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Performance Evaluation of Alamouti STBC over Rayleigh, Rician and Nakagami Fading Channels

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Abstract –**Alamouti code is a simple space-time code that can be used for transmit diversity systems. This is a class of easily decoded space-time codes that achieve full diversity order in Rayleigh fading channels. Alamouti exist only for certain numbers of transmit antennas and do not provide array gain like diversity techniques that exploit transmit channel information. When channel state information (CSI) is available at the transmitter, though, the space-time codeword can be used to support different numbers of transmit antennas. The objective of this paper is to design a method for comparison of bit error rate (BER) performance of Alamouti STBC over Rayleigh, Rician and Nakagami fading channels for BPSK and QPSK modulation techniques.**

Keywords – **Alamouti STBC, BER, BPSK, CDMA, CSI, MIMO, OFDM, QPSK.**

I. Introduction

With the ever growing demand of present generation, need for high speed communication has become an utmost priority. Various multicarrier modulation techniques have used in order to meet these demands some few methods are Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM). Orthogonal Frequency Division Multiplexing is a frequency – division multiplexing (FDM) scheme utilized as a digital multi – carrier modulation scheme. A data is carried by large number of closely spaced orthogonal sub – carriers. The data is divided into several parallel streams of channels, one for each sub – carriers. Each sub – carrier is modulated with a conventional modulation scheme (such as QPSK) at a low symbol rate, maintaining total data rates similar to the conventional single carrier modulation schemes in the same bandwidth. The development of OFDM systems are comprises of Frequency Division Multiplexing, Multicarrier Communication and Orthogonal Frequency Division Multiplexing [1].

In wireless channels, a signal sent from a transmitter does not follow a single path before it reaches at receiver. Instead, objects present in the environment cause it to traverse many different paths by means of physical effects such as reflection and refraction. Thus, multiple versions of the transmitted signal reach the receiver. The observed signal at the receiver is a sum of these multiple signals, and it is typically different from the originally transmitted one. Furthermore, in real applications, the relative positioning of transmitter-receiver pairs and the overall state of the objects between them may vary frequently in time, causing a change in the multiple links that signals follow. As a result, it is not rare that the signal observed by a receiver does not suffice to recover the actually transmitted signal. This factor, known as "multipath fading" or simply as "fading", is a fundamental problem in wireless communication. Space-time coding was first described by Tarokh, Seshadri and Calderbank as a solution to this problem. It claims to increase the reliability of data transmission in wireless systems. Like many other wireless schemes, it is based on a technique known as diversity.

II. Multiple Antenna Systems (MIMO)

Multiple antennas can be used at the transmitter and receiver, an arrangement called a MIMO system.

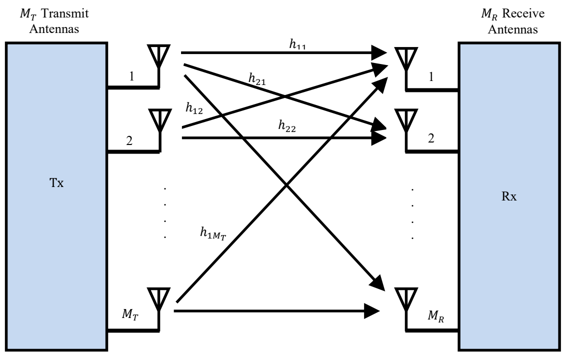

Figure 1: General MIMO [2]

In a dense multipath scattering environment a MIMO system takes advantage of the spatial

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diversity that is obtained by spatially separated antennas. MIMO systems may be implemented in a number of different methods to obtain either a diversity gain to combat signal fading or to obtain a capacity gain. A MIMO system typically consists of M_T transmit and M_R receive antennas (Figure 1).

By using the same channel, every antenna receives not only the direct components but also the indirect components intended for the other antennas. The direct link from antenna 1 to 1 is specified with h_{11}, etc., while the indirect link from antenna 1 to 2 is identified as cross component h_{21}, etc. From this, the transmission matrix H with the dimensions $M_R \times M_T$.

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{...} & h_{1M_T} \\ h_{21} & h_{22} & h_{...} & h_{2M_T} \\ h_{..} & h_{..} & h_{...} & h_{.M_T} \\ h_{M_R1} & h_{M_R2} & h_{n...} & h_{M_RM_T} \end{bmatrix} \quad (1)$$

A lot of research work has been done in this segment, which can be found in [3]-[9].

