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MIMO-OFDM System for Improved Diversity Using STBC

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Abstract— **Severe attenuation in a multipath wireless environment makes it extremely difficult for the receiver to determine the transmitted signal unless the receiver is provided with some form of diversity, i.e., some less-attenuated replica of the transmitted signal is provided to the receiver. Space–time block coding, is a solution to this problem. In this 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 affected by noise. Space–time block codes provides us the advantage to achieve the maximum diversity order for a given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm. In this paper we describe space time coding with OFDM and compare BER performance and diversity with different modulation schemes and different antenna arrangement.**

Keywords: **Diversity, multipath channels, multiple antennas, space–time block codes, wireless communication.**

I. Introduction

Multiple-input multiple-output (MIMO) technology constitutes a breakthrough in the design of wireless communications systems, and is already at the core of several wireless standards.

By applying MIMO technology, we can directly take advantage of 2 very important properties [8];

1. Diversity
2. Multiplexing.

Diversity means that the system provide a receiver with multiple replicas (copies) of the same information bearing signal, the duplicated signals are slightly changed by fading. The 3 types of Diversity techniques are:

a. Space Diversity

This means the antenna elements are sufficiently spaced apart to achieve independence between the transmitted and received signals. The spatial separation needs to be at least half the wavelength to obtain desired results of independence.

b. Time Diversity – without wasting bandwidth

The same information is transmitted in different Time slots with the time slots separated by measures equal to or greater than the coherence time of the channel.

c. Frequency Diversity

The same information is transmitted on different carrier frequencies which are separated by measures equal to or greater than the coherence bandwidth of the channel.

The reliability of the network is improved by taking advantage of the space and time diversity while the rate of transmission is improved by multiplexing.

The earliest ideas in this field of MIMO were given by A.R. Kaye and D.A. George (1970) and W. van van Etten (1975, 1976). Jack Winters of Bell laboratories wrote an article titled “Optimum Combining in Digital Mobile Radio with Co-channel Interference” [3]. After publishing the article a number of efforts have been made by many engineers and academics to better understand the MIMO system. Spatial Multiplexing using MIMO was proposed in 1993 by Arogyaswami Paulraj and Thomas Kailath. In the year 1996, few major studies had been made in increasing the signal efficiency over MIMO channels. This year Gregory G. Raleigh and V.K. Jones combinedly wrote a paper titled as “Multivariate Modulation and Coding for Wireless Communication” [4]. In that paper they claimed that multi-path channels can have a multiplicative capacity effect if the multi-path-signal propagation is used in an appropriate communications structure. In the commercial arena, Iospan Wireless Inc. developed the first commercial system in 2001 that used MIMO-OFDMA technology. Iospan technology supported both diversity coding and spatial multiplexing. In 2006, several companies (Beceem Communications, Samsung, Runcom Technologies, etc.) have developed MIMO-OFDMA based solutions for IEEE 802.16e WIMAX broadband mobile standard. All upcoming 4G systems will also employ MIMO technology. Several research groups have demonstrated over 1 Gbit/s prototypes.

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OFDM

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications. Conceptually, OFDM is a specialized FDM, the additional constraint being: all the carrier signals are orthogonal to each other. In OFDM, the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other, meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver; unlike conventional FDM, a separate filter for each sub-channel is not required.

Orthogonality

Two periodic signals are orthogonal when the integral of their product over one period is equal to zero.

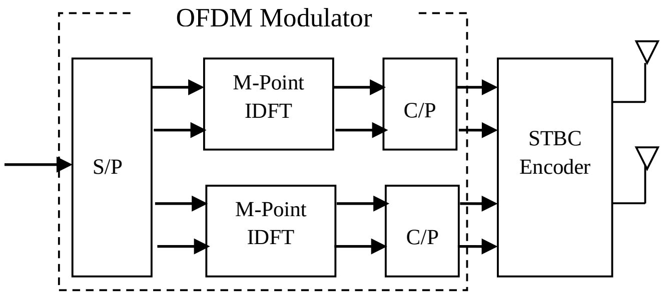
For the case of continuous time:

