutive time slots. Hence the received signal is:

$$y_1 = h_1 x_1 + h_2 x_2 + n_1 \quad (5)$$

$$y_2 = -h_1 x_2^{*} + h_2 x_1^{*} + n_2 \quad (6)$$

With perfect SI, this can be maximum-likelihood (ML) decoded as:

$$\tilde{x}_1 = h_2^* y_1 + h_1 y_2^* = (|h_1|^2 + |h_2|^2)x_1 + \tilde{n} \quad (7)$$

$$\tilde{x}_2 = h_2^* y_1 - h_1 y_2^* = (|h_1|^2 + |h_2|^2)x_2 + \tilde{n}_2 \quad (8)$$

The Rayleigh probability density function is given as :

$$f_R(r) = \frac{r}{\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \quad (9)$$

which on integrating yields the corresponding cumulative probability distribution function:

$$\mathrm{Pr}ob(r < R) = \int_0^R f_R(r) = 1 - e^{\frac{-R^2}{2\sigma^2}} \quad (10)$$

The mean value of the Rayleigh distribution is given by:

$$E[R] = \int_0^\infty r f_R(r) dr \quad (11)$$

The Rayleigh-fading model [12] [13] [15] [16] assumes that all paths are relatively equal-that is, that there is no dominant path. Despite the fact that Rayleigh fading is the most popular model, occasionally there is direct line of sight path in mobile radio channels and in indoor wireless as well. The presence of a direct path is usually required to close the link in satellite communications. In this case, the reflected paths tend to be weaker than the direct path, and we model the complex envelope as:

$$\tilde{E} = E_o + \sum_{n=1}^{N} E_n e^{j\theta_n} \quad (12)$$

Where the constant term represents the direct path and the summation represents the collection of reflected paths. This model is referred to as RICIAN FADING model. The analysis proceeds in a manner similar to the Rayleigh fading case, but with the addition of a constant term. A key factor in the analysis is the ratio of the power in the direct path to the power in the reflected paths. The ratio is referred to as the RICIAN FACTOR, defined as:

$$K = \frac{s^2}{\sum_{n=1}^{N} |E_n|^2} \quad (13)$$

Where $s^2 = |E_o|^2$. The Rician K-factor is often expressed in dB. The calculation of the amplitude density function in the Rician fading case is more involved than with Rayleigh fading, so we merely give the result here. We have:

$$f_R(r) = \frac{r}{\sigma^2} e^{-(r^2+s^2)/2\sigma^2} I_0\left(\frac{rs}{\sigma^2}\right) \qquad r \geq 0 \quad (14)$$

Where $I_0(.)$ is the modified Bessel function of zeroth order. Deep fades are less probable than with the Rayleigh channel, and the probability of their occurrence decreases as the K factor increases.

II. Simulation Model

The information source is encoded using a space-time block code, and the constellation symbols are transmitted from different antennas. The receiver estimates the transmitted bites by using the signals of the received antennas. We consider a wireless communication system with T antennas at the base station and R antennas at the remote. At each time slot t, signals c_t^j j=1,2,…T are simultaneously transmitted from T transmit antennas. At time slot t the signal r_t^j, received at antenna j, is given by:

$$r_t^j = \sum_{i=1}^{n} \alpha_{i,j} c_t^i + \eta_t^i \quad (15)$$

where the noise sample η_t^j are independent of a zero mean complex Gaussian random variable. The average energy of the symbol transmitted from each antenna is normalized to one, so that the average power of received signal at each receive antenna is n and the signal-to-noise ratio is SNR. Assuming perfect channel information is available at the receiver, the computed decision metric is:

$$\sum_{t=1}^{l} \sum_{j=1}^{m} \left| r_t^j - \sum_{i=1}^{n} \alpha_{i,j} c_t^i \right|^2 \quad (16)$$

over all code words i.e.

$$c^1{}_1 c^2{}_1 \ldots c^n{}_1 c^1{}_2 c^2{}_2 \ldots c^n{}_2 \ldots c^1{}_1 c^2{}_1 \ldots c^n{}_1$$

and decides in favor of the code word that minimize the sum.

