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ON IMAGE TRANSMISSION IN MIMO COMMUNICATION CHANNELS USING ALAMOUTI SPACE-TIME CODES

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Abstract: Transmitting large amounts of data through wireless communication channels, at high speed and low error probability, is a major challenge for the researchers in the field. In this paper, aspects of image transmission in Multiple-Input Multiple-Output (MIMO) communication channels are studied, using binary phase-shift keying (BPSK) modulation and Alamouti space-time block code (STBC) with 2 transmitting and 2 receiving antennas. Alamouti code performance is simulated on large random data sequence for different values of signal-to-noise ratio (SNR). Also, some simulation results on image broadcasting using Alamouti STBC are presented.

Keywords: wireless, space-time codes, MIMO channels, fading.

1. INTRODUCTION

In wireless communications, transmitting large amounts of data through, at high speed and low error probability, is a major challenge for the researchers in the field.

In general, communications through wireless channels are affected by time-varying characteristics of propagation environment (e.g. different objects present into environment, by means of physical effects such as reflection and refraction).

A signal sent from a transmitter does not follow a single path to its destination. It traverses many different paths, in so-called multipath propagation, so that multiple versions of the transmitted signal reach the receiver (Pottie, 1995). Therefore, in communications through wireless radio channels, the received signal cannot be modeled in a simple way as a copy of the transmitted signal corrupted by additive Gaussian noise (Jafarkhani, 2005).

On each path, the signal experiences different attenuations, phase shifts on one or more frequency components, and time delays, in a process which is called signal fading. The observed signal at the receiver is a sum of these multiple signals, being different from the transmitted original one through fading channel (FC). In addition, the paths that signal follows are changing in time, due to changing of relative positions of the transmitter, receiver, and also of the objects in the environment (Foschini and Gans, 1998). To improve data transmission through FC, coded modulation techniques were proposed (Sundberg and Seshadri, 1993).

There are moments of time, when the signal observed by a receiver is not sufficient to recover the actually transmitted signal, and this is an important problem in wireless communications. A solution is to transmit more replicas of the signal, using a technique called transmit diversity, which can be provided using temporal, frequency, polarization, and spatial resources (Guey, Fitz, Bell and Kuo, 1996).
Spatial diversity is obtained by deploying multiple antennas at both the transmitter and receiver (Balaban and Salz, 1991). In this case, the communication channel is Multiple-Input Multiple-Output (MIMO) type. Each antenna element in a MIMO system operates on the same frequency and

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therefore does not require extra bandwidth. In addition, the total power through all antenna elements is less than or equal to that of a single antenna system. Transmit diversity has been studied extensively as a method of combating detrimental effects in wireless fading channels due to its relative simplicity of implementation (Alamouti, 1998), (Foschini, 1996), and feasibility of having multiple antennas at the base station (Foschini and Gans, 1998), (Tarokh and Jafarkhani, 2000). Combined effects of transmitter diversity and channel coding were also studied (Hiroike, Adachi and Nakajima, 1992).

Space-time codes (STC) are used in wireless communication systems with multiple transmitting antennas, to improve the reliability of data transmission, especially at high data rate (Tarokh, Seshadri and Calderbank, 1998). Data streams are divided into multiple, redundant copies, which are transmitted to the receiver, assuring reliable decoding and full recovery of the data (Raleigh and Cioffi, 1996). Space–time trellis coding (STTC) techniques extend trellis encoded modulation in spatial dimensions and combine coding techniques appropriate to multiple transmit antennas with complex decoding algorithms at the receiver (Alamouti,Tarokh and Poon, 1998). These codes provide both diversity gain which can be maximized, and encoding gain depending on the complexity of the code (the number of states in the trellis) without loss of spectral efficiency. Space-time block codes (STBC) reduce the decoder complexity of the receiver, using linear decoder based on orthogonal construction of the code matrix. However, STBC codes lack of encoding gain (Tarokh, Jafarkhani and Calderbank, 1999). The most practical STC are designed for two to four transmit antennas, which perform extremely well especially in slow fading environments. Alamouti space-time codes represent simple methods to develop space-time diversity, by using 2 transmitting antennas and N_R receiving antennas (Alamouti, 1998).

In this paper, aspects of image transmission in MIMO communication channels are studied, using PSK modulations and Alamouti space-time code, with $N_R = 2$.

The paper is organized as follows. Section 2 describes mathematical models for MIMO communication systems and STC techniques. In section 3, Alamouti space-time code is decribed. Simulation results are presented in section 4 and conclusions are pointed out in section 5.

