BER ANALYSIS OF MMSE EQUALISATION AND ML DECODING BY USING MIMO-OFDM-STBC TECHNIQUES

N.Sreekanth
Asso Prof., Department of ECE,
K.S.R.M.College of Engineering,
Kadapa, A.P., India

Dr M.N.GiriPrasad
Professor , Department of ECE,
J.N.T U.A
Anantapur,A.P, India

***Abstract*— space–time block coding, a new evolution for communication over Rayleigh fading channels using multiple transmit antennas. Data is encoded using a space–time block code and the encoded data is split into n streams which are simultaneously transmitted using n transmit antennas. The received signal at each receive antenna is a linear superposition of the n transmitted signals perturbed by noise. Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space–time block code and gives a maximum-likelihood decoding algorithm which is based only on linear processing at the receiver. Space–time block codes are designed to achieve the maximum diversity order for a given number of transmit and receive antennas subject to the constraint. It is shown that using multiple transmit antennas and space–time block coding provides remarkable performance at the expense of almost no extra processing. In this work we propose a generally applicable equalization technique for space-time block coded (STBC) MIMO orthogonal frequency division multiplexing (OFDM) communication systems. Maximum likelihood approaches are developed and iterative solutions are proposed. BER Analysis for BPSK in Rayleigh channel With two transmit and one receive antenna as well as two transmit and two receive antennas for Alamouti STBC case shows higher performance. The maximum likelihood algorithm is based on iterative least squares with projection .**

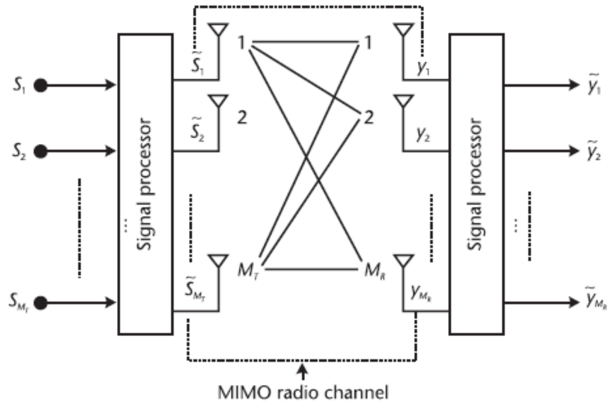
***Keywords*—Orthogonality, Maximal ratio combining, BER, MIMO, STBC , Rayleigh fading channel, etc.**

I.INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a technique in which the total transmission bandwidth is split into a number of orthogonal subcarriers so that a wideband signal is transformed in a parallel arrangement of narrowband 'orthogonal' signals[1]. In this way, a high data rate stream that would otherwise require a channel bandwidth far beyond the actual coherence bandwidth can be divided into a number of lower rate streams. Increasing the number of subcarriers increases the symbol period so that, ideally, a frequency selective fading channel is turned into a flat fading one. In other words, OFDM handles frequency selective fading resulting from time dispersion of multipath channels by expanding the symbol duration [1]. Very high data rates are consequently possible and for this reason it has been chosen as the transmission method for many standards from cable-based Asymmetric Digital Subscriber Line (ADSL), to wireless systems such as the IEEE 802.11a/g local area network, the IEEE 802.16 for broadband metropolitan area network and digital video and audio broadcasting. The fact that the OFDM symbol period is longer than in single carrier modulation, assures a greater robustness against Inter-Symbol Interference (ISI) caused by delay spread. Orthogonal frequency division multiplexing (OFDM) is an efficient multi-carrier modulation technique which can be combined with transmitter and receiver diversity communication systems. Maximal ratio combining (MRC) and space-time block coding (STBC) can be used in conjunction with receiver and transmitter diversity in order to increase the communication system's performance. For these systems, channel estimation and tracking must be performed since the receiver requires channel state information for decoding. for the MIMO case, basic, simplified, significant tap catching (STC) and comb-type channel estimation techniques have been simulated. In all cases, discrete mobile multipath fading and additive white Gaussian noise (AWGN) channels have been chosen as simulated channels. The bit error rate (BER) performances of the simulated communication systems were obtained. A performance comparison between the OFDM systems utilizing different channel estimation methods was conducted and simulated.

