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Cognitive MIMO Receiver with Spatial Multiplexing and OSTBC Technique for Fading Channel

K. Ambika[1], M. Loganathan[2]
[1]PG Scholar, Department of Electronics and Communication Engineering., Thanthai Periyar Govt. Institute of Technology, Vellore, India
[2]Assistant Professor, Department of Electronics and Communication Engineering., Thanthai Periyar Govt. Institute of Technology, Vellore, India

***Abstract*: Recently many researchers have been working on MIMO systems with STBC to improve the performance of system without additional bandwidth or transmit power requirements. In MIMO system, the transmitter and receiver are equipped with multiple antennas. The MIMO system provides multiple independent channels, so the channel capacity increases linearly with the number of antennas. Orthogonal Space-time block codes (OSTBC) have been shown to perform well with Multiple -Input Multiple Output (MIMO) systems. The design aspect of wireless system aims at improvement in spectral efficiency and coverage area with reliable performance. The Spatial Multiplexing (SM) and Orthogonal Space-time Block Coding (OSTBC) schemes provide the different benefits according to the Channel quality. Therefore, base station must have the capability of detecting both SM and OSTBC from each CR user at the same time. The Space-Time Block Codes (STBC) for wireless networks that uses multiple numbers of antennas at both transmitter and receiver. The simulations have been done in MATLAB. The STBC which includes the Alamouti Scheme as well as an orthogonal**

***Keywords*: cognitive Radio, MIMO, Spatial multiplexing, OSTBC, QPSK, Fading Channel**

1. Introduction

In wireless communications, Cognitive radio spectrum is a scarce resource and hence imposes a high cost on the high data rate transmission. MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. Multi-antenna systems currently play and are expected to keep playing a very important role in future multimedia wireless communication system. Future MIMO systems are predicted to provide tremendous improvement in spectrum utilization. Multiple antennas when used with appropriate Orthogonal Space-Time Coding (STC) techniques can achieve huge performance gains in multipath fading wireless links.

MIMO technology it is found that between the transmitter and the receiver the signal can take multiple paths. Previously, these multiple paths only serve to introduce interference, but by using MIMO these additional paths may serve as advantage as they can be used to provide additional robustness to the radio link. The two coding methods or algorithms used in MIMO are Spatial Diversity and Spatial Multiplexing. Multiple-antenna channels provide spatial diversity, which can be used to improve the reliability of the link. Multiple antennas, when used at both the transmitter and the receiver, create a MIMO propagation channel. Using sophisticated coding at the transmitter and substantial signal processing at the receiver, the MIMO channel can be provisioned for higher data rates, resistance to multipath fading, lower delays, and support for multiple users.

A. MIMO (Multiple input Multiple Output)

Multiple input multiple output communication pronounced like a single processing technique to enhance the execution of wireless correspondence system by using numerous receiving antenna at transmitter side and beneficiary side or both. By combating or exploiting multipath scattering, MIMO techniques improve communication performance in communication channel between a transmitter and receiver. Spatial diversity improves reliability the purpose of spatial multiplexing is to maximize throughput. MIMO has turned into a key component of remote correspondence measures including Long Term Evolution, IEEE 802.11n, IEEE 802.11ac, WiMAX, HSPA+ (3G).

These two systems are listed below

1. MIMO implemented using diversity techniques – provides diversity gain–Aimed at improving the reliability.
2. MIMO implemented using spatial-multiplexing techniques–provides degrees of freedom or multiplexing gain – Aimed at improving the data rate of the system.
3. MIMO implemented using improving Spectrum efficiency becomes the most efficient method of network performance.

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2. Alamouti scheme

Alamouti scheme is the basis of the Space Time Coding technique. Using two transmit antennas and two receive antenna, the scheme provides the same diversity order as maximal-ratio receiver combining (MRRC) with two transmit antenna and two receive antennas. The scheme may easily be generalized to two transmit antennas and M receive antennas to provide a diversity of 2M.

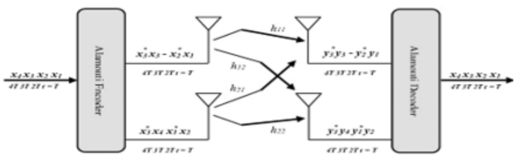

Fig. 1. Alamouti space-time encoder and decoder

A. *Encoder unit*

The encoder and decoder of the Alamouti scheme system is shown in Figure1. Here the information to be transmitted is modulated and fed to the space time encoder. The space time encoder consists of two transmit antennas as part of the multiple input multiple output technology. So here the information is transmitted through two separate antennas. Each transmitting and the receiving antenna pair has a channel, represented by different channel coefficients. These channel coefficients play a major role in the design of the system. As the number of antennas increases at both the ends of the channel, the complexity of the system also increases.

B. *Decoder unit*

In the decoder, the received signal is fed to the channel estimator. The estimated coefficients of the channel together with the combiner are given as the input to the maximum likelihood detector. The detected signal is then fed to the demodulator. The demodulator gives the original information which is transmitted. The space-time block codes are the higher version of the Alamouti scheme. i.e, increment of the number of antennas of the Alamouti scheme, the space-time block codes will result. As an example of the STBC's, a case of 4 transmitted antennas and four receive antenna is explained here.