2. MATHEMATICAL MODELS

In a MIMO communication system, multiple antennas at both transmitter and receiver are used. This allows multiple space-independent channels to be created.

Consider a MIMO system with N_T transmitting and N_R receiving antennas, as illustrated in Fig. 1. In this paper, only propagation channels with flat fading and without memory are considered.

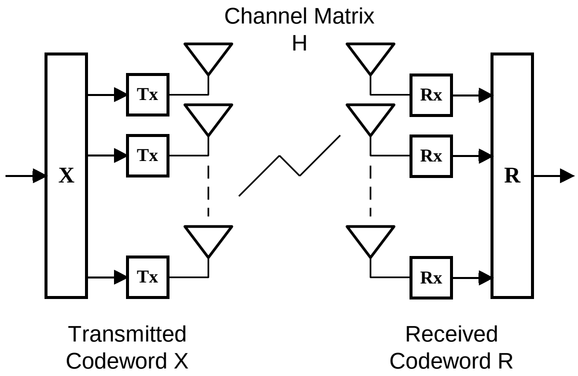

Fig.1. MIMO communication system

The signals submitted by the N_T antennas during a symbol period are noted x_i, $i = 1...N_T$, where index i represents the signal emitted by the antenna i. These signals form the column vector **x** of size $[N_T, 1]$:

(1) $$\mathbf{x} = \left[x_1, x_2 \ldots x_{N_T}\right]^T$$

The MIMO channel, considered without memory and with flat fading, is modelled by the channel matrix **H**, of size $[N_R, N_T]$. This matrix is called transfer function of MIMO channel. It contains the channel fading coefficients, h_{jk}, between the broadcasting antenna k and the receiving antenna j. At every moment of time t, the channel matrix is:

(2) $$\mathsf{H}_t = \begin{bmatrix} h_{1,1}^t & h_{1,2}^t & \cdots & h_{1,N_T}^t \\ h_{2,1}^t & h_{2,2}^t & \cdots & h_{2,N_T}^t \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R,1}^t & h_{N_R,2}^t & \cdots & h_{N_R,N_T}^t \end{bmatrix}$$

In general, channel matrix **H** varies in time. The MIMO channel behavior can be characterized based on the changing rate of channel fading coefficients, which defines the channel coherence time, t_c.

One part of the transmitted signals goes through propagation channels and it is received subsequent to the N_R receiving antennas. At every moment of time t, the received signal by the receiving antenna j, $r_{t,j}$, is a linear combination of all signals, fading and channel-added noise:

(3) $$r_j^t = \sum_{i=1}^{N_T} h_{ji}^t \cdot x_i^t + \eta_j^t ,$$

where $\eta_{t,j}$ is Gaussian noise, with zero mean and σ^2 diversity. The received signals form the column vector R of size [N_R, 1]:

(4) $$\mathbf{r} = \left[r_1, r_2 \ldots r_{N_R}\right]^T$$

Similarly, the column vector of Gaussian noise is:

(5) $$\mathbf{n} = \left[\eta_1, \eta_2 \ldots \eta_{N_R}\right]^T$$

The linear relationship between input and output of the MIMO channel is:

(6) $$\mathbf{r} = \mathbf{H}\cdot\mathbf{x} + \mathbf{n}$$

Taking into account the transmission of a frame with L symbols, which are transmitted successively during the frame time, T_F, the column vector **x** transforms into space-time codeword matrix **X**. Similarly, column vectors **r** and **n** transform into matrices.

(7) $$\mathsf{X} = \begin{bmatrix} x_1^1 & x_1^2 & \cdots & x_1^L \\ x_2^1 & x_2^2 & \cdots & x_2^L \\ \vdots & \vdots & \ddots & \vdots \\ x_{N_T}^1 & x_{N_T}^2 & \cdots & x_{N_T}^L \end{bmatrix}$$

(8) $$\mathsf{R} = \begin{bmatrix} r_1^1 & r_1^2 & \cdots & r_1^L \\ r_2^1 & r_2^2 & \cdots & r_2^L \\ \vdots & \vdots & \ddots & \vdots \\ r_{N_R}^1 & r_{N_R}^2 & \cdots & r_{N_R}^L \end{bmatrix}$$

(9) $$\mathsf{N} = \begin{bmatrix} \eta_1^1 & \eta_1^2 & \cdots & \eta_1^L \\ \eta_2^1 & \eta_2^2 & \cdots & \eta_2^L \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{N_R}^1 & \eta_{N_R}^2 & \cdots & \eta_{N_R}^L \end{bmatrix}$$

