Capacity Improvement of Space Time Block Code Spatial Modulation for Three Transmit Antennas

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Abstract

A new technique is proposed in this paper to increase the capacity of space time block code-spatial modulation (STBC-SM) by 0.5 bit/s/Hz. This technique is achieved by doing a switching between STBC-SM and SM in order to increase the capacity. The Bit Error Rate (BER) of this scheme is evaluated by MATLAB simulation, and it is found that it has a better performance compared with that of the hybrid STBC (for the same capacity) by about 6-4 dB at BER of $10^{-5}$.

1. Introduction

The main two requirements for next generation communication systems are high data rate and high reliable communication [1,2]. Spectral efficiency is viable because systems are band limited and user’s demands are growing continuously. Application of multiple input multiple output (MIMO) technique is the best technique to improve link capacity, and potentially increase spectral efficiency [3]. Recently, operators, manufacturers, and the research community are focusing their efforts to include MIMO techniques in most of the 21st-century standards such as LTE, WiMAX, WiFi, and cognitive radio [4]. It is known that a wireless communication link in a fading environment with MIMO techniques can greatly increase the capacity and reliability when using space-time coding [5]. An efficient transmit diversity scheme is called Space time block coding (STBC) is used to combat detrimental effects of wireless fading channels because of its simple decoding maximum-likelihood (ML) algorithm accomplishing full diversity at a radio receiver. A transmit diversity technique using space time block coding (STBC) is an important technique for future wireless systems, since it can provide high diversity gain by exploiting the multi-path environment without requiring additional bandwidth [5,6].

The concept of spatial modulation (SM) to remove the interchannel interference (ICI) completely between the transmit antennas of a MIMO link is introduced in [7]. The information is conveyed not only by the amplitude/phase modulation (APM) techniques, but also by the antenna indices. Space-time block coded spatial modulation (STBC-SM) is introduced in [8], which combines spatial modulation (SM) and space-time block coding (STBC) to take advantage of the benefits of both while avoiding their drawbacks. In the STBC-SM scheme, the transmitted information symbols are expanded not only to the space and time domains but also to the spatial (antenna) domain which corresponds to the on/off status of the transmit antennas available at the space domain, and therefore both core STBC and antenna indices carry information. A low-complexity maximum likelihood (ML) decoder is used for the STBC-SM scheme, which profits from the orthogonality of the core STBC.

In this paper, a capacity improvement technique for STBC-SM is introduced. It is achieved by making a switching between STBC-SM and SM to increase the capacity.

In Section 2, a review of the space time block code is presented. In Section 3, a review of the hybrid STBC is introduced. Space time block code spatial modulation is presented in Section 4. In Section 5, the model and an optimal decoder for the STBC-SM system is described. In Section 6, switching technique between STBC-SM and SM is discussed. In Section 7, simulation results of the proposed system are presented. Finally, Section 8 includes the main conclusions of the paper.

Notation: Bold lowercase and capital letters are used for column vectors and matrices, respectively. $(\cdot)^*$ and $(\cdot)^H$ denote complex conjugation and Hermitian transposition respectively.

2. Space Time Block Code STBC

A STBC for two transmit antennas is proposed by Alamouti [9]. The code matrix is given by
where $x_1, x_2 \subset \text{QAM/PSK}$ constellation. It is assumed that, channel is flat fading over two time slots and a single receive antenna, the received signals are expressed by:

$$
\begin{bmatrix}
  r_1 \\
  r_2
\end{bmatrix} = H_2 \cdot
\begin{bmatrix}
  x_1 \\
  x_2
\end{bmatrix} +
\begin{bmatrix}
  n_1 \\
  n_2
\end{bmatrix}
$$

(2)

where $r_i$ and $n_i$ are the received signal and the complex Gaussian noise added at the $i$-th time slot respectively. $H_2$ is the channel matrix, and it is denoted as $H_2$ for two transmit antenna schemes and given by:

$$
H_2 =
\begin{bmatrix}
  h_1 & h_2 \\
  h_2^* & -h_1^*
\end{bmatrix}
$$

(3)

where $h_j$ is the channel gain of the path from the $j$-th transmit antenna to the receiver. The received signals can be decoded using the following simple linear decoding method.

$$
\begin{bmatrix}
  \hat{x}_1 \\
  \hat{x}_2
\end{bmatrix} = \frac{1}{\alpha^2} H_2^H \cdot
\begin{bmatrix}
  r_1 \\
  r_2
\end{bmatrix}
$$

(4)

where $\alpha^2 = |h_1|^2 + |h_2|^2$. Because of the orthogonality property provided by the Alamouti code, the above simple linear detection scheme produces ML performance.