C. *MIMO Spatial Multiplexing*

To take advantage of the additional throughput capability, MIMO utilizes several sets of antennas. In many MIMO systems, just two are used, but there are no reason why further antennas cannot be employed and this increases the throughput. In any case for MIMO spatial multiplexing the number of receiver antennas must be equal to or greater than the number of transmit antennas.

To take advantage of the additional throughput offered, MIMO wireless systems utilize a matrix mathematical approach. Data streams t1, t2 . . . can be transmitted from antennas 1, 2 . . . n. Then there are a variety of paths that can be used with each path having different channel properties. To enable the receiver to be able to differentiate between the different data streams it is necessary to use. These can be represented by the properties h12, travelling from transmit antenna one to receive antenna 2 and so forth. In this way for a three transmit, three receive antenna system a matrix can be set up:

r1 = h11 t1 + h21 t2 + h31 t3
r2 = h12 t1 + h22 t2 + h32 t3
r3 = h13 t1 + h23 t2 + h33 t3

Where r1 = signal received at antenna 1, r2 is the signal received at antenna and h is the channel coefficient the transmitted signal.

In matrix format this can be represented as:

To recover the transmitted data-stream at the receiver it is necessary to perform a considerable amount of signal processing. First the MIMO system decoder must estimate the individual channel transfer characteristic hij to determine the channel transfer matrix. Once all of this has been estimated, then the matrix [H] has been produced and the transmitted data streams can be reconstructed by multiplying the received vector with the inverse of the transfer matrix.

[T] = [H]-1 x [R]

D. *Space Time block code*

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 and then sent to the maximum likelihood detector where the decision rules are applied. 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.

A space time block code is usually represented by a matrix. Each row represents a time slot and each column represents one antenna's transmissions over time.

E. *OSTBC encoder and decoder*

The OSTBC Encoder block encodes the information symbols from the BPSK or QPSK Modulator by using either the Alamouti code for two transmit antennas or other generalized complex orthogonal codes for the two or three transmit antennas. The number of transmit antennas is given to this block as an input. The output of this block is an (Ns x Nt) variable-size matrix, where the number of columns (Nt) corresponds to the number of transmit antennas and the number of rows (Ns) corresponds to the number of orthogonal code samples transmitted over each transmit antenna in a frame.

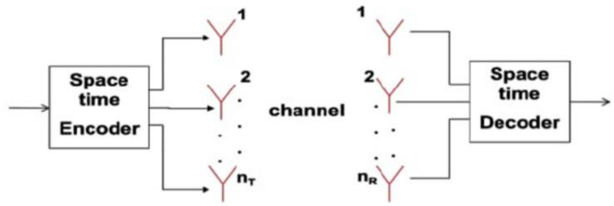

Fig. 2. OSTBC encoder

F. OSTBC decoder

The OSTBC Combiner object combines the input signal (from all of the receive antennas) and the channel estimate signal to extract the soft information of the symbols encoded by an OSTBC. The combining algorithm uses only the estimate for the first symbol period per code word block. A symbol demodulator or decoder would follow the Combiner object in a MIMO communications system. Every TX and the Rx antenna pair has a channel, represented by different channel coefficients. In designing of any wireless system channel coefficients play important role. Complexity of that system is directly proportional to the number of antennas.

G. The Almouti 2X2 MIMO scheme

Alamouti scheme is considered the foundation stone for the Space Time Coding technique. Here the mathematical explanation of the scheme with two transmitting and two receiving antennas is also explained. Two-branch transmit diversity scheme is implemented. Using two transmit antennas and two receive antenna. This scheme could easily be generalized into two transmit antennas and M receive antennas to provide a diversity order of 2M.

At the Tx side, two symbols are taken from the source data and sent to the modulator. After that, Alamouti space-time encoder takes the two modulated symbols, in this case called and creates encoding matrix X, where the symbols and are mapped to two transmit antennas in two transmit time slots. The encoding matrix is given by,

$$X = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}.$$

Now the received vector after first time slot will be,

$$\begin{bmatrix} y_{11} \\ y_{12} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_{11} \\ n_{12} \end{bmatrix}.$$

Now the received vector after the second timeslot will be,

$$\begin{bmatrix} y_{21} \\ y_{22} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} -x_2^* \\ x_1^* \end{bmatrix} + \begin{bmatrix} n_{21} \\ n_{22} \end{bmatrix}$$

$\begin{bmatrix} y_{21} \\ y_{22} \end{bmatrix}$ = received vector in 1st time slot by antenna 1 &2.

$\begin{bmatrix} y_{21} \\ y_{22} \end{bmatrix}$ = received vector in 2nd time slot by antenna 1 & 2.

$\begin{bmatrix} n_{11} \\ n_{12} \end{bmatrix}$ = noise vector during time slot 1.

$\begin{bmatrix} n_{21} \\ n_{22} \end{bmatrix}$ = noise vector during time slot 2.