In this case, the input-output model for MIMO slow fading channel is:

(10) $$\mathbf{R} = \mathbf{H}\cdot\mathbf{X} + \mathbf{N}$$

For fast fading channel, the model is:

(11) $$\mathbf{R} = [\mathbf{H_1}\cdot\mathbf{x_1}, \mathbf{H_2}\cdot\mathbf{x_2}, \ldots, \mathbf{H_L}\cdot\mathbf{x_L}] + \mathbf{N}$$

In space-time coding, for each symbol, each transmitting antenna transmits a different version of the same input, generated by the space-time encoder. A MIMO communication system with STC is shown in Fig. 2.

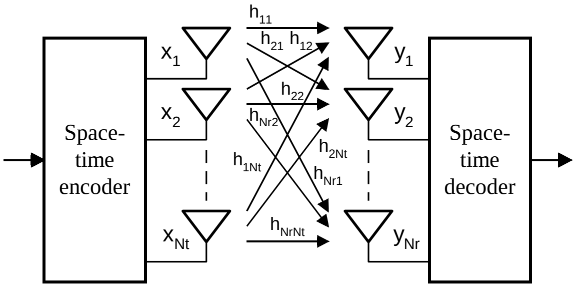

Fig.2. MIMO communication system with space-time coding

During one symbol, the space–time encoder generates N_T modulated complex symbols, which form the column vector **x** as input to the MIMO communication channel. At the receiver, the N_R received signals, which form the column vector **y** as output from MIMO channel, are used by the space-time decoder to obtain the original symbol. It is assumed that the receiver decoder uses an algorithm to estimate the maximum plausible sequence of information transmitted. At the reception, squared Euclidean distance is used between presumably received sequence and the received one:

(12) $$\sum_t \sum_{j=1}^{n_R} \left| y_t^j - \sum_{i=1}^{n_T} h_{j,i}^t x_t^i \right|^2$$

3. ALAMOUTI SPACE-TIME CODES

Based on orthogonal construction of the code matrix, Alamouti codes reduce the decoder complexity of the receiver, using linear decoder. Also, low encoding complexity is involved, in exchange for a reduced encoding gain.

Space-time block codes generalize the transmission scheme discovered by Alamouti to an arbitrary number of transmitting antennas and are able to achieve the full diversity promised by the transmitting and receiving antennas.

These codes retain the property of having a very simple maximum likelihood decoding algorithm based only on linear processing at the receiver. The structure of STBC encoder, which generates codeword matrix **X**, is illustrated in Fig. 3.

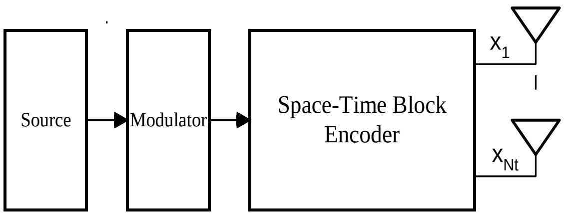

Fig.3. Space-time block encoder

At each moment of time t, the source generates an m-block of binary information, which is first modulated using a constellation S with 2^m points. The modulator produces a modulated block of K real or complex symbols from S.

The space-time block encoder generates the codeword matrix **X** of size [N_T, L], which is transmitted through N_T antennas, in L time slots equals to L symbol periods. The **X** matrix elements are linear combinations of the K modulated symbols and their conjugates.

In STBC, the number of symbols that encoder receives as inputs to each encoding operation is K. The number of transmission periods used to forward the coded symbols through each antenna is L. In other words, L symbols are transmitted by each antenna for each input block of K symbols. In this case the coding rate is:

$$R = \frac{K}{L} \tag{13}$$

A line i of **X** matrix contains the L sequentially broadcasted symbols by i antenna, while a column j means sequentially broadcasted symbols by all N_T antennas during j time slot.

$$\mathbf{x}_i = [x_{i1}\ x_{i2}\ \dots\ x_{iL}],\ \ i = 1\dots N_T \tag{14}$$

The codeword matrix **X** is built with lines being orthogonal each other:

$$\langle x_i, x_k \rangle = \sum_{j=1}^{L} x_{ij} \cdot x_{kj}^{*} = 0,\ i \neq k,\ \ i,k \in \{1,\dots N_T\} \tag{15}$$

where < , > is the inner product for vectors with complex elements. As a result, the **X** matrix has the property:

$$\mathbf{X} \cdot \mathbf{X}^H = c \cdot \left(|x_1|^2 + |x_2|^2 + \dots + |x_K|^2 \right) \cdot \mathbf{I}_{N_T} \tag{16}$$

where $\mathbf{X}^H$ is complex conjugate transpose of **X**, c is a constant and $\mathbf{I}_{NT}$ is the unit matrix of size [N_T, N_T].