III. Proposed Method

Alamouti STBC

MIMO stands for Multiple Input Multiple Output and most often refers to the multiplicity of antennas at the transmitter and the receiver side. There are different schemes of MIMO. We have studied one of these schemes, which is proposed by Siavash M. Alamouti [10]. This scheme has the advantage of achieving a high spatial diversity order in the absence of channel knowledge at the transmitter while keeping the number of receive antennas at the mobile set to a small number. We have concentrated on a two transmitters and two receiver's configuration scheme with the channel model depicted in Figure 2.

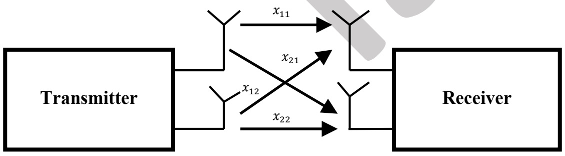

Figure 2: Channel Model for MIMO (2×2)

In Figure 2, x_{11}, x_{12}, x_{21} and x_{22} denote the channel's impulses responses between transmit and receive antennas.

In the Alamouti MIMO scheme [10], diversity is introduced both in space and time to combat the effects of time-varying multipath fading. The diversity is achieved using the Alamouti Space Time Coding where the signal is coded at the transmitter and decoded in the receiver. The symbols, c_0 and c_1 are coded at the transmitter according to table 1.

Table 1: Alamouti Space-Time coding for 2×2 MIMO system

	TX_1	TX_2
time: t	c_0	c_1
time: $t+T$	$-c_1^*$	c_0^*

Notice that 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. This forms the simple explanation of the transmission scheme with Alamouti Space Time Block coding.

Equalization Techniques

A. Zero Forcing Equalizer

Zero Forcing Equalizer is a linear equalization algorithm used in communication systems; it inverts the frequency response of the channel. The name Zero forcing corresponds to bringing down the Inter Symbol Interference (ISI) to zero in a noise free case. This will be useful when ISI is more predominant when comparing to the noise.

Consider a 2×2 MIMO channel, the received signal on the first receive antenna is,

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1 = [h_{11}h_{12}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \quad (2)$$

The received signal on the Second receive antenna is,

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2 = [h_{21}h_{22}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \quad (3)$$

The equation can be represented in matrix notation as follows:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{11}h_{12} \\ h_{21}h_{22} \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \quad (4)$$

Equivalently, $Y = HX + N$

Where, Y = Received Symbol Matrix. H = Channel matrix. X = Transmitted symbol Matrix. N = Noise Matrix.

To solve for x, we need to find a matrix W which satisfies $WH = I$. The Zero Forcing (ZF) detector for meeting this constraint is given by,

$$W = (H^H H)^{-1} H^H \quad (5)$$

Where, W - Equalization Matrix and H - Channel Matrix

This matrix is known as the pseudo inverse for a general $m \times n$ matrix where,

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$$H^H H = \begin{pmatrix} h_{11}^* h_{21}^* \\ h_{12}^* h_{22}^* \end{pmatrix} \begin{pmatrix} h_{11} h_{21} \\ h_{12} h_{22} \end{pmatrix} = \begin{bmatrix} |h_{11}|^2 + |h_{21}|^2 & h_{11}^* h_{12} + h_{21}^* h_{22} \\ h_{12}^* h_{11} + h_{22}^* h_{21} & |h_{12}|^2 + |h_{22}|^2 \end{bmatrix} \quad (6)$$

Zero forcing equalizer tries to null out the interfering terms when performing the equalization while doing so, there can be amplification of noise. Hence Zero forcing equalizer is not the best possible equalizer.

B. MMSE Equalizer

Minimum Mean Square Error (MMSE) approach alleviates the noise enhancement problem by taking into consideration the noise power when constructing the filtering matrix using the MMSE performance-based criterion.

The MMSE approach tries to find a coefficient W which minimize the criterion,

$$E\left\{[W_{y-x}][W_{y-x}]^H\right\} \quad (7)$$

On solving,

$$W = (H^H H + N_0 I)^{-1} H^H \quad (8)$$

When comparing to the equalization, apart from the $N_0 I$ team both the equations are comparable. When the noise term is zero, the MMSE equalization reduced to ZF equalizer.