In an OFDM system, the input bit stream is multiplexed into N symbol streams, each with

II.SYSTEM MODEL



Fig(1) MIMO-OFDM system model

symbol period T, and each symbol stream is used to modulate parallel, synchronous sub-carriers [10]. The sub-carriers are spaced by 1 in frequency, thus they are orthogonal over the interval (0, T).

A typical discrete-time baseband OFDM transceiver system is shown in Figure(1). First, a serial-to-parallel (S/P) converter groups the stream of input bits from the source encoder into groups of $\log_2 M$ bits, where M is the alphabet of size of the digital modulation scheme employed on each sub-carrier. A total of N such symbols, X_m, are created. Then, the N symbols are mapped to bins of an inverse fast Fourier transform (IFFT). These IFFT bins correspond to the orthogonal sub-carriers in the OFDM symbol. Therefore, the OFDM symbol can be expressed as

$$X(n)=1/N\sum_{m=0}^{N-1} X(m)\ \exp\left(\frac{j2\pi nm}{N}\right) \text{ -------(2.1)}$$

Where the X(m)'s are the baseband symbols on each sub-carrier. The digital-to-analog (D/A) converter then creates an analog time-domain signal which is transmitted through the channel.

At the receiver, the signal is converted back to a discrete N point sequence y(n), corresponding to each sub-carrier. This discrete signal is demodulated using an N-point fast Fourier transform (FFT) operation at the receiver. The demodulated symbol stream is given by:

$$Y(m)= \sum_{m=0}^{N-1} y(n)\ \exp\left(\frac{-j2\pi nm}{N}\right) + W(m) \text{ ---(2.2)}$$

where, W(m) corresponds to the FFT of the samples of w(n), which is the Additive White Gaussian Noise (AWGN) introduced in the channel.

The high speed data rates for OFDM are accomplished by the simultaneous transmission of data at a lower rate on each of the orthogonal sub-carriers. Because of the low data rate transmission, distortion in the received signal induced by multi-path delay in the channel is not as significant as compared to single-carrier high-data rate systems. For example, a narrowband signal sent at a high data rate through a multipath channel will experience greater negative effects of the multipath delay spread, because the symbols are much closer together [3]. Multipath distortion can also cause inter-symbol interference (ISI) where adjacent symbols overlap with each other. This is prevented in OFDM by the insertion of a cyclic prefix between successive OFDM symbols. This cyclic prefix is discarded at the receiver to cancel out ISI. It is due to the robustness of OFDM to ISI and multipath distortion that it has been considered for various wireless applications and standards.

OFDM SYSTEM

Let us use an OFDM system loosely based on IEEE 802.11a specifications.

Parameter	**Value**
FFT size. nFFT	64
Number of used subcarriers. nDSC	52
FFT Sampling frequency	20MHz
Subcarrier spacing	312.5kHz
Used subcarrier index	{-26 to-1, +1 to +26}
Cyclic prefix duration, Tcp	0.8us
Data symbol duration, Td	3.2us
Total Symbol duration, Ts	4us

.

Eb/No and Es/No in OFDM

The relation between **symbol energy** and the **bit energy** is as follows:

$$\frac{E_s}{N_0} = \frac{E_b}{N0}\left(\frac{nDSC}{nFFT}\right)\left(\frac{Td}{Td+Tcp}\right).$$

Expressing in decibels,

$$\frac{E_s}{N_0}dB = \frac{E_b}{N0}dB + 10log_{10}\left(\frac{nDSC}{nFFT}\right) + 10log_{10}\left(\frac{Td}{Td+Tcp}\right)$$

Rayleigh multipath channel model shown in figure(2), the channel was modelled as n-tap channel with each the real and imaginary part of each tap being an independent Gaussian random variable. The impulse response is,

$$h(t) = \frac{1}{\sqrt{n}}\left[h_1(t-t_1) + +h_2(t-t_2) + \cdots + h_n(t-t_n)\right]$$

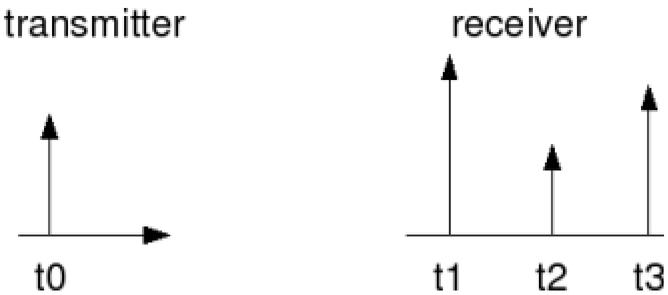
where

$h_1(t-t_1)$ is the channel coefficient of the 1st tap,

$h_2(t-t_1)$ is the channel coefficient of the 2nd tap and so on shown in Fig(2).

