Research Article

Transmit antenna selection schemes for STBC-SM

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Abstract: The coupling of space-time block codes (STBCs) with the spatial modulation (SM) scheme can introduce a spatial diversity to the SM systems. This paper presents antenna selection techniques to provide an additional coding gain with the space-time block coded spatial modulation (STBC-SM). Specifically, the selection of optimal transmit antenna elements at the transmitter to send a spatially modulated space-time block code is studied. This paper studies the effects of applying the capacity optimized antenna selection (COAS) algorithm with the STBC-SM. The COAS algorithm has a suboptimal performance with a trade-off between complexity and bit-error-rate (BER) enhancement. Simulation results for STBC-SM with a spectral efficiency of 3 bits/s/Hz have been introduced with and without antenna selection.

Key words: Antenna selection, spatial modulation, diversity, space time block coded spatial modulation

1. Introduction

Multiple-input-multiple-output (MIMO) system is one of the most substantial technologies used in wireless communication systems for its ability to beat on multipath fading and improve the transmission quality [1]. In [2], a transmission method has been suggested for MIMO systems termed spatial modulation, which utilizes the spatial locations of multiple transmit antennas as well as the classical M-ary signal constellations to convey the data.

The STBC technique provides transmit diversity with linear decoding complexity [3]. STBC-SM scheme is introduced in [4]. STBC-SM makes use of STBC as well as the antenna index domain in order to take the advantages of both schemes (transmit diversity from the STBC and increased spectral efficiency from the SM) to relay information. Alamouti's code [3] is utilized as the STBC code matrix. In the STBC-SM, Alamouti's STBC matrix depends on the two complex symbols and the two active transmit antennas which are selected from all transmit antennas in order to transmit the symbols. Rotation angles between overlapped codewords are used to maximize the minimum coding gain distance (CGD). However, with a higher number of transmitting antennas, the rotation angles between transmitted codewords need a complex optimization process and the minimum CGD between the STBC matrices becomes smaller.

In [5], the performance study of applying two AS methods on SM is introduced, which are EDAS and COAS, where the channel state information (CSI) is imperfect at the receiver. The results of applying both AS methods on SM provide a significant SNR gains, in low- and midrange of SNR, over the conventional MIMO systems that use AS techniques. In [6, 7], a transmit antenna selection (TAS) scheme is proposed to obtain superior system performance for SM transmission. Maximizing the minimum Euclidean distance (ED) among

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the valid transmit vectors was used as the decision metric for optimal antenna selection. This proposed TAS scheme offered a considerable SNR gain in comparison to the classical SM. Not only did combining TAS with SM improves error performance, it increased the diversity order of SM as well as its robustness against spatial correlation. In [8], the researchers focused on reducing the search complexity of EDAS-SM scheme. In EDAS-SM, an extensive search over all possible antenna subsets is done in order to obtain the optimal antenna set, this causes high search complexity and impractical to implementation of EDAS-SM scheme [9]. Two methods are suggested to resolve this problem in this paper, tree search-based antenna selection (TSAS) and decremental antenna selection (D-AS). The TSAS method gives a similar result of the (BER) of the optimal EDAS with a reduction in search complexity. In contrast, the D-AS method gives a trade-off between the search complexity and the performance (BER) and its result is close to the BER of the optimal EDAS. Antenna selection schemes are also used with different spatial modulation schemes to introduce transmit diversity and/or coding gain [10–15].

The diversity of full rate space-time block code is limited to two [16]. In this paper, antenna selection schemes are used to enhance the STBC-SM performance. In [17], applying the AS on STBCs was proposed. The selection algorithm chooses the pair of antennas which maximizes the SNR at the receiver from the total transmit antennas. This selection algorithm is applied on Alamouti code and the results show an important improvement in average SNR and the outage capacity. The researchers in [18] developed two AS algorithms for MIMO systems with STBC in flat fading channels with a selection criterion that depends on the type of channel knowledge. The first algorithm is based on the perfect channel information, which selects the antenna group that maximizes the channel matrix Frobenius norm. The second algorithm is based on a statistical channel information, which selects the antenna group that maximizes the determinant of the covariance of the vectorized channel. The first algorithm is applied to Alamouti STBC and the second is applied to generalized STBCs. Both algorithms provide an enhancement in coding and diversity gains.

In [19], the two best transmit antennas are chosen to maximize the SNR at the receiver. The suggested selection algorithm is employed with Alamouti STBC. Simulation results proved that utilizing AS with Alamouti STBC obtained a diversity order similar to that of achievable from utilizing all transmit antennas. In [20], the same authors of the preceding scheme applied the same antenna selection algorithm on space time trellis codes (STTCs). The selected antennas have been utilized to convey STTC that intended for two transmit antennas. Simulation results proved that utilizing AS with STTC obtained a diversity order similar to that of achievable from utilizing all transmit antennas.