A space-time block code is defined as by a R x T transmission matrix G, the entries of which are linear combinations of the variables $x_1, x_2, \ldots, x_k$ and their conjugates. For examples, G_2 represents a code which utilizes two transmit antennas and is defined by:

$$G_2 = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \qquad (17)$$

The code rate is given as:

S=number of symbols (or signals) in G/Total number of time slots.

For example, for G_3

Number of signals=4(x_1, x_2, x_3, x_4)

Number of time slots=8 (number of rows)

Therefore, S=4/8=1/2

A real orthogonal design of size n is an n x n orthogonal matrix whose rows are permutations of real numbers $\pm x_1, \pm x_2, \pm x_3, \ldots, \pm x_n$.Without loss of generality, the first row can be assigned as $(x_1, x_2, \ldots, x_n)$. For example, real orthogonal designs for n=3 is:

$$G_3 = \begin{bmatrix} x_1 & x_2 & x_3 \\ -x_2^* & x_1^* & 0 \\ x_3^* & 0 & -x_1^* \\ 0 & x_3^* & -x_2^* \end{bmatrix} \qquad (18)$$

Due to orthogonality, the diversity order of this code is nm. The rate of code is b bits/s/Hz, which is optimal under the diversity order nm for the constellation size 2^b. Orthogonality also simplifies the minimum-distance decoding rule. Let $\delta_k(i)$ be the sign of x_i in the k^{th} row of G. It follows that the receiver only needs to combine received signals linearly:

$$R = \sum_{t=1}^{n} \sum_{j=1}^{m} r_t^j \alpha_{\epsilon t(i),j} \delta_k(i) \qquad (19)$$

and decide on r_i such that:

$$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \\ \hat{x}_3 \end{bmatrix} = \frac{1}{\|H\|^2} \sum_{j=1}^{M} \begin{bmatrix} h^*_{1,j} r_{1,j} + h^*_{2,j} r^*_{2,j} + h^*_{3,j} r_{3,j} \\ h^*_{2,j} r_{1,j} - h_{1,j} r^*_{2,j} - h_{3,j} r^*_{4,j} \\ h^*_{3,j} r_{1,j} + h_{1,j} r^*_{3,j} + h_{2,j} r^*_{4,j} \end{bmatrix} \qquad (20)$$

where $H = \sum_{i=1}^{N} \sum_{j=1}^{M} \|h_{ij}\|^2$, $\hat{x}_n$ is the estimated transmitted symbols, $\|H\|$ is the channel matrix norm, r is the received symbol and h^* is the channel state information available at the receiver.

However, by developing generalized real orthogonal designs, space-time codes for other numbers of antenna can be obtained. The channel state information describing how a signal propagates from the transmitter to the receiver and represents the combined effect of, for example, scattering, fading, and power decay with distance is needed to be passed onto the receiver for correct channel estimation.