The real and imaginary part of each tap is an independent Gaussian random variable with mean 0 and variance 1/2.

The term $\frac{1}{\sqrt{n}}$ is for normalizing the average channel power over multiple channel realizations to 1.



Figure(2): Impulse response of a multipath channel

Cyclic prefix

The need for cyclic prefix and how it plays the role of a buffer region where delayed information from the previous symbols can get stored. Further, since addition of sinusoidal with a delayed version of the sinusoidal does not change the frequency of the sinusoidal (affects only the amplitude and phase), the orthogonality across subcarriers is not lost even in presence of multipath[6].

Since the defined cyclic prefix duration is 0.8us duration (16 samples at 20MHz), the Rayleigh channel is chosen to be of duration 0.5us (10 taps).

Expected Bit Error Rate

The BER for BPSK in a Rayleigh fading channel is defined as

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{(E_b/N_0)}{(E_b/N_0)+1}}\right).$$

Fourier transform of a Gaussian random variable is still has a Gaussian distribution. So, I am expecting that the frequency response of a complex Gaussian random variable will be still be independent complex Gaussian random variable over all the frequencies.

"frequency response of a complex Gaussian random variable is also complex Gaussian.

Given so, the bit error error probability which we have derived for BER for BPSK in Rayleigh channel holds good even in the case of OFDM.

Simulation model

<u>BER simulation of BPSK in a 10-tap Rayleigh fading channel:</u>

(a) Generation of random binary sequence

(b) BPSK modulation i.e bit 0 represented as -1 and bit 1 represented as +1

(c) Assigning to multiple OFDM symbols where data sub carriers from -26 to -1 and +1 to +26 are used, adding cyclic prefix,

(d) Convolving each OFDM symbol with a 10-tap Rayleigh fading channel. The fading on each symbol is independent.

(e) Concatenation of multiple symbols to form a long transmit sequence

(f) Adding White Gaussian Noise

(g) Grouping the received vector into multiple symbols, removing cyclic prefix

(h) Converting the time domain received symbol into frequency domain

(i) Dividing the received symbol with the known frequency response of the channel

(j) Taking the desired sub carriers

(k) Demodulation and conversion to bits

(l) Counting the number of bit errors

(m) Repeating for multiple values of Eb/No

The simulation results are as shown in the plot below Figure(3).

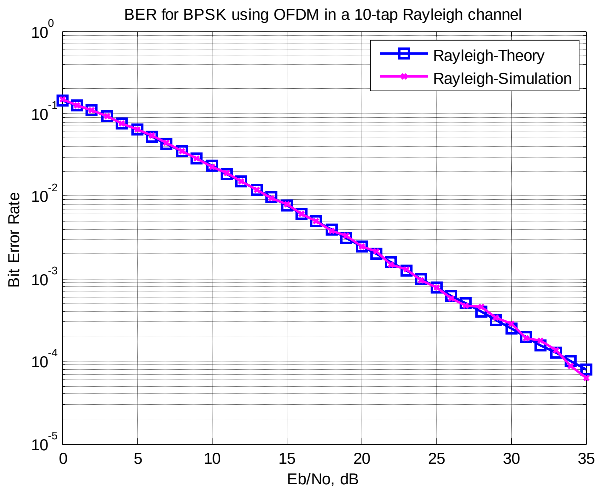


Figure: (3): BER plot for BPSK with OFDM modulation in a 10-tap Rayleigh fading channel

III.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 and the equalized signal $c[k]\otimes y[k]$, i.e.,

Where,

$e[k]$ is the error at sample time k,

c is column vector of dimension $[K \times 1]$ storing the equalization coefficients,

y is column vector of dimension $[K \times 1]$ storing the received samples,

K is the number of taps in the equalizer,

$R_{ys} = E(ys[k])$ is the cross correlation between received sequence and input sequence ,

$R_{sy} = E(s[k]y^T)$ is the cross correlation between received sequence and input sequence and

$R_{yy} = E(yy^T)$ 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 $E(e[k])^2$.