STBC-SM is a MIMO transmission scheme that offers improvements in BER performance with an acceptable linear decoding complexity. The need to improve the reliability (error performance) of the STBC-SM scheme still exists. One of the methods used to improve performance is the application of AS techniques. Motivated by this, this paper applies the COAS algorithm for STBC-SM scheme. The main contribution of this paper is to overcome the difficulty of designing STBC-SM with a high number of transmit antennas by using a simple antenna selection scheme. The bit error performance expression is used to prove the effectiveness of the TAS with STBC-SM.

2. Space time block coded-spatial modulation (STBC-SM)

In spite of the spectral efficiency feature given from the spatial (antenna) domain in the SM scheme, SM scheme is incapable to obtain transmit diversity. STBC-SM, which was suggested in [4], is a MIMO transmission scheme that combines the multiplexing gain (spectral efficiency) of SM with STBCs transmit diversity gain in order to

take advantages of both and avert their drawbacks. In STBC-SM, the symbols of STBC and the positions of the active transmit antennas carry data. In [4], the Alamouti's STBC was selected, as the core STBC because of its advantages in terms of transmit diversity and simplified ML detection, then STBC-SM scheme was generalized for more than two transmit antennas. At the receiver, a low-complexity ML decoder is used. The simplicity of decoder comes from the orthogonality which is inherited from the Alamouti's STBC.

2.1. STBC-SM transmitter

In [4], the concept of STBC-SM is introduced through an example (STBC-SM with BPSK modulation and four transmit antennas). Consider a MIMO system equipped with $N_t = 4$ transmit antennas which are used to send the Alamouti's STBC. The codebook consists of the following codewords:

$$\boldsymbol{\chi}_1 = \{\mathbf{X}_{12}, \mathbf{X}_{34}\} = \left\{ \begin{pmatrix} s_1 & s_2 & 0 & 0 \\ -s_2^* & s_1^* & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 0 & s_1 & s_2 \\ 0 & 0 & -s_2^* & s_1^* \end{pmatrix} \right\} \tag{1}$$

$$\boldsymbol{\chi}_2 = \{\mathbf{X}_{41}, \mathbf{X}_{23}\} e^{j\theta_2} = \left\{ \begin{pmatrix} s_2 & 0 & 0 & s_1 \\ s_1^* & 0 & 0 & -s_2^* \end{pmatrix}, \begin{pmatrix} 0 & s_1 & s_2 & 0 \\ 0 & -s_2^* & s_1^* & 0 \end{pmatrix} \right\} e^{j\theta_2} \tag{2}$$

where $\boldsymbol{\chi}_k$, $k=1,2$ are called the STBC-SM codebooks. Each codebook contains two STBC-SM codewords $\mathbf{X}_{ij}$ $i = 1, \cdots, 4$, $j = 1, \cdots, 4$ which do not overlap with each other (no overlapping columns). The resulting STBC-SM code is $\boldsymbol{\chi} = \cup_{i=1}^{2} \boldsymbol{\chi}_k$. θ_k is a rotation angle, which is used to reduce the impact of the overlapping columns of codeword pairs from different codebooks on transmit diversity order. Therefore, θ_k must be selected in order to achieve maximum diversity and coding gains for a given modulation format. Minimum CGD between two STBC-SM codewords is a significant design parameter for quasi-static Rayleigh fading channels (which the channel fading coefficients still not change through the transmission of a frame).

Let $\mathbf{X}_{ij}$ and $\hat{\mathbf{X}}_{ij}$ be the sent and the incorrectly detected codewords, respectively. The minimum CGD between these codewords is defined as,

$$d_{min}(\mathbf{X}_{ij}, \hat{\mathbf{X}}_{ij}) = \min_{\mathbf{X}_{ij}, \hat{\mathbf{X}}_{ij}} \det \left((\mathbf{X}_{ij} - \hat{\mathbf{X}}_{ij})^H (\mathbf{X}_{ij} - \hat{\mathbf{X}}_{ij}) \right) \tag{3}$$

The minimum CGD between two codebooks $\mathbf{X}_i$ and $\mathbf{X}_j$ is known as:

$$d_{min}(\boldsymbol{\chi}_i, \boldsymbol{\chi}_j) = \min_{k,l} d_{min}(\mathbf{X}_{ik}, \mathbf{X}_{jl}) \tag{4}$$

and the minimum CGD of an STBC-SM code is defined by,

$$d_{min}(\boldsymbol{\chi}) = \min_{i,j,i \neq j} d_{min}(\boldsymbol{\chi}_i, \boldsymbol{\chi}_j) \tag{5}$$

Observing that, the d_{min} corresponds to the determinant criterion, which says that the minimum determinant of $(\mathbf{X}_i - \mathbf{X}_j)(\mathbf{X}_i - \mathbf{X}_j)^H$ among all $i \neq j$ has to be large to obtain high coding gains [4].