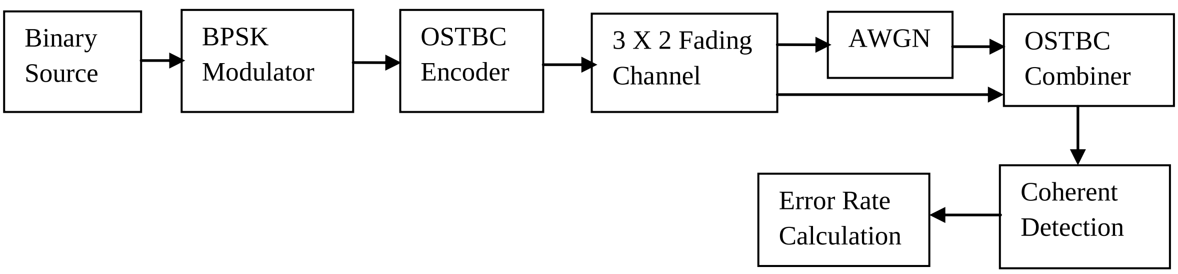

Fig 1: SIMULINK Blocks for BPSK modulated transmission model

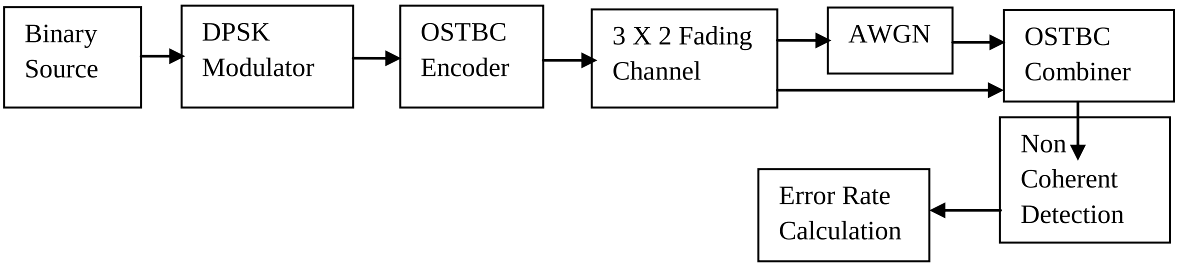

Fig 2: SIMULINK Blocks for DPSK modulated transmission model

III. Simulation Results

A stream of binary digits is generated with 3 samples per frame which is BPSK modulated and transmitted via three transmitters through a multipath Rayleigh fading channel, the error probability of which has been plotted. The receiver diversity improves the performance by a fair margin. As the number of receivers is increased the error probability is reduced drastically and thus makes the system much more efficient. Moreover a similar stream is made to pass through the multipath Rician fading channel via three transmitters. The signal through the channel is received using one and two receivers respectively, the error probability of which is determined.

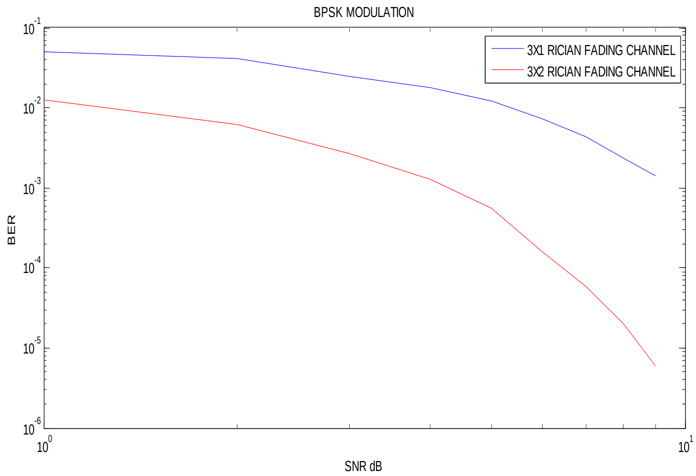

Fig 3: BER Vs SNR curve for a BPSK modulated bit stream via multipath Rician fading channel

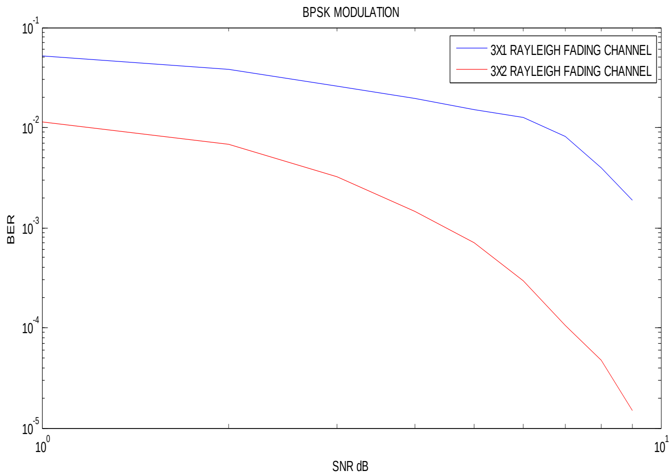

Fig 4: BER Vs SNR curve for a DPSK modulated bit stream via multipath Rayleigh fading channel