$$\int_0^T \cos(2\pi n f_0 t)\cos(2\pi m f_0 t)dt = 0,$$

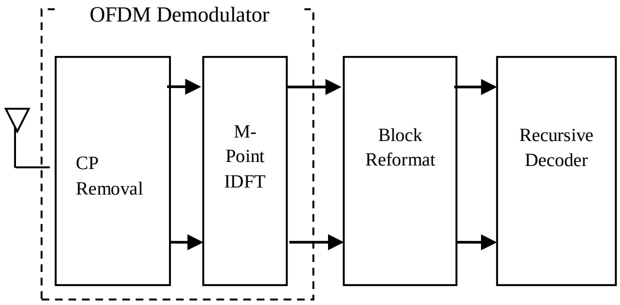
For the case of discrete time:

$$\sum_{k=0}^{N-1} cos\left(\frac{2\pi kn}{N}\right) cos\left(\frac{2\pi km}{N}\right) dt = 0,$$

Where $m \neq n$ in both cases.



(a) Transmitter structure



(b) Receiver structure

Figure1: STBC-OFDM block diagram

II. METHODOLOGY

A. MIMO with STBC

One of the methodologies for exploiting the capacity in MIMO system consists of using the additional diversity of MIMO systems, namely spatial diversity, to combat channel fading. This can be achieved by transmitting several replicas of the same information through each antenna. By doing this, the probability of losing the information decreases exponentially. The antennas in a MIMO system are used for supporting a transmission of a SISO system since the targeted rate of is that of a SISO system. The diversity order or diversity gain of a MIMO system is defined as the number of independent receptions of the same signal. A MIMO system with N_t transmit antennas and N_r receive antennas has potentially full diversity (i.e. maximum diversity) gain equal to $N_t N_r$.

The different replicas sent for exploiting diversity are generated by a space-time encoder which encodes a single stream through space using all the transmit antennas and through time by sending each symbol at different times [5].

B. Alamouti STBC

A simple transmit diversity technique for wireless communication, 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 $\{x_1, x_2, x_3 \ \dots x_n\}$

2. In normal transmission, we will be sending x1 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,

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send x_1 and x_2 from the first and second antenna. The second time slot send $-x_2^*$ and x_1^* from the first and second antenna. 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.

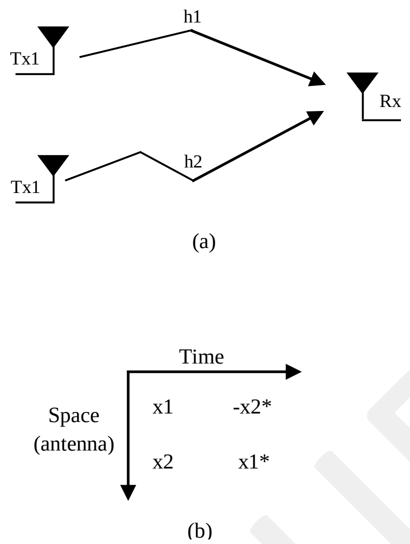

Figure-2: Transmit, 1-Receive Alamouti STBC coding

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,

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

Where

y_1, y_2,is the received symbol on the first and second timeslot respectively,h_1 is the channel from 1st transmit antenna to receive antenna, h_2 is the channel from 2st transmit antenna to receive antenna,x_1, x_2 are the transmitted symbols and n_1, n_2 is the noise on 1st,2st 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:

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

Let us define. $H = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$To solve for, $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$ we know that we need to find the inverse of H.

We know, for a general m x n matrix, the pseudo inverse is defined as,

$$H^+ = (H^H H)^{-1} H^H$$

The term,

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

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,

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

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

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

If you compare the above equation with the estimated symbol following equalization in Maximal Ratio Combining, you can see that the equations are identical [7].

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C. OSTBC System Model

Consider a MIMO system, where OSTBC is employed at the transmitter and the transmitted signals are subject to certain block fading, i.e., the channel coefficients remain constant during the transmission of a block, and change to some new values when another block arrives. In such a system, the received signals of a transmitted code block are given by