In this paper, Alamouti space-time code with N_R = 2 is used. The Alamouti encoder structure is shown in Fig. 4.

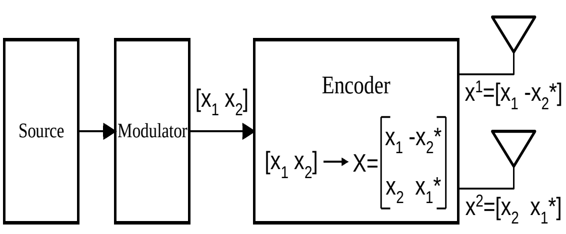

Fig.4. Alamouti encoder with PSK modulation

For example, in the case of Quadrature phase-shift keying (QPSK) modulation, the modulator gets at the input two bits of information and produces two complex symbols [x_1 x_2], with $x_i \in S = \{1, j, -1, -j\}$. If Binary phase-shift keying (BPSK) modulation is used, then S has real points and $x_i \in S = \{1, -1\}$.

For each encoding operation, the encoder takes the group of two modulated complex symbols, and generates the codeword matrix X:

$$\mathbf{X} = \begin{array}{c|cc|} & t & t+T \\ \hline T_{x1} & x_1 & -x_2^* \\ T_{x2} & x_2 & x_1^* \end{array} \tag{17}$$

Encoder outputs are transmitted during two consecutive symbol periods through the two transmitting antennas. During the first period, the two signals x1 and x2 are transmitted simultaneously through the first and second antenna, respectively T_{x1} and T_{x2}. In the second period, T_{x1} antenna broadcasts $-x_2^*$ signal, and T_{x2} antenna broadcasts x_1^* signal.

The two lines of **X** matrix are:

$$x^1 = [x_1, -x_2^*] \text{ and } x^2 = [x_2, x_1^*] \tag{18}$$

The inner product of the two lines is:

$$< \mathbf{x}^1, \mathbf{x}^2 > = x_1 x_2^* - x_2^* x_1 = 0 \tag{19}$$

The **X** matrix has the same property as all STBC:

$$\mathbf{X} \cdot \mathbf{X}^H = \left(|x_1|^2 + |x_2|^2 \right) \cdot \mathbf{I}_2 \tag{20}$$

The signals received by antenna j at time t and t + T are $r_{j,1}$ and respectively $r_{j,2}$:

$$\begin{aligned} r_{j,1} &= h_{j,1} \cdot x_1 + h_{j,2} \cdot x_2 + \eta_{j,1} \\ r_{j,2} &= -h_{j,1} \cdot x_2^* + h_{j,2} \cdot x_1^* + \eta_{j,2} \end{aligned} \tag{21}$$

The matrix form is:

$$\mathbf{r}_j = \begin{bmatrix} r_{j,1} & r_{j,2} \end{bmatrix} = \begin{bmatrix} h_{j,1} & h_{j,2} \end{bmatrix} \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} + \begin{bmatrix} \eta_{j,1} & \eta_{j,2} \end{bmatrix} \tag{22}$$

The decoder uses a maximum plausibility algorithm, selecting the most likely look symbols $\hat{x}_1$ and $\hat{x}_2$. Considering a source of information without memory, x_2 and x_1 modulated symbols are independent to each other. Hence, it is possible separate decoding of the two symbols:

$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = \begin{bmatrix} \arg\min\limits_{\hat{x}_1 \in S} \left(\sum_{j=1}^{N_R} \left| \tilde{r}_{j,1} - \left(|h_{j,1}|^2 + |h_{j,2}|^2 \cdot \hat{x}_1 \right) \right|^2 \right) \\ \arg\min\limits_{\hat{x}_2 \in S} \left(\sum_{j=1}^{N_R} \left| \tilde{r}_{j,2} - \left(|h_{j,1}|^2 + |h_{j,2}|^2 \cdot \hat{x}_2 \right) \right|^2 \right) \end{bmatrix} \tag{23}$$

4. EXPERIMENTAL RESULTS

In this section, Alamouti code performance on large data transmission is studied, and some simulation results on image broadcasting using Alamouti STBC are presented.