Rayleigh fading [12] [13] is dominant in the scenario when there are multiple indirect paths between the transmitter and receiver without a distinct dominant path, such as LOS path. In the mobile radio channels, the Rayleigh distribution is usually used to describe the statistical time varying nature of the envelope detected at the receiver for a flat faded environment. Rayleigh fading can be dealt with analytically, providing insights into performance characteristics that can be used in difficult environments, such as downtown urban settings. However, where there is line-of-sight, direct path is normally the strongest component that goes into deeper fade as compared to the multipath components. This kind of signal is approximated by Rician distribution. As the dominating component run into deeper fade the signal characteristic goes from Rician to Rayleigh distribution. The derivation of the probability density function of the amplitude is more involved than for Rayleigh fading, and a Bessel function occurs in the mathematical expression. The error rate is determined and is observed to be improved for higher signal to noise ratio in case of multipath Rician fading channel.

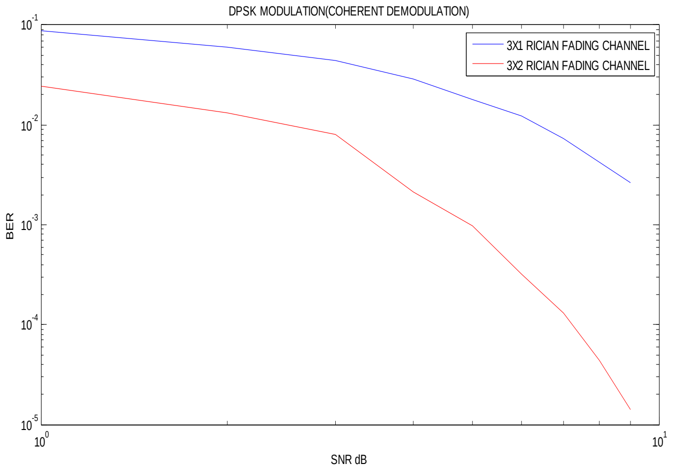

Fig 5: BER Vs SNR curve for a DPSK modulated bit stream via multipath Rician fading channel

Rayleigh fading [12] [13] is dominant in the scenario when there are multiple indirect paths between the transmitter and receiver without a distinct dominant path, such as LOS path. In the mobile radio channels, the Rayleigh distribution is usually used to describe the statistical time varying nature of the envelope detected at the receiver for a flat faded environment. Rayleigh fading can be dealt with analytically, providing insights into performance characteristics that can be used in difficult environments, such as downtown urban settings. However, where there is line-of-sight, direct path is normally the strongest component that goes into deeper fade as compared to the multipath components. This kind of signal is approximated by Rician distribution. As the dominating component run into deeper fade the signal characteristic goes from Rician to Rayleigh distribution. The derivation of the probability density function of the amplitude is more involved than for Rayleigh fading, and a Bessel function occurs in the mathematical expression. The error rate is determined and is observed to be improved for higher signal to noise ratio in case of multipath Rician fading channel.

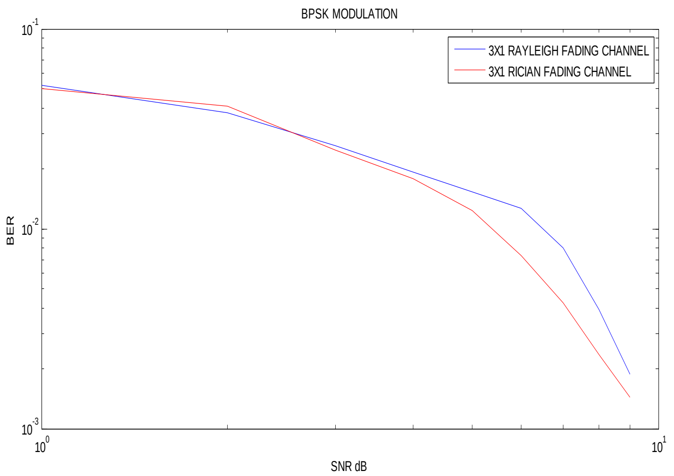

Fig 6: BER Vs SNR curve for a DPSK modulated bit stream via multipath Rayleigh fading channel