Differentiation with respect to c and equating to 0

Simplifying,

$$\begin{aligned} R_{sy} &= E(s[k]y^T) \\ &= E(s[k](hs[k]+n)^T) \\ &= h^T E(s^2[k]) + E(s[k]n) \\ &= h \end{aligned}$$,

Note :

a) $E(s^2[k]) = 1$ is the variance of the input signal

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

Simulation Model

Matlab simulation for computing BER for BPSK with 3 tap ISI channel with MMSE Equalization:

(a) Generation of random binary sequence

(b) BPSK modulation i.e bit 0 represented as -1 and bit 1 represented as +1

(c) Convolving the symbols with a 3-tap fixed fading channel.

(d) Adding White Gaussian Noise

(e) Computing the MMSE and ZF equalization filter at the receiver

(f) Demodulation and conversion to bits

(g) Counting the number of bit errors

(h) Repeating for multiple values of Eb/No

The simulation results are as shown in the plot Figure(4). ..

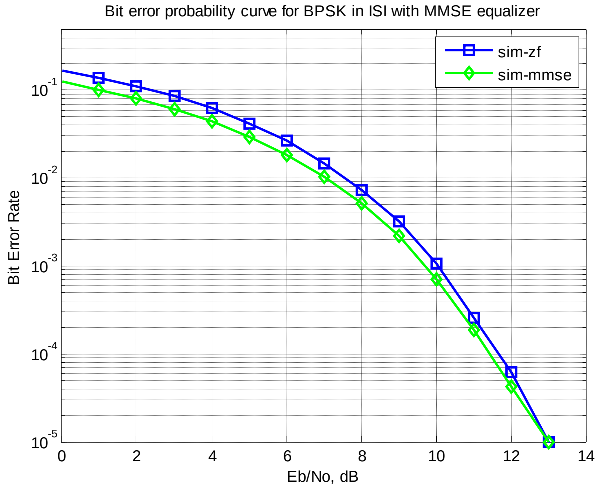


Figure: (4) BER plot for BPSK in a 3 tap ISI with mmse equalizer

IV. ALAMOUTI STBC

Three receive diversity schemes – Selection combining, Equal Gain Combining and Maximal Ratio Combining. All the three approaches used the antenna array at the receiver to improve the demodulation performance, albeit with different levels of complexity. Time to move on to a **transmit diversity** scheme where the information is spread across multiple antennas at the transmitter. lets discuss a popular transmit diversity scheme called **Alamouti Space Time Block Coding (STBC)[9]**. For the discussion, we will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK.

A simple Space Time Code, suggested by Mr. Siavash M Alamouti in his landmark October 1998 paper – A Simple Transmit Diversity Technique for Wireless Communication[10], offers a simple method for achieving spatial diversity with two transmit antennas. The scheme is as follows:

1. Consider that we have a transmission sequence,
   For example $\{x_1, x_2, x_3, \ldots, x_n\}$
2. 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.
3. However, Alamouti suggested that 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.

4. 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.

5. This forms the simple explanation of the transmission scheme with Alamouti Space Time Block coding shown in Figure: (5)-(6)

