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MIMO Network and the Alamouti, STBC (Space Time Block Coding)

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Abstract In the present world, the spectrum efficiency along with the capacity and coverage of wireless networks are being improved by wireless specialists. Wireless link performance could be enhanced and improved by using multiple antenna technology called Space time wireless technology. There exists some advancement in the present MIMO techniques which could further improve the overall wireless Local Area Network (LANs) and Wide Area Network (WANs). In Multipath fading performance gain is very important which could be achieved by using an efficient Space-Time Coding (STC) technique. This Space Time coding along with Alamouti Scheme is a very vibrant research topic. In the forthcoming generation of mobile communication there will be a need of high data rate, reliable communication link and vast multimedia capabilities, STBC is the one solution for these. This paper presents the Space-Time Block Codes (STBC) for wireless networks using Alamouti Scheme in which multiple antennas are being used at both transmitter and receiver. The simulations have been done in MATLAB.

Keywords: *Space-Time Coding (STC), Alamouti scheme, Rayleigh fading, transmit diversity, Multiple Input Multiple Output (MIMO)*

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1. Introduction

Wireless communication holds a very important role in communication industry because of its remarkable capabilities. Media and common people are very much fascinated by the modern wireless communication. Over the last decade the Cellular system shows remarkable growth. So, Cellular phones captured the overall market and become an important device for every business and daily life communication in almost every country in the world. Due to this exponential growth, most of the wired line communication system is being replaced by the wireless communication system. Example could be, in most of the Schools, government departments, shopping malls and homes there exists wireless local area networks which replace wired network. Evolution is taking place as applications, like wireless sensor networks, smart homes and appliances and automated highways and factories are emerging from research ideas to concrete systems. This enormous growth of wireless systems together with the evaluation in the laptop computers shows us a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure.

In the present research, the idea is to achieve maximum receive diversity with the help of multiple antennas. This could benefit the performance gain of the receive diversity as by using multiple transmitters and receivers. The starting era for the development of transmit diversity techniques was early 1990. Since from that era research in that field grow rapidly due to its benefits. This multiple-input multiple-output (MIMO) technology is the building block or a cornerstone for wireless communication systems, as MIMO offers high data rate and better performance with less noise makes it feasible for efficient wireless link for transmit diversity.

2. MIMO Technology

In a reliable wireless communication system combating with the multipath fading is the biggest challenge. This fading effect could be resolvable by using spatial diversity in which multiple antennas at the transmitter and/or the receiver are used. In addition to this reliability improvement, a MIMO system increases system through put by transmitting multiple data streams. Thus, we get improved reliability and higher throughput with enhanced spectral efficiency and higher channel capacity.

MIMO systems can be defined per Figure 1, where transmitter and receiver is containing multiple antennas for a wireless communication [1]. In MIMO the transmit signals from a (TX) antennas at one end and the receive signals from a (RX) antennas at the other end are combined in a way so that bit-error rate (BER) and SNR of the communication for each MIMO user will be improved. So, this advantage could be used to increase the quality of service for a network.

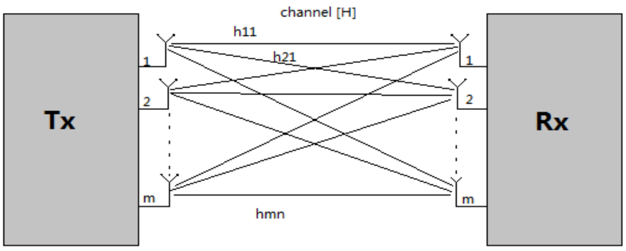

Figure 1. MIMO system

$$[Y] = [H][T] + n(noise)$$

[Y] = Received Signal.
[H] = Channel Matrix.
[T] = Transmitted signal..

A) ***Diversity***

Antennas configuration is very important but in MIMO another important aspect is the transmission of data across the available channel. Multiple antennas introduce various propagation paths. So, improvement is needed for reliable communication by sending same data across all available propagation paths. This process is called spatial diversity or simply diversity

Diversity allows combating with fading by sending same information across the independent channel. This could reduce the amount of fade suffered by every data copy by sending multiple copies of a data on independently fading channels. Less fading will be guaranteed on at-least one of the copy of a data. This will increase the chance to receive the proper transmitted data and reliability of the whole system will also be improved. Co-channel interference will become less by applying this strategy.