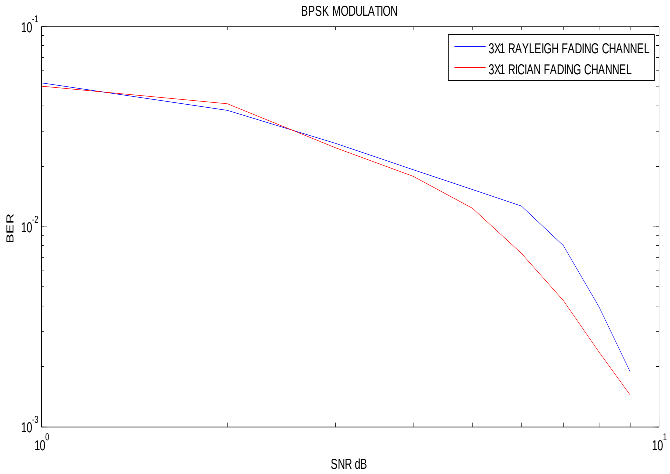

Fig 7: BER Vs SNR curve for a BPSK modulated bit stream via multipath Rician and Rayleigh fading channel

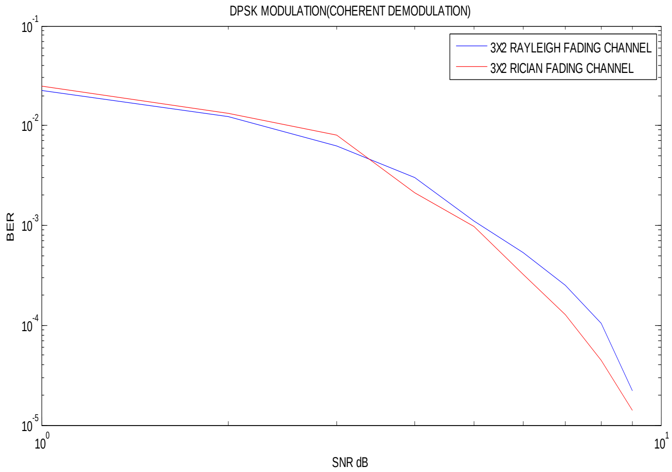

Fig 8: BER Vs SNR curve for a DPSK modulated bit stream via multipath Rician and Rayleigh fading channel

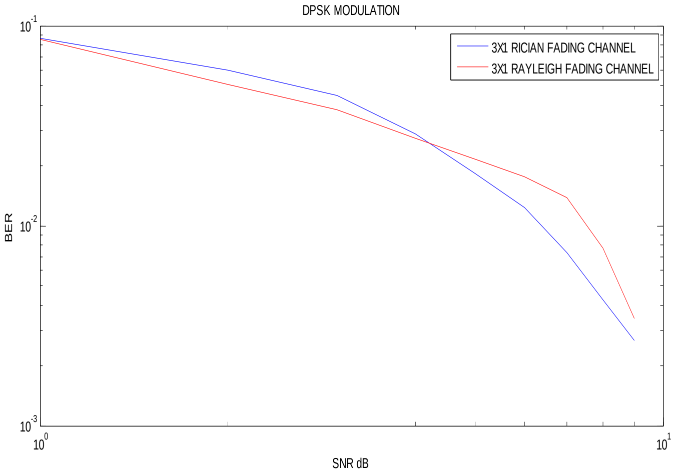

Fig 9: BER Vs SNR curve for a DPSK modulated bit stream via multipath Rician and Rayleigh fading channel

Binary Phase shift keying offers the highest noise margin as it uses 2 phases separated by 180^0. Thus the position of the constellation points is irrelevant. It is unsuitable for high data-rate applications as it is able to modulate only 1 bit/symbol. Differential phase shift keying (DPSK) is a common form of phase modulation that conveys data by changing the phase of the carrier wave.