In STBC-SM we choose θ that maximizes $d_{min}(\boldsymbol{\chi})$ in (5) in order to increase the coding gain for each configuration of modulated symbols and active antenna subsets. The STBC-SM scheme spectral efficiency is given by,

$$m = \frac{1}{2} \log_2 c + \log_2 M \texttt{ bits/s/Hz}, \tag{6}$$

where M is the size of modulated symbols constellation and c the total number of STBC-SM code matrices (codewords), $c = \left\lfloor \frac{N_t}{2} \right\rfloor_{2^p}$, where N_t is the total number of transmit antennas, p is a positive integer. The total number of codewords considered should be an integer power of 2. In STBC-SM transmitter, at each two consecutive symbol time duration, 2^m input bits, $u = (u_1, u_2, \cdots, u_{\log_2 c}, u_{\log_2 c+1}, \cdots, u_{\log_2 c+2\log_2 M})$, selects the antenna-pair indices $l = u_1 2^{\log_2 c-1} + u_2 2^{\log_2 c-2} + \cdots + u_c 2^{\log_2 0}$ by the first $\log_2 c$ bits and selects the symbol pair (s_1, s_2) by the last $2\log_2 M$ bits. The block diagram representation of the STBC-SM transmitter is shown in Figure 1.
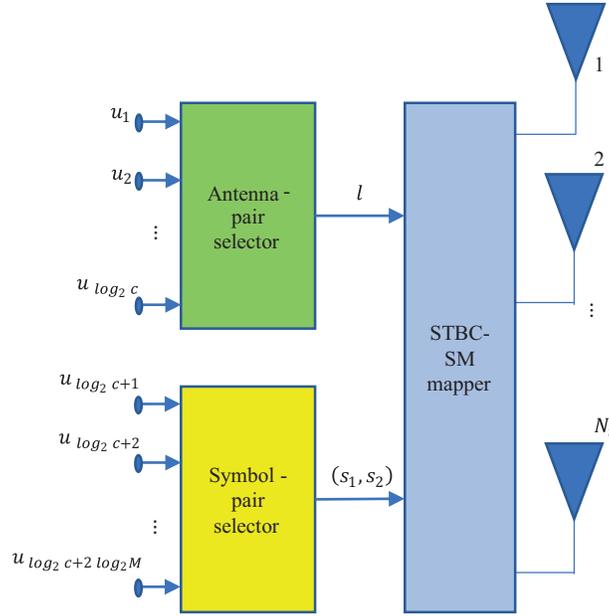
Figure 1. Block diagram of the STBC-SM transmitter.

2.2. STBC-SM receiver

The received signal matrix $\mathbf{Y}$ which has dimension $2 \times N_r$ can be written as,

$$\mathbf{Y} = \sqrt{\frac{\rho}{\mu}}\mathbf{X}_\chi \mathbf{H} + \mathbf{n}, \tag{7}$$

where $\mathbf{X}_\chi \in X$ is the $2 \times N_t$ STBC-SM transmission matrix, μ is a normalization factor to ensure that ρ is the average SNR at each receive antenna, $\mathbf{H}$ is the $N_r \times N_t$ channel matrix, that is assumed to be fixed during the transmission of a codeword and takes independent values from one codeword to another. Channel matrix $\mathbf{H}$ is assumed to be known at the receiver. $\mathbf{n}$ is the $2 \times N_r$ noise matrix. Assume N_t transmit antennas are used and the total number of STBC-SM codewords is c. Then for M-ary signal constellation, we can construct cM^2 different transmission matrices. For ML decoder, we will search over all cM^2 transmission matrices and select which one that minimizes the following metric:

$$\tilde{\mathbf{X}}_\chi = \arg \min_{\mathbf{X}_\chi \in \chi} \left\| \mathbf{Y} - \sqrt{\frac{\rho}{\mu}}\mathbf{X}_\chi \mathbf{H} \right\|^2. \tag{8}$$

Taking advantage of the Alamouti's STBC orthogonality, the ML search of (8) can be simplified. The decoder can retrieve the data symbol vector from (7) and attain the following equivalent system model,

$$\mathbf{Y} = \sqrt{\frac{\rho}{\mu}} \mathbf{H}_{ij} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \mathbf{n}, \tag{9}$$

where $\mathbf{H}_{ij}$ is the $2N_r \times 2$ equivalent channel matrix of the Alamouti coded-SM scheme, which has c different realizations with respect to the STBC-SM codewords.

$$\boldsymbol{\mathcal{H}}_{ij} = \begin{bmatrix} h_{1i}e^{j\theta} & h_{1j}e^{j\theta} \\ h_{1j}^*e^{-j\theta} & -h_{1i}^*e^{-j\theta} \\ h_{2i}e^{j\theta} & h_{2j}e^{j\theta} \\ h_{2j}^*e^{-j\theta} & -h_{2i}^*e^{-j\theta} \\ \vdots & \vdots \\ h_{N_ti}e^{j\theta} & h_{N_tj}e^{j\theta} \\ h_{N_tj}^*e^{-j\theta} & -h_{N_ti}^*e^{-j\theta} \end{bmatrix} \tag{10}$$

where i and j are the indices of the two Alamouti transmitting antennas and θ is the optimized rotation angle that maximizes $d_{min}(\boldsymbol{\chi})$ in (5), $\mathbf{y}$ and $\mathbf{n}$ represent the $2N_r \times 1$ received signal and noise vectors, respectively. The columns of $\