In Figure 2, transmitting with single antenna as well receiving with single antenna shows us" 0" diversity so if we increase the number of receiving antennas by one. In this system two copies of the same data will be sent through different channels with different fading characteristics. So, if one of the link will be failed the data will be delivered by the second link as shown in Figure 3.

1) *Time Diversity*

At different time slots, multiple versions of the same message signal are transmitted. In this a redundant forward error correction code is added in the message and spread on different time slots. Different channel coding is also used with it.

2) *Frequency Diversity*

The message signal is transmitted using different frequencies in form of different channels or spread over a wide spectrum. OFDM is the common example of frequency diversity.

3) *Space diversity:*

To transmit the signal different propagation paths will be available for a signal. Multiple wires could be used to transmit the data in the case of wired transmission. Wireless transmission also avails that diversity by transmitting the signal through multiple antennas and receives them also through multiple receive antennas.

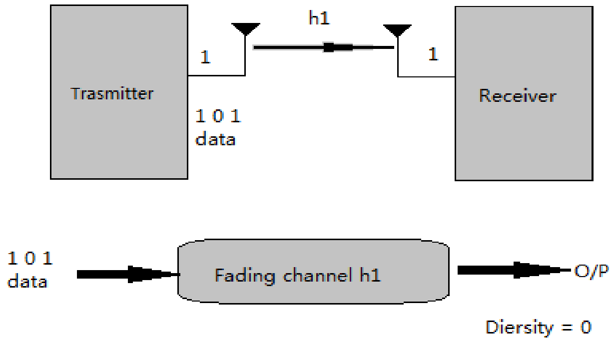

Figure 2. Zero Diversity between transceiver pair

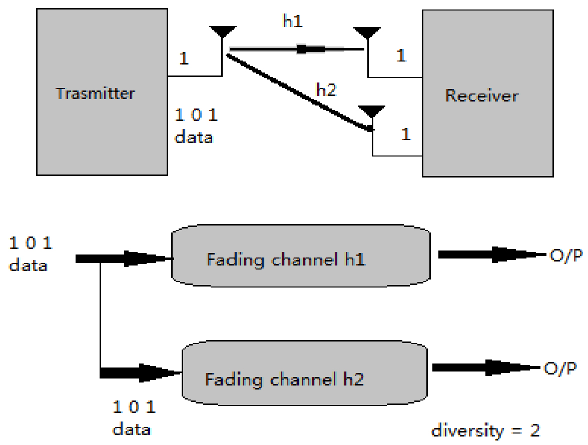

Figure 3. With Diversity between transceiver pair

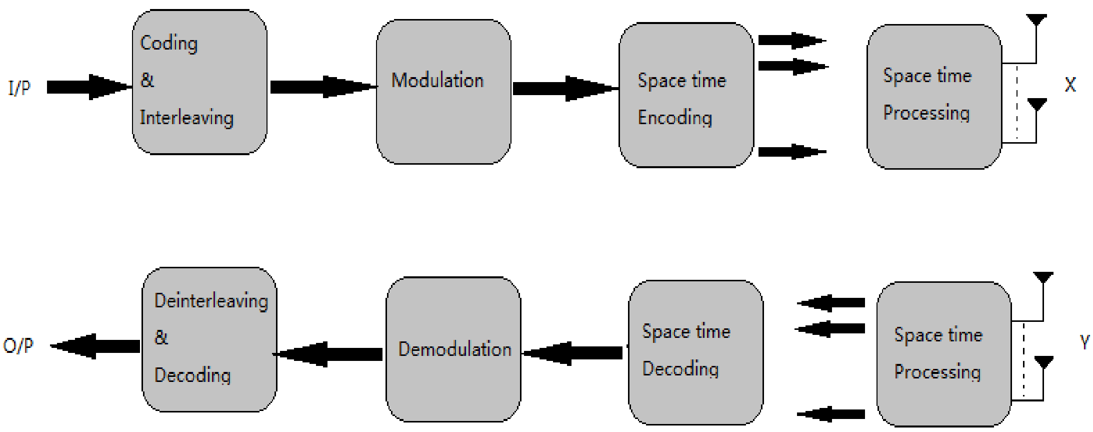

Figure 4. MIMO System Block diagram

B. *Equations*

It is important to know the power distribution of the signal. The Covariance matrix is very useful in determining the power of a received signal.