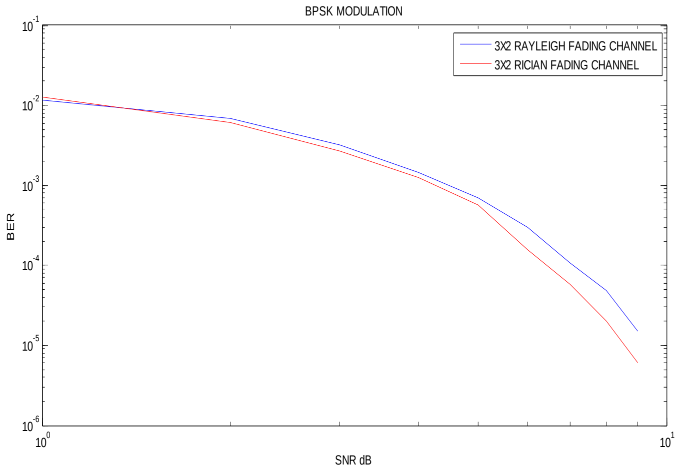

Fig 10: BER Vs SNR curve for a BPSK modulated bit stream via multipath Rician and Rayleigh fading channel

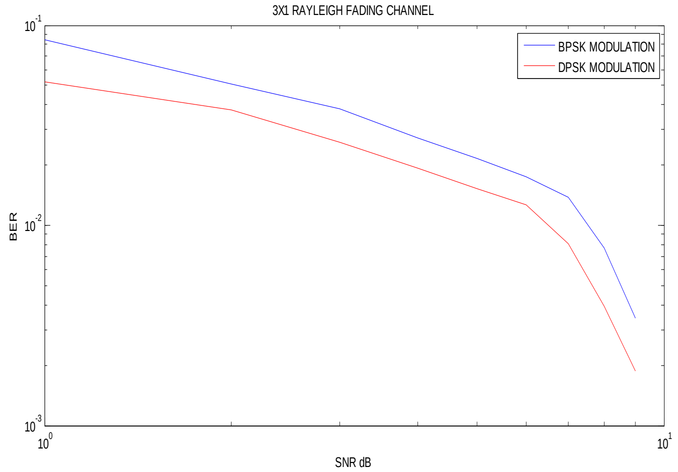

Fig 11: BER Vs SNR curve for a DPSK and BPSK modulated bit stream via multipath Rayleigh fading channel

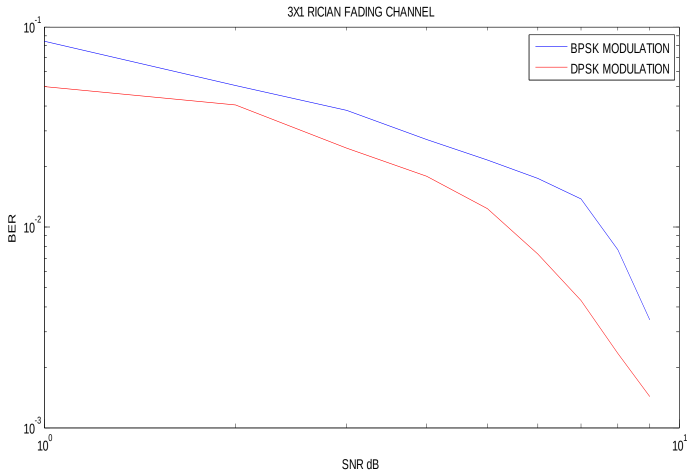

Fig 12: BER Vs SNR curve for a DPSK and BPSK modulated bit stream via multipath Rician fading channel

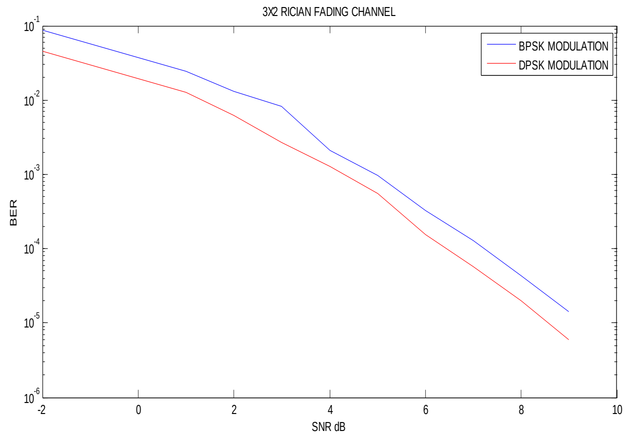

Fig 13: BER Vs SNR curve for a DPSK and BPSK modulated bit stream via multipath Rician fading channel