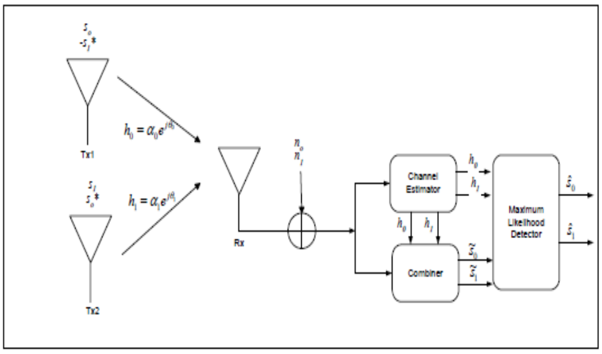


Figure: (5) Alamouti's 2Tx and 1Rx STBC Scheme

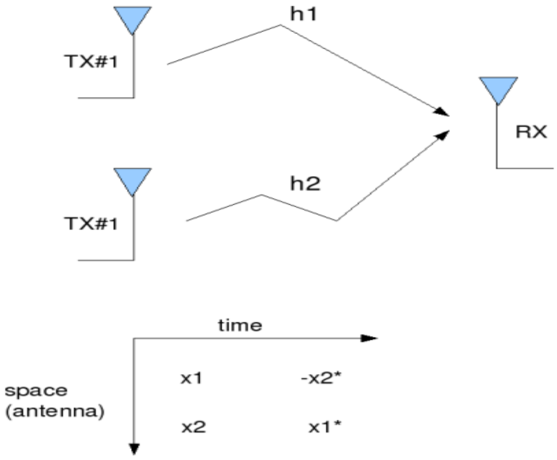


Figure: (6) 2-Transmit, 1-Receive Alamouti STBC coding

Other Assumptions

1. The channel is flat fading – In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication.

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

3. For the i^{th} transmit antenna, each transmitted symbol gets multiplied by a randomly varying complex number h_i . As the channel under consideration is a Rayleigh channel, the real and imaginary parts of h_i are Gaussian distributed having mean $\mu_{h_i} = 0$ and variance $\sigma^2_{h_i} = \frac{1}{2}$.

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 n has the Gaussian probability density function with

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

6. The channel h_i is known at the receiver.

Receiver with Alamouti STBC

In the first time slot, the received signal is,

$$y_1 = h_1 x_1 + h_2 x_2 + n_1 = [h_1 \ h_2]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1.$$

In the second time slot, the received signal is,

$$y_2 = -h_1 x_2^* + h_2 x_1^* + n_2 = [h_1 \ h_2]\begin{bmatrix} -x_2^* \\ x_1^* \end{bmatrix} + n_2$$

.

Where

y_1, y_2 is the received symbol on the first and second time slot respectively,
h_1 is the channel from 1^{st} transmit antenna to receive antenna,
h_2 is the channel from 2^{nd} transmit antenna to receive antenna,
x_1 , x_2 are the transmitted symbols and
n_1, n_2 is the noise on 1^{st},2^{nd} time slots.

Since the two noise terms are independent and identically distributed,

$$E\left\{\begin{bmatrix} n_1 \\ n_2^* \end{bmatrix}\begin{bmatrix} n_1^* & n_2 \end{bmatrix}\right\} = \begin{bmatrix} |n_1|^2 & 0 \\ 0 & |n_2|^2 \end{bmatrix}.$$

For convenience, the above equation can be represented in matrix notation as follows:

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \underbrace{\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix}.$$

Let us define $\boldsymbol{H} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$. To solve for

$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$, we know that we need to find the inverse of $\boldsymbol{H}$. We know, for a general m x n matrix, the pseudo inverse is defined as,

$$\boldsymbol{H}^{+} = (\boldsymbol{H}^{H}\boldsymbol{H})^{-1}\boldsymbol{H}^{H}.$$

The term,

$$(H^H H) = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} = \begin{bmatrix} |h_1|^2+|h_2|^2 & \\ 0 & |h_1|^2+|h_2 \end{bmatrix}$$

. Since this is a diagonal matrix, the inverse is just the inverse of the diagonal elements, i.e

$$(H^H H)^{-1} = \begin{bmatrix} \frac{1}{|h_1|^2+|h_2|^2} & 0 \\ 0 & \frac{1}{|h_1|^2+|h_2|^2} \end{bmatrix}.$$

The estimate of the transmitted symbol is,

$$\widehat{\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}} = (H^H H)^{-1} H^H \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}$$

$$= (H^H H)^{-1} H^H \left(H \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \right)$$

$$= \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + (H^H H)^{-1} H^H \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix}.$$

By compare the above equation with the estimated symbol following equalization in Maximal Ratio Combining, we can see that the equations are identical.

Alamouti STBC with two receive antenna

The principle of space time block coding with 2 transmit antenna . With two receive antenna's the system can be modeled as shown in the figure (7) below.

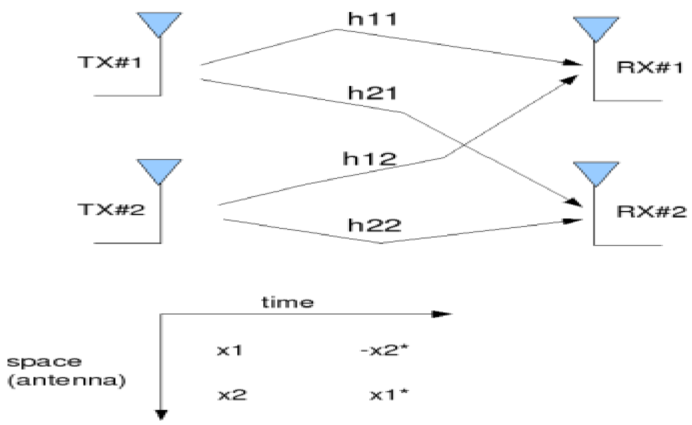


Figure: (7) Transmit 2 Receive Alamouti STBC

The received signal in the first time slot is,

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

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

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

where

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

$\begin{bmatrix} y_1^2 \\ y_2^2 \end{bmatrix}$ are the received information at time slot 2 on receive antenna 1, 2 respectively, h_{ij} is the channel from i^{th} receive antenna to j^{th} transmit antenna,