Consider a symbol period "T_s" for a transmitted signal. Therefore,

$$R_{xx} = E\left\{xx^H\right\} = I_m. \quad \text{(I)}$$

So, within the limit of "T_s"

$$R_{yy} = E\left[Hxx^H H^H\right] + E\{nn^H\}$$

$$R_{yy} = EH\left\{xx^H\right\} H^H + R_{nn}$$

$$R_{yy} = HH^H + R_{nn}.$$

So, for alarger value of"T_s"

$$R_{yy} = E\left\{HH^H\right\} + R_{nn} \quad \text{(II)}$$

Where,

R_{nn} = *Noise Covariance matrix.*

Off-diagonal elements of R_{xx} and R_{yy} gives the correlation between signals at different antenna elements. Equation II gives the information of received signal power with the help of covariance matrix $E\{HH^H\}$.

3. Space Time Block Code

It is the advance form of an Alamouti scheme; it holds all the important features of Alamouti scheme as well some advancement. These generalized codes are orthogonal in nature and transmit antennas can achieve full diversity through this. As already mentioned that STBC are the advancement of Alamouti Space time code in which the encoding and decoding schemes are the same as there in the Alamouti on both the transmitter and receiver sides. Data is constructed in the form of a matrix in which the column are equal to the number of the transmit antennas and the number of rows equal to the number of time slots for the transmission of data. The received signals at the Rx side sent to the maximum likelihood detector after combining.

In Space time block coding, spatial and temporal diversity is used. This coding scheme involves the transmission of multiple copies of the data. Through which many problems like fading and thermal noise could be solved. Due to the presence of redundancy in the data some copies may arrive less corrupted at the receiver. Through Space-time block codes maximum diversity could be achievable for the given number of transmit and receive antennas [8]. This increases the popularity of STBC and has made it most widely used scheme. A good result with the help of training-based methods exits in that scheme. This training-based scheme considered as an advantage for the accurate and reliable MIMO channel. This advantage could be prolonged to the bandwidth efficiency. The reason is that pure training-based schemes reduce the bandwidth efficiency by using long training sequence which is helpful to achieve a reliable MIMO channel estimation. This pilot sequence technique is used in many wireless communication systems due to its computational complexity.

4. Alamouti Coding Scheme

Alamouti scheme is considered the foundation stone for the Space Time Coding technique [10]. 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 [7]. 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 x_1 and x_2 creates encoding matrix X, where the symbols x_1 and x_2 are mapped to two transmit antennas in two transmit time slots. The encoding matrix is given by,

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

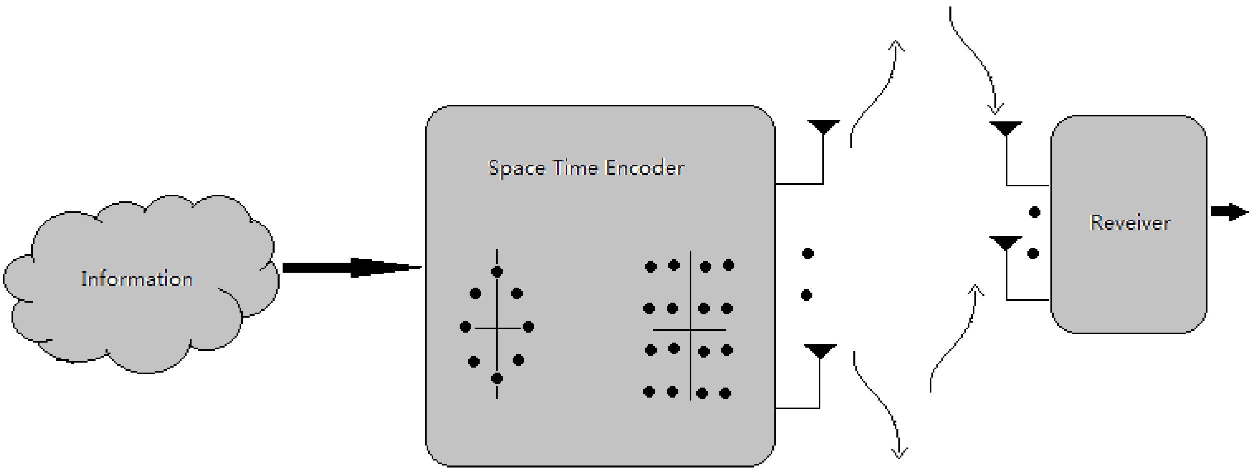

Figure 5. STBC flow digram using alamouti scheme

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 5 and Figure 6. The transmitted information after modulation fed to the space time encoder [13]. 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.