$$R = HS + N,$$

Where $R \in C^{Nr\times Nc}$ the received signal matrix is $H \in C^{Nr\times Nt}$ is the instantaneous channel matrix. $S \in C^{Nr\times Nc}$ is the OSTBC code block obtained via orthogonally encoding K modulated symbols $s_1. \; . \; .s_k$. The code block lasts for a period of N_c modulated symbols, resulting in a spatial code rate $R = K/Nc$. $\mathbf{N} \in C^{Nr\times Nc}$ Is the noise matrix, whose elements is independent and identically distributed complex Gaussian variables with zero means and unit variances. Generally speaking, the code rate $R \,(\leq 1)$ is a function of N_t: in the Alamouti scheme, $N_t = 2$ and $R = 1$; in the half-rate scheme [3], $Nt > 2$ and $R = \frac{1}{2}$; and in the square-matrix embeddable scheme, $N_t \geq 2$ and

$$R = \frac{[log_2 N_t] + 1}{2[log_2 N_t]}$$

Where [.] is the ceiling function. Throughout this paper, we assume that the channel matrix H is independently drawn according to a certain distribution. Letting ΔT (seconds) denote the duration of a modulated symbol, the assumption above says, for every $N_c \Delta T$ seconds, the channel matrix H changes independently to a new value according to a certain distribution.

With perfect channel state information (CSI) and maximum likelihood decoding at the receiver, the MIMO channel H (remaining constant for a period of $N_c \Delta T$ seconds) is decoupled into K effective single-input single-output (SISO) channels, whose input-output relation is

$$r_k = \sqrt{\frac{\rho tr(H^H H)}{N_t R}} s_k + n_k, \qquad K = 1, \ldots, K$$

Where $tr(.)$the trace of a matrix, $.^H$ is is the conjugate transposition, r_k is the received signal, ρ is the total power transmitted through N_t antennas, s_k is the unit-powered data symbol transmitted, n_k is the Gaussian noise with zero mean and unit variance, and all $n_k's$ are statistically independent.

Based on the effective SISO model, the instantaneous signal-to-noise ratio (SNR) for each SISO sub-channel is readily obtained

$$\gamma_{OSTBC} = \frac{\rho tr(H^H H)}{N_t R} = \frac{\rho}{N_t R} \sum_{i=1}^{M} \lambda_i$$

Where M is the rank of H, and $\lambda_i's$ are the descending-order eigen-values of $H^H H$, i.e., $\lambda_1 \geq \,..\lambda_M > 0$.

III. Results

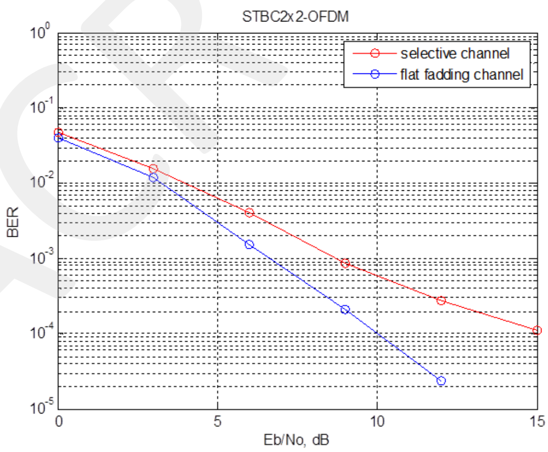

Figure 3: Channel response of 2x2 MIMO system incorporating STBC and OFDM using QPSK

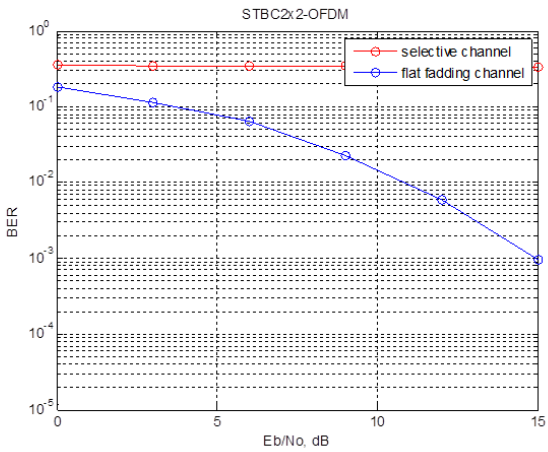

Figure 4: Channel response of 2x2 MIMO system incorporating STBC and OFDM using BPSK