x_1, x_2 are the transmitted symbols,

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

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

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

Let us define

$$\boldsymbol{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix}$$

,To solve for $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$, we know that we need to find the inverse of $\boldsymbol{H}$. $\boldsymbol{H}^+ = (\boldsymbol{H}^H \boldsymbol{H})^{-1} \boldsymbol{H}^H$.The term,

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

Since this is a diagonal matrix, the inverse is just the inverse of the diagonal elements, i.e

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

The estimate of the transmitted symbol is,

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

.

V. BER with Almouti STBC

Since the estimate of the transmitted symbol with the Alamouti STBC scheme is identical to that obtained from MRC, the BER with above described Alamouti scheme should be same as that for MRC. However, there is a small catch.

With Alamouti STBC, we are transmitting from two antennas. Hence the total transmits power in the Alamouti scheme is twice that of that used in MRC. To make the comparison fair, we need to make the total transmit power from two antennas in STBC case to be equal to that of power transmitted from a single antenna in the MRC case. With this scaling, we can see that **BER performance of 2Tx, 1Rx Alamouti STBC case has a roughly 3dB poorer performance that 1Tx, 2Rx MRC case**.

From the Maximal Ratio Combining, the bit error rate for BPSK modulation in Rayleigh channel [8]with 1 transmit, 2 receive case is,

$$P_{e,MRC} = p_{MRC}^2 \left[1 + 2(1 - p_{MRC})\right],$$

where $p_{MRC} = \frac{1}{2} - \frac{1}{2}\left(1 + \frac{1}{E_b/N_0}\right)^{-1/2}$.

With **Alamouti 2 transmit antenna, 1 receive antenna STBC** case,

$$p_{STBC} = \frac{1}{2} - \frac{1}{2}\left(1 + \frac{2}{E_b/N_0}\right)^{-1/2}$$

and

Bit Error Rate is

$$P_{e,STBC} = p_{STBC}^2 \left[1 + 2(1 - p_{STBC})\right].$$

1. There is no cross talk between x_1, x_2 after the equalizer.
2. The noise term is still white.

$$E\left\{H^H \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \begin{bmatrix} n_1^* & n_2 \end{bmatrix} H\right\} = H^H \begin{bmatrix} |n_1|^2 & 0 \\ 0 & |n_2|^2 \end{bmatrix} H = \begin{bmatrix} |n_1|^2 & 0 \\ 0 & |n_2|^2 \end{bmatrix} \begin{bmatrix} |h_1|^2 + |h_2|^2 & 0 \\ 0 & |h_1|^2 + |h_2|^2 \end{bmatrix}$$

.

Simulation Model for BPSK in Rayleigh channel With two transmit and one receive antenna:

The Matlab simulation performs the following

(a) Generate random binary sequence of +1's and -1's.

(b) Group them into pair of two symbols

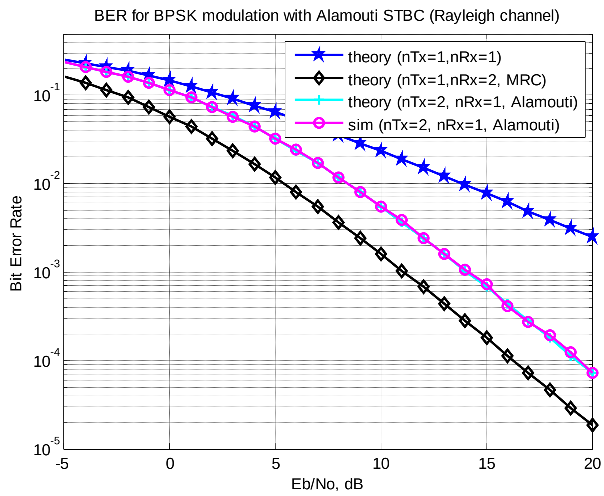
(c) Code it per the Alamouti Space Time code, multiply the symbols with the channel and then add white Gaussian noise.