3. Hybrid STBC

Hybrid MIMO transceiver schemes combine pure diversity schemes (e.g. STBC) with pure spatial multiplexing schemes (e.g. V-BLAST) [10]. With this idea, hybrid MIMO schemes achieve a compromise between spatial multiplexing and diversity transmission gains.

In this paper, a hybrid MIMO transceiver, whose structure is shown in Figure 1 is used. It employs three elements to transmit with two spatial multiplexing layers. In the first layer one spatially multiplexed antenna is used, while in the second layer an Alamouti STBC encoder is used. Two or more antennas may be used in the receiver. The input bit stream is mapped to symbols using a BPSK modulator.

![Figure 1. Hybrid STBC](image)

During two symbol periods, the sequence of symbols $\{x_i\}_{i=1}^4$ is transmitted and multiplexed over the three antennas. Therefore, when $n_R = 3$, over two symbol periods, as shown below
The Hybrid system adopted in this paper, uses minimum mean square error MMSE detection with ordered successive interference cancellation (SIC) decoding where the layer with the highest post detection SNR is detected first, then nullled and the process is repeated for all layers, iteratively [11].

4. Space-Time Block Coded Spatial Modulation (STBC-SM)

In the STBC-SM scheme [8], shown in Figure (2), both STBC symbols and the indices of the transmit antennas from which these symbols are transmitted, carry information. It choses Alamouti’s STBC as the core STBC due to its advantages in terms of spectral efficiency and simplified ML detection. During each two consecutive symbol intervals, \(2^m\) bits \(u=(u_1, u_2, \cdots, u \log_2 c, u \log_2 c+2, \cdots, u \log_2 2+2 \log_2 M)\) enter the STBC-SM transmitter, where the first \(\log_2 c\) bits determine the antenna-pair position \(\ell=\ell_1 2^{\log_2 c}+\ell_2 2^{\log_2 c-2}+\cdots+u 2^{\log_2 2+0}\) that is associated with the corresponding antenna pair, while the last \(2\log_2 M\) bits determine the symbol pair \((x_1, x_2)\) \(\in \gamma^2\). The spectral efficiency of the STBC-SM scheme is larger than that of Alamouti’s scheme by an amount of \((1/2\log_2 c)\) bits/s/Hz provided by the antenna modulation.

A MIMO system STBC SM with four transmit antenna that transmit the Alamouti STBC can be expressed by one of the following four codewords [8],

\[
\chi_1 = \left\{ \begin{array}{c}
X_{11}, X_{12} \\
\{ 
\begin{array}{cc}
x_1 & x_2 \\
-x_2 & x_1 \\
0 & 0
\end{array}
\} \\
\{ 
\begin{array}{cc}
x_1^* & x_2^* \\
-x_2^* & x_1^*
\end{array}
\}
\end{array} \right.
\]

\[
\chi_2 = \left\{ \begin{array}{c}
X_{21}, X_{22} \\
\{ 
\begin{array}{cc}
x_1 & x_2 \\
-x_2 & x_1 \\
0 & 0
\end{array}
\} \\
\{ 
\begin{array}{cc}
x_1^* & x_2^* \\
-x_2^* & x_1^*
\end{array}
\}
\end{array} \right.
\]

\[
\chi_j = \chi_j e^{j\theta}, \quad j=1,2, \quad \text{which do not interfere to each other.} \quad \theta \quad \text{is a rotation angle to be optimized for a given modulation format to ensure maximum diversity and coding gain at the expense of expansion of the signal constellation. However, if \(\theta\) is not considered, overlapping columns of codeword pairs from different codebooks would reduce the transmit diversity order to one.}
\]
5. System Model and Optimal ML Decoder for the STBC-SM System

Consider a MIMO system with \( n_T \) transmit and \( n_R \) receive antennas in the presence of a quasi-static Rayleigh flat fading MIMO channel. From a given constellation \( C \) such as, PSK or QAM that is assumed to have unit energy, \( L \) symbols \( S_1, S_2, \cdots, S_L \) are chosen randomly and independently to form an input symbol sequence \( s = (S_1, S_2, \cdots, S_L)^T \in \chi \). To be transmitted from the \( M \) transmit antennas in the system, the \( L \) symbols are encoded into a space-time block codeword matrix \( X(s) \) of size \( T \times M \), following some specific forms, like Alamouti code structure, where \( T \) is the block codeword. The received space-time signal, denoted by the \( T \times N \) matrix \( Y \), can be expressed as

\[
Y = \sqrt{\frac{\rho}{\mu}} X(s) H + N
\]  