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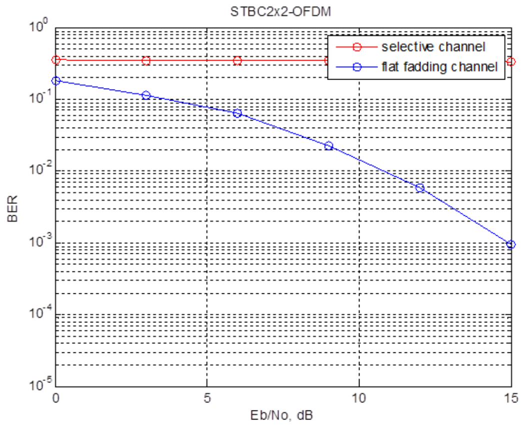

Figure 5: Channel response of 2x2 MIMO system incorporating STBC and OFDM using 64QAM

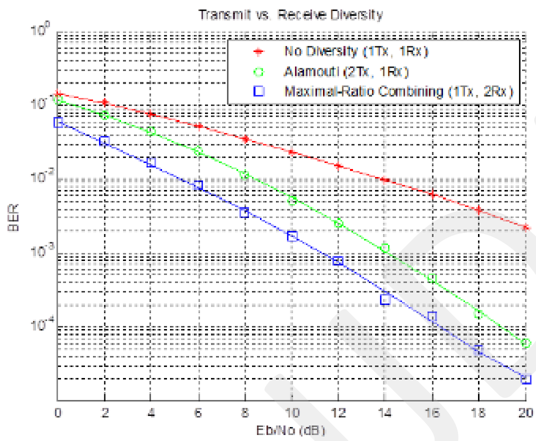

Figure 6: Comparison of different diversity scheme diversity

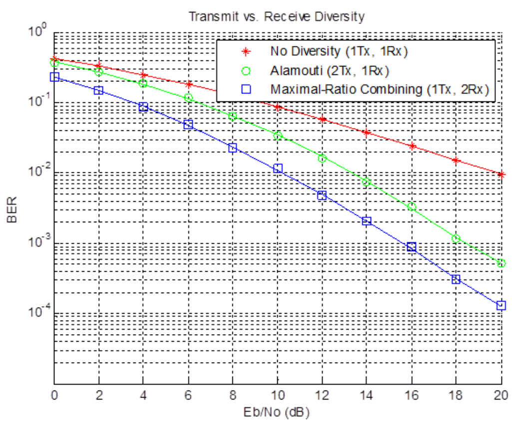

Figure 7: Comparison of different diversity scheme diversity

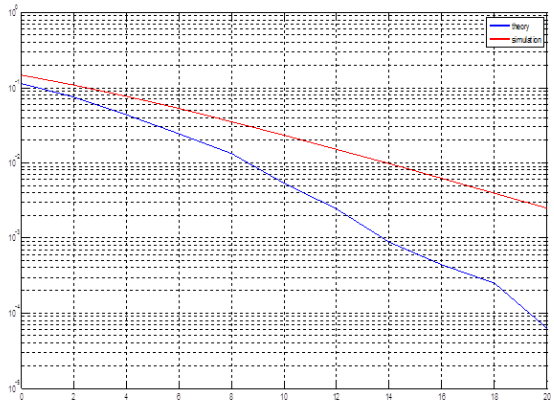

Figure 8: Theoretical and Practical Simulation

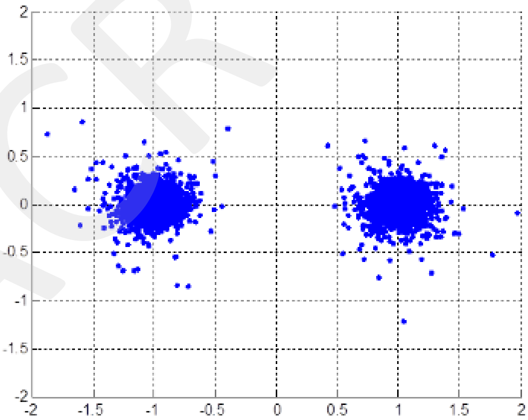

Figure 9: Scatter diagram of system

IV. CONCLUSION

Space-time block codes are a remarkable modulation scheme discovered recently for the multiple antenna wireless channels. They have an elegant mathematical solution for providing full diversity over the coherent, flat-fading channel. In addition, they require extremely simple encoding and decoding. The above results show that diversity of the system and BER performance is improved using STBC-OFDM with MIMO system.

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