5. Experimental Results

As orthogonal in nature this Alamouti space-time code can achieve the full transmit diversity of Nt = 2. In general simulation results shows the bit-error-rate (BER) versus signal-to-noise-ratio (Eb/No) performance for Alamouti transmit diversity scheme on slow fading channels. Assumptions were being made that the receiver has the perfect knowledge of the channel coefficient. In simulations, another assumption was made, that the fading has no dependency on the transmit antenna to each receive antenna and the total transmit power is the same.

Figure 6 shows the result of Alamouti scheme with 16-QAM. 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 Figure 6, We can see that Alamouti scheme performance with 16-QAM is not good as BPSK [3].

From Figure 7 BER curves improves. On the other hand, better results are produced if the received side uses maximum number of antennas. Diversity clearly depends on the number of receive antennas so it diversity and receive antennas are directly proportional. Higher diversity will give better performance. So, while designing the STBC for an application, it is needed to select the number of antennas at both ends of the communication link, the modulation and the rate of transmission. By using the proper STBC technology, it is possible to improve the data rate and range of the wireless communication systems. The simulation is totally being done in MATLAB.

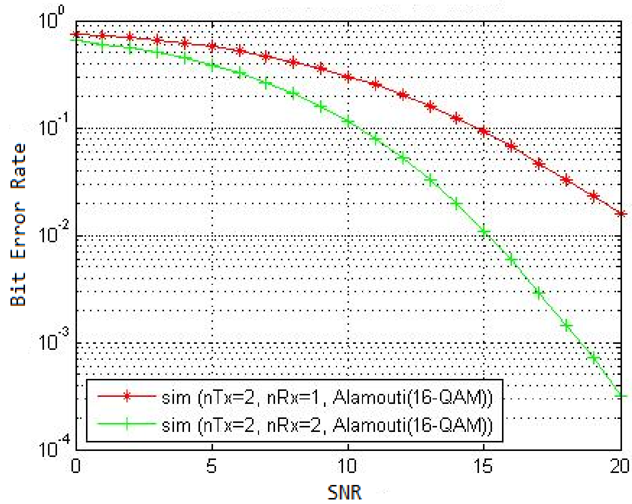

Figure 6. Alamouti (16-QAM)

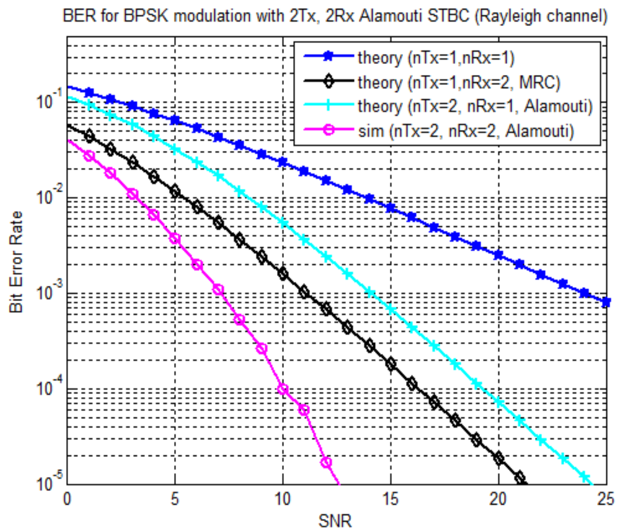

Figure 7. Alamouti Scheme with BPSK

6. Conclusion

In this paper the overall concept of MIMO technology is explained. Also, the Space-Time Coding is being explained in the light of a simple Alamouti scheme. In simulation, this Alamouti scheme has been simulated for BPSK modulation in Rayleigh channel. Again, the Alamouti scheme has been simulated in Rayleigh channel for 16-QAM modulations and the BER are compared. After that the BER of Orthogonal Space-Time Block Coding Number of transmit antennas has been determined for different code rates and modulation. So, concluded that better BER curve could be achievable by the system which uses more number of antennas at both sides of the communication link. An application decides which modulation can be used. For example, in technologies like Television satellite transmission higher modulation methods could be employed because the accuracy of received data at the user end is not essential. In mobile communication technology, the BER is very important. So, we must need greater accuracy. Therefore, lower order modulation methods (QPSK and 16-QAM) are usually employed. So, the application decides which modulation and the combination of antennas in the communication link.

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