(6)

where \( X(s) \in \chi \) is the \( 2 \times n_T \) STBC-SM transmission matrix, transmitted over two channels, and \( \mu \) is a normalization factor to ensure that \( \mu \) is the average SNR at each receive antenna. \( H \) and \( N \) denote the \( n_T \times n_R \) channel matrix and \( 2 \times n_R \) noise matrix, respectively. The entries of \( H \) and \( N \) are assumed to be independent and identically distributed (i.i.d.) complex Gaussian random variables with zero means and unit variances. It is assumed that \( H \) remains constant during the transmission of a codeword and takes independent values from one codeword to another. It is assumed that \( H \) is perfectly known at the receiver, but not at the transmitter [13]. Assuming \( n_T \) transmit antennas are employed, the STBC-SM code has \( c \) codewords, from which \( cM^2 \) different transmission matrices can be constructed. An ML decoder must make an exhaustive search over all possible \( cM^2 \) transmission matrices, and decides in favor of the matrix that minimizes the following metric:

\[
\hat{X}(s) = \arg \min_{X(s)} \left\| Y - \sqrt{\frac{\rho}{\mu}} X(s) H \right\|
\]  

(7)

The minimization in Equation (7) can be simplified due to the orthogonality of Alamouti’s STBC as follows. The decoder can extract the embedded information symbol vector from Equation (5), and obtain the following equivalent channel model:

\[
y = \sqrt{\frac{\rho}{\mu}} H_{\chi} x + N
\]  

(8)

where \( H_{\chi} \) is the \( 2n_R \times 2 \) equivalent channel matrix of the Alamouti coded SM scheme, which has \( c \) different realizations according to the STBC-SM codewords. In Equation (6), \( y \) and \( n \) represent the \( 2n_R \times 1 \) equivalent received signal and noise vectors, respectively. Due to the orthogonality of Alamouti’s STBC, the columns of \( H_{\chi} \) are orthogonal to each other for all cases and, consequently, no ICI occurs in scheme as in the case of SM.

\[
H_{\chi} = \begin{bmatrix}
    h_{1,1} & h_{1,2} \\
    h_{2,1} & h_{2,2} \\
    \vdots & \vdots \\
    h_{nR,1} & h_{nR,2}
\end{bmatrix}
\]
where \( \varphi = e^{i \theta} \). Generally, we have \( c \) equivalent channel matrices \( H_\ell \), \( 0 \leq \ell \leq c - 1 \), and for the \( \ell \)-th combination, the receiver determines the ML estimates of \( x_1 \) and \( x_2 \) using the decomposition resulting from the orthogonality of \( h_{\ell,1} \) and \( h_{\ell,2} \) as follows [13]:

\[
\hat{x}_{1,\ell} = \arg \min_{x_{1,\ell}} \left( y - \frac{\rho}{\mu} h_{1,\ell} x_1 \right)^2 \\
\hat{x}_{2,\ell} = \arg \min_{x_{2,\ell}} \left( y - \frac{\rho}{\mu} h_{2,\ell} x_2 \right)^2
\]

\[\text{(10)}\]

where \( h_\ell = [h_{\ell,1} h_{\ell,2}] \), \( 0 \leq \ell \leq c - 1 \), and \( h_{\ell,i}, i = 1, 2, \) is a \( 2n_R \times 1 \) column vector. The associated minimum ML metrics \( m_{1,\ell} \) and \( m_{2,\ell} \) for \( x_1 \) and \( x_2 \) are

\[
m_{1,\ell} = \arg \min_{x_{1,\ell}} \left( y - \frac{\rho}{\mu} h_{1,\ell} x_1 \right)^2 \\
m_{2,\ell} = \arg \min_{x_{2,\ell}} \left( y - \frac{\rho}{\mu} h_{2,\ell} x_2 \right)^2
\]

\[\text{(11)}\]

respectively. Since \( m_{1,\ell} \) and \( m_{2,\ell} \) are calculated by the ML decoder for the \( \ell \)-th combination, their summation \( m_\ell = m_{1,\ell} + m_{2,\ell}, 0 \leq \ell \leq c - 1 \) gives the total ML metric for the \( \ell \)-th combination. Finally, the receiver makes a decision by choosing the minimum antenna combination metric as

\[
\hat{\ell} = \arg \min_{\ell} m_\ell
\]

for which \( (\hat{x}_{1,\hat{\ell}}, \hat{x}_{2,\hat{\ell}}) = (x_{1,\hat{\ell}}, x_{2,\hat{\ell}}) \). As a result, the total number of ML metric calculations in Equation (7) is reduced from \( cM^2 \) to \( 2cM \), yielding a linear decoding complexity as is also true for the SM scheme. The last step of the decoding process is the demapping operation based on the look-up table used at the transmitter, to recover the input bits \( \hat{\mu} = (\hat{\mu}_1, \cdots, \hat{\mu}_{\log_2 c}, \hat{\mu}_{\log_2 c+1}, \cdots, \hat{\mu}_{\log_2 c+\log_2 M}) \) from the determined spatial position (combination) \( \hat{\ell} \) and the information symbols. The block diagram of the ML decoder described above is given in Figure 3.
6. STBC-SM switched with SM