(d) Equalize the received symbols

(e) Perform hard decision decoding and count the bit errors

(f) Repeat for multiple values of E_b/N_0 and plot the simulation and theoretical results.

The simulation results are as shown in the plot below Fig (8).



Fig(8) BER plot for BPSK in Rayleigh channel With two transmit and one receive antenna

Simulation Model for BPSK in Rayleigh channel With two transmit and two receive antenna:

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(a) Generate random binary sequence of +1′s and -1′s.

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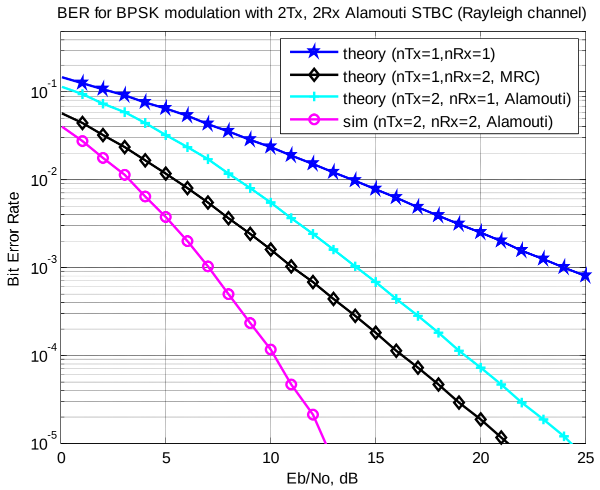
(c) Code it per the Alamouti Space Time code, multiply the symbols with the channel and then add white Gaussian noise.

(d) Equalize the received symbols

(e) Perform hard decision decoding and count the bit errors

(f) Repeat for multiple values of Eb/No and plot the simulation and theoretical results.

The simulation results are as shown in the plot below Fig (9).



Fig(8) BER plot for BPSK in Rayleigh channel With two transmit and two receive antenna

VI. CONCLUSION

While performing Matlab simulations, the channel model we use also plays an important role. Mobile wireless multipath fading channels can be simulated by discrete multipath channel models with desired properties.

In this work we develop a generally applicable equalization technique for space-time block coded (STBC) MIMO orthogonal frequency division multiplexing (OFDM) communication systems. Maximum likelihood approaches are developed and Iterative solutions are proposed. The maximum likelihood algorithm is based on iterative least squares with projection.

We can observe that the BER performance is much better than 1 transmit 2 receive MRC case. This is because the effective channel concatenating the information from 2 receive antennas over two symbols results in a diversity order of 4. In general, with ***m*** receive antennas, the diversity order for 2 transmit antenna Alamouti STBC is 2***m***.BER plots for BPSK in Rayleigh channel With two transmit and one receive antenna as well as two transmit and two receive antennas for Alamouti case are derived and simulated.. It is also shown that the minimum mean square error MMSE channel estimator for OFDM transmitter diversity systems has a lower computational complexity and better performance by assuming that the channel is a flat fading Rayleigh multi path channel and the modulation is BPSK.

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N.Sreekanth is native of Kadapa town of Kadapa District of Andhra Pradesh, India. He received A.M.I.E.(ECE) degree from I.E.I.(INDIA) India in 2001, M.Tech degree from SriKrishnadevaraya University, Anantapur, Andhra Pradesh, India in 2005. Currently he is pursuing PhD from J.N.T.U., Anantapur, A.P under the esteemed guidance of Dr.M.N.GiriPrasad. And his area of interest is Digital and wireless communications. He is a member of ISTE, IEI (E-mail: amail2sree@gmail.com).

Dr.M.N.GiriPrasad is native of Hindupur town of Anantapur District of AndhraPradesh, India. He received B.Tech degree from J.N.T University College of Engineering, Anantapur, Andhra Pradesh, India in 1982, M.Tech degree from SriVenkateshwara University, Tirupati, Andhra Pradesh, India in 1994 and He has been honored with PhD in2003 from J.N.T.U. Hyderabad., Andhra Pradesh, India. Presently he is working as Professor in department of Electronics and Communication at J.N.T.UA., Anantapur, Andhra Pradesh, India. His research areas are Wireless Communications and Biomedical Instrumentation. He is a member of ISTE, IE & NAFE.
(E-mail: mahendran_gp@rediffmail.com).