Communication Channel

A. Rayleigh Fading Channel

Rayleigh fading is caused by multipath reception. The mobile antenna receives has large number of, say N, reflected and scattered replicas of same signal. Because of constructive and destructive interference, the instant received power seen by mobile antenna becomes a random variable, dependent upon the site of the antenna. The probability distribution function of phase and amplitude of this random variable is given by:

$$p(R) = \frac{R}{\sigma^2} \exp\left(-\frac{R^2}{2\sigma^2}\right) \quad (9)$$

B. Rician Fading Channel

Rician fading is similar to Rayleigh fading except for the fact that there exists a strong line-of-sight component along with reflected waves. Redefined Rician models also consider

- That the dominant component can be a phasor sum of two or more dominant components for e.g. the line-of-sight, plus a ground reflection. This joint signal is then mostly treated as a deterministic process.
- That the dominant wave can be subjected to the shadow attenuation. This is a popular supposition in the modelling of satellite channels.

Besides the leading component, mobile antenna receives a large number of reflected and scattered waves. The PDF of the amplitude can be determined as:

$$f_\rho(\rho) = \frac{\rho}{\sigma^2} exp\left\{-\frac{\rho^2 + C^2}{2\sigma^2}\right\} I_0\left(\frac{\rho C}{\sigma^2}\right) \quad (10)$$

Where I_0, is modified Bessel function of first kind and zero order.

C. Nakagami Fading Channel

Nakagami Fading occurs for multipath scattering with relatively larger time-delay spreads, with different clusters of reflected waves. Within any one cluster, the phases of individual reflected waves are random, but the time delays are approximately equal for all the waves. As a result the envelope of each cluster signal is Rayleigh Distributed. The average time delay is assumed to differ between the clusters. If the delay times are significantly exceed the bit period of digital link, the different clusters produce serious inter-symbol interference. The Nakagami Distribution termed the magnitude of the received envelope by the distribution:

$$p(r) = \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega_p}\right)^m r^{2m-1} exp\left\{-\frac{mr^2}{\Omega_p}\right\} \quad (11)$$

IV. Simulation And Results

The performance of proposed algorithms has been studied by means of MATLAB simulation.

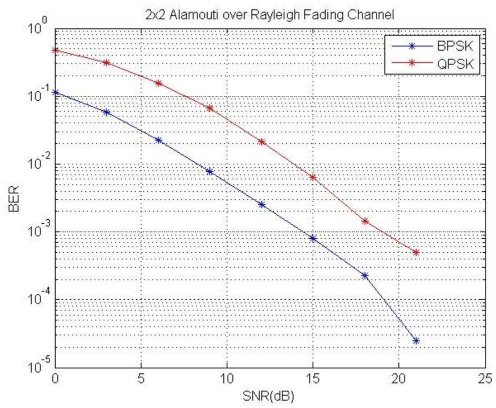

Figure 3: Comparison of BER performance of Alamouti for BPSK and QPSK modulation in Rayleigh fading channel

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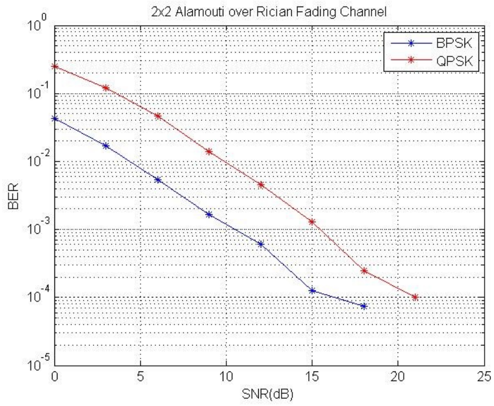

Figure 4: Comparison of BER performance of Alamouti for BPSK and QPSK modulation in Rician fading channel

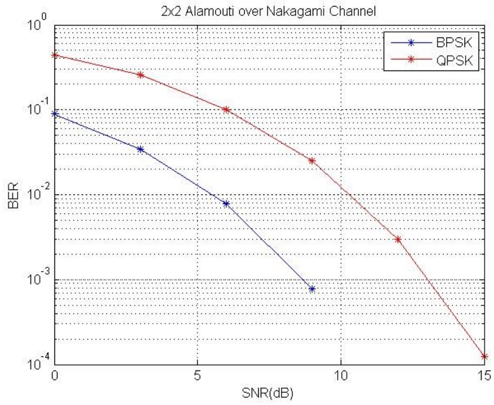

Figure 5: Comparison of BER performance of Alamouti for BPSK and QPSK modulation in Nakagami fading channel

V. Conclusion

The most prominent space-time block codes (STBCs) is the Alamouti code. The approach in this paper is to isolate the analysis of Alamouti STBC system over different fading channels. Simulation results show comparison of BER performance between the BPSK and QPSK modulation techniques for Rayleigh, Rician and Nakagami fading channels. And finally it is found that the Alamouti with BPSK scheme shows better results in terms of BER as compared to QPSK scheme.

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