The technique proposed in this paper to increase the capacity by 0.5bit/s/Hz of STBC-SM is done by switching between STBC-SM, mention in Section 4 and SM. In this technique, four code word are to be transmitted as follows:

$$A = \begin{bmatrix} x_1 & x_2 & 0 \\ -x_2 & x_1 & 0 \end{bmatrix}, \quad B = \begin{bmatrix} 0 & x_1 & x_2 \\ 0 & -x_2 & x_1 \end{bmatrix} \cdot e^{j\theta_1},$$

$$C = \begin{bmatrix} x_1 & 0 & 0 \\ 0 & 0 & x_2 \end{bmatrix} \cdot e^{j\theta_2} \quad \text{and} \quad D = \begin{bmatrix} x_1 & 0 & 0 \\ 0 & 0 & x_2 \end{bmatrix} \cdot e^{j\theta_3}$$

(15)

where $\theta_1 = \pi/2$, $\theta_2 = \pi/4$ and $\theta_3 = 3\pi/2$. However, two bits are required to determine antennas indices (selected code word) compared with only one bit in the previous method. Therefore, the spectral efficiency of the proposed method is increased by 0.5bit/s/Hz compared with that of the STBC-SM. On the other hand, decoding of this method is also similar to the above method, unless $H_x$ are taken as follows

$$H_0 = \begin{bmatrix} h_{1,1} & h_{1,2} & h_{1,3} \\ h_{2,1} & h_{2,2} & h_{2,3} \\ \vdots & \vdots & \vdots \\ h_{d,1,2} & h_{d,1,3} & 0 \end{bmatrix}, \quad H_1 = \begin{bmatrix} h_{1,1} \cdot \varphi_1 & 0 \\ 0 & -h_{1,3} \cdot \varphi_1 \\ \vdots & \vdots & \vdots \end{bmatrix},$$

$$H_2 = \begin{bmatrix} h_{2,1} \cdot \varphi_1 & 0 \\ 0 & -h_{2,3} \cdot \varphi_1 \\ \vdots & \vdots & \vdots \end{bmatrix}, \quad H_3 = \begin{bmatrix} h_{2,2} \cdot \varphi_1 & h_{2,3} \cdot \varphi_1 \\ h_{3,2} \cdot \varphi_1 & h_{3,3} \cdot \varphi_1 \\ \vdots & \vdots & \vdots \end{bmatrix}$$

(16)

where $\cdot \varphi_i$ is $e^{j\varphi_i}$. 

Figure 3. The block diagram of the ML decoder
7. Simulation Results

The performances of the three different schemes; STBC-SM, STBC-SM switched with SM and Hybrid STBC are evaluated using MATLAB simulation. The source signal is modulated by BPSK and the receiver is assumed to have perfect channel state information. The energy per bit is calculated as:

\[ \frac{E_s}{N_0} = \frac{m,n}{k,N_r} \frac{E_b}{N_0} \]  

where \( E_s \) is the energy per symbol, \( E_b \) is the energy per bit, \( m \) is the number of bits per symbol, \( n \) is the number of bits to be transmitted, \( k \) is the number of bits actually transmitted and \( N_r \) is the number of receiving antennas. Figure 4 shows the BER values of the three techniques for BPSK modulation, with three antennas at the receiving side. It is observed that the performance is degraded when the capacity is increased. It is also found that the system, which uses switching between STBC-SM and SM, has the best performance by about 6 dB at BER of \( 10^{-5} \) compared with the hybrid system. Figure 5 shows the BER values of the three techniques with four antennas at the receiving side. For the same capacity, it is found that the system, which uses switching between STBC-SM and SM has also the best performance (by about 4 dB at BER of \( 10^{-5} \)) compared with the hybrid system.

8. Conclusions

In this paper, a new technique for capacity improvement of STBC-SM is introduced. The proposed scheme switches between STBC-SM and SM. The performance of the proposed scheme is evaluated by MATLAB simulation, and the results state that its performance is better than hybrid STBC for the same capacity by about 4dB at a bit error rate of \( 10^{-5} \). The proposed scheme actually has the same complexity compared to STBC-SM with only small degradation error performance.

Figure 4. BER performance of STBC-SM and Improved systems with three receiving antennas
Figure 5. BER performance of STBC-SM and Improved systems with four receiving antennas

9. References