For simulations, a MIMO channel is considered with $N_T = 2$ and $N_R = 2$, which is affected by Rayleigh slow fading. In this case, the fading coefficients are complex Gaussian random variables, with independent random variables for real and complex part, and also with identical distributions, with equal variance and zero mean. Also they are fixed during a block broadcast and change for every block. The channel matrix H is:

$$\mathbf{H} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \quad (24)$$

The decoder uses maximum plausibility algorithm to estimate broadcasted symbols, based on separate decoding presented in eq. (23).

To simulate Alamouti code performance, a large random data sequence is used. It contains 10^6 bits of 0 and 1 values with equal probability.

The data set is modulated using BPSK modulation, resulting a modulated data set, with -1 and 1 values. The modulated data sequence is divided into $5{\cdot}10^5$ blocks of 2 bits and the Alamouti encoder forms $5{\cdot}10^5$ different **X** matrices of size [2, 2].

The bit error rate (BER) is the performance criterion. The BER curves are obtained depending on the signal-to-noise ratio (SNR), which is a chosen vector in the range [2, 27] dB. For every SNR value, the entire data sequence is transmitted through MIMO channel and the error vector between received and original data sequences is computed. The simulation results are illustrated in Fig. 5.

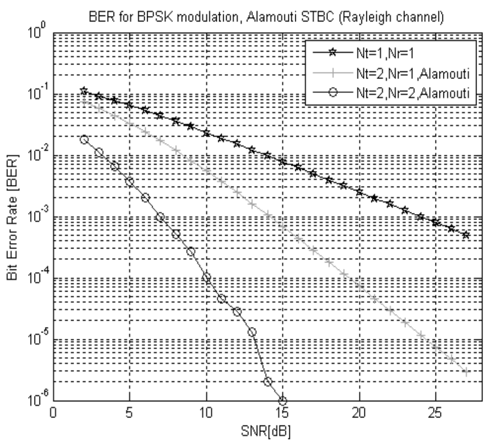

Fig.5. Alamouti code performance for a random data sequence of 10^6 bits

The real BER of Alamouti STBC with N_T=2 and N_R=2 (solution S3) is represented with "o" magenta mark. It is compared with theoretical performance of a simple communication channel (S1), drawn with "*" blue mark, and also with an Alamouti code with N_T=2 and N_R=1 (S2), drawn with "+" green mark.

It can be observed that for Alamouti STBC with N_T=2 and N_R=2, the BER curve decreases much faster than other two solutions. For two SNR values 5 and 10 [dB] respectively, used for image transmission next, the BER numerical values are represented in Tabel 1.

Table 1 BER numerical values

	BER*1000		
SNR [dB]	S1	S2	S3
5	64.1827	32.8577	3.7270
10	23.2687	5.5282	0.1100

The image transmission through MIMO channel using BPSK modulation and Alamouti STBC with N_T=2 and N_R=2 is simulated on a well known grayscale image, lena.bmp. The image has a resolution of 512*512 pixels with 8 bit grayscale, as illustrated in Fig. 6.

Fig.6. The original image with 512*512 pixels and 8 bit grayscale

After modulation, the data stream has 2^{21} bits, and it is divided into 2^{20} symbol blocks. The image transmission is repeated for two SNR values: 5 and 10 [dB], respectively.

The received image for SNR = 5 [dB], illustrated in Fig. 7, is compared with original one, and an image error is computed. The most part of the pixels received with errors are affected by changing of 1 bit in grayscale byte. The bit error rate is small and the decoder estimate well the broadcasted symbols, even for small values of SNR.

Fig.7. The received image, which results after Alamouti decoding for SNR = 5 [dB]

The number of error bits (NEB) is computed by comparing the original data sequence, and the estimated one determined by the Alamouti decoder. This number and the corresponding BER are represented in Table 2, for the two cases of SNR.

Table 2 NEB for image transmission

	Data set = 2.097.152 bits	
SNR [dB]	NEB	BER*1000
5	7641	3.6435
10	235	0,1121

It can be observed that BER values are comparable with those determined in first case, for Alamouti code performance analysis. In addition, the NEB drastically decreases with increasing of SNR.

5. CONCLUSIONS

A MIMO channel with BPSK modulation and Alamouti space-time block code with 2 transmitting and 2 receiving antennas was modeled. The bit error rate was determined by simulations for different values of SNR. Also, some simulation results on image broadcasting using Alamouti STBC are presented. The decoder estimates well the broadcasted symbols, even for small values of SNR.

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