Now,

$$y = Hx + n$$

$$y = \begin{bmatrix} y_{11} & y_{12} & y_{21}^* & y_{22}^* \end{bmatrix}^T$$

$$x = \begin{bmatrix} x_1 & x_2 \end{bmatrix}^T$$

$$n = \begin{bmatrix} n_{11} & n_{12} & n_{21}^* & n_{22}^* \end{bmatrix}^T.$$

By combining the above equations, we get,

$$\begin{bmatrix} y_{11} \\ y_{12} \\ y_{21}^* \\ y_{22}^* \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_{11} \\ n_{12} \\ n_{21}^* \\ n_{22}^* \end{bmatrix}.$$

Alamouti scheme's encoder and decoder are shown in Figure. The transmitted information after modulation fed to the space time encoder. The space time encoder consists of two TX antennas. In these two separate antennas are used to transmit the information. Every Tx and the Rx antenna pair has a channel, represented by different channel coefficients. In designing of any wireless system channel coefficients play important role. Complexity of that system is directly proportional to the number of antennas.

3. Simulation results and discussion

Alamouti space-time code is an orthogonal scheme that can achieve the full transmit diversity of Nt = 2. The bit-error-rate (BER) versus signal-to-noise-ratio (Eb/No (dB)) performance for Alamouti transmit diversity scheme on slow fading channels is evaluated by simulation. In the simulation, it is assumed that the receiver has the perfect knowledge of the channel coefficient.

It is also assumed that the fading is mutually independent from each transmit antenna to each receive antenna and the total transmit power is the same for all cases. Figure 1 shows the Alamouti scheme BER versus Eb/No performance with coherent BPSK modulation. From the simulation result, it is very clear to see that Alamouti scheme has the same diversity as the two-branch maximal ratio combining (MRC).

However, from Graph 1, and Graph 2 we can see that Almouti scheme performance is worse than the two-branch MRC by 3 dB and that is because the energy radiated from the single antenna in the MRC is the double of what radiates from each transmit antenna in the Alamouti scheme. To reach the same results, the total transmit power from each transmit antenna in the Alamouti scheme has to be equal to the transmit power of the MRC. Also Fig. 3 gives the BER curves for the Alamouti scheme for QAM modulations in Rayleigh channel.

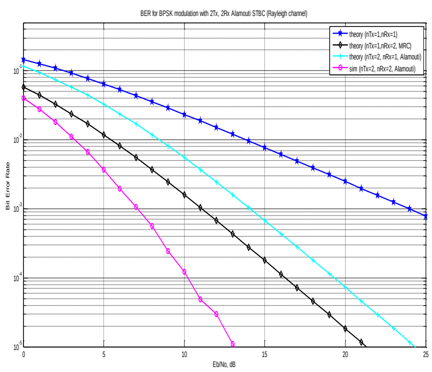

Fig. 3. Graph 1: BER of OSTBC for Nt=2 & Nr=2 in Rayleigh channel

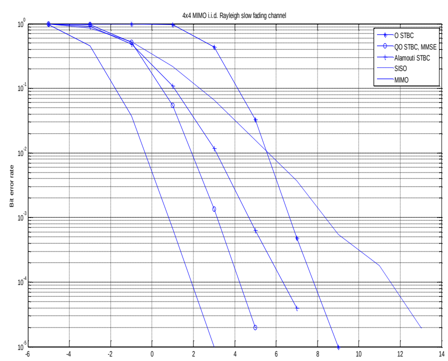

Fig. 4. Graph 2: BER of OSTBC for NT=NR=2 in Rayleigh channel

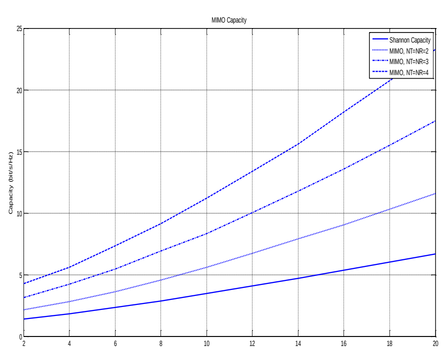

Fig. 5. Graph 3: Channel capacity of OSTBC Rayleigh channel

4. Conclusion

This paper gives a basic overview of the MIMO technology. A basic introduction to Space-Time Coding has been provided by presenting Alamouti's scheme. The Alamouti scheme has been simulated for BPSK modulation in Rayleigh channel. The same Alamouti scheme has been again simulated in Rayleigh channel for QPSK, 16-QAM and 64-QAM modulations and the BER are compared. After that the BER of Orthogonal Space-Time Block Coding that has 4 number of transmit antennas has been determined for different code rates and modulation (QPSK, 16-QAM, 64-QAM).

The better BER curve produced by a system which uses more number of antennas at both sides of the communication link. A particular application decides which modulation can be used. For example, in technologies like TV satellite transmission, higher modulation methods (256-QAM and 512-QAM) could be employed because the accuracy of received data at the user end is not essential. Other correction techniques could be employed to improve the performance of such systems. However, in mobile technology, the bit-error-rate is very important. In this case, accuracy is essential. Therefore, lower order modulation methods (QPSK and 16-QAM) are usually employed.

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