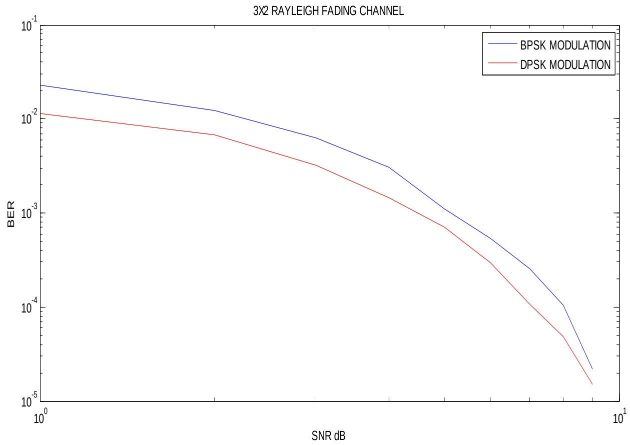

Fig 14: BER Vs SNR curve for a DPSK and BPSK modulated bit stream via multipath Rayleigh fading channel

BPSK [15] modulated bit stream can only be demodulated using coherent detector. On the contrary differentially encoded data can be demodulated using coherent as well as non-coherent techniques.The envelope detector is a very simple method of demodulation that does not require a coherent demodulator. It consists of an envelope detector that can be a rectifier (anything that will pass current in one direction only) or other non-linear that enhances one half of the received signal over the other and a low-pass filter. The rectifier may be in the form of a single diode or may be more complex. Many natural substances exhibit this rectification behavior, which is why it was the earliest modulation and demodulation technique used in radio. The filter is usually an RC low-pass type.The product detector multiplies the incoming signal by the signal of a local oscillator with the same frequency and phase as the carrier of the incoming signal. After filtering, the original audio signal will result.

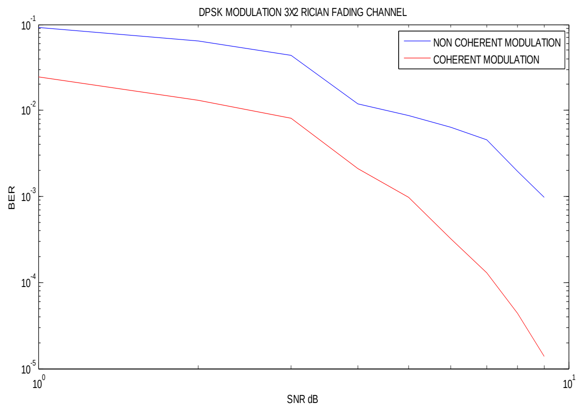

Fig 15: BER Vs SNR curve of coherent and non-coherent detection of a DPSK modulated bit stream via multipath Rician fading channel

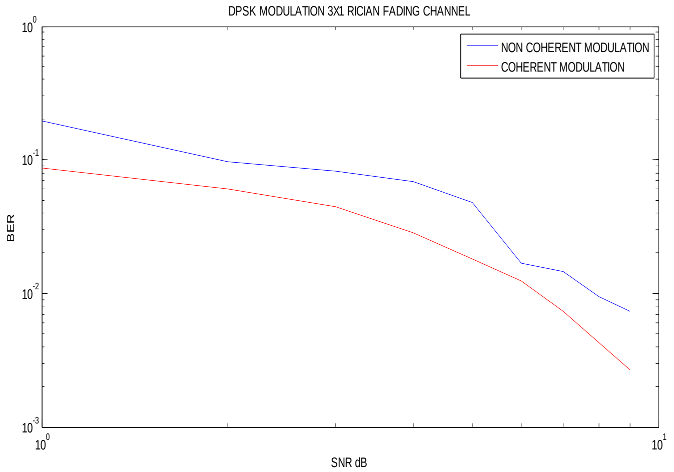

Fig 16: BER Vs SNR curve of coherent and non-coherent detection of a DPSK modulated bit stream via multipath Rician fading channel

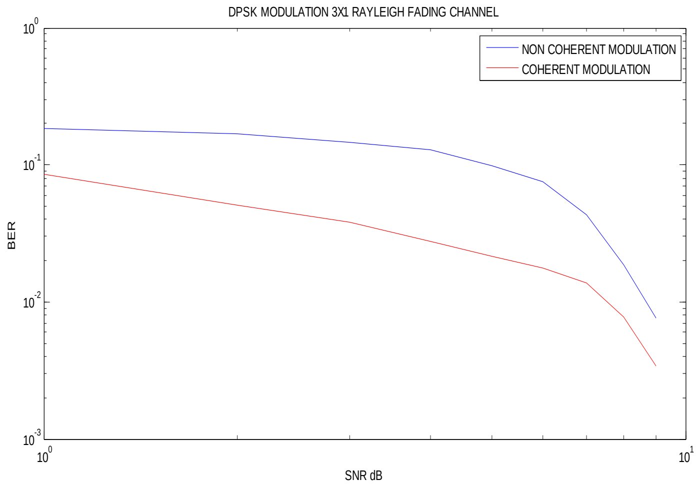

Fig 17: BER Vs SNR curve of coherent and non-coherent detection of a DPSK modulated bit stream via multipath Rayleigh fading channel

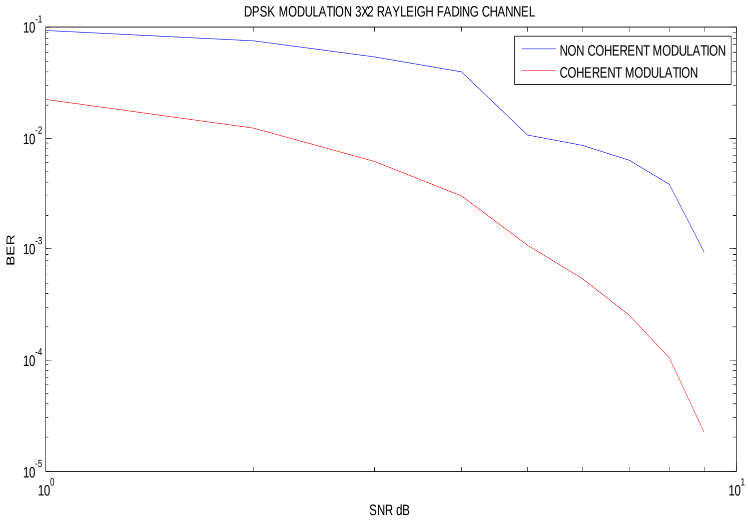

Fig 18: BER Vs SNR curve of coherent and non-coherent detection of a DPSK modulated bit stream via multipath Rayleigh fading channel

IV. Conclusion

This project addresses space-Time block coding issues pertaining to fading channel impairments that are recognized to be the major limitations in realizing the potential enhancements in performance and capacity of envisioned broadband wireless communications. Our focus has been on designing Space Time codes in the presence of channel selectively for both single- and multi-user environments. It has been shown that with proper designs Space Time Coding is an effective tool to combat fading channels that are encountered with broadband wireless communications. The goal of this project on Space Time Coding is to significantly advance performance, capacity and high-speed delivery of information in broadband wireless communication systems. The ultimate object is to have wireless services such as mobile computing, high speed internet access, and other personal communication services delivered with improved quality of service and better accessibility to more people.

We provide space-time block codes for transmission using multiple transmit antennas. We describe both their encoding and decoding algorithms. The decoding of these codes has very little complexity. Simulation results were provided to demonstrate that significant gains can be achieved by increasing the number of transmit chains with very little decoding complexity.

From the performance, with different antenna configurations and propagation conditions the proposed system is capable of improving data rate and maximizing throughput efficiency without increasing the bandwidth requirement, power consumption and complexity. It is understood that both MIMO technology and wider bandwidth channels will be required to reliably satisfy the higher throughput demands of next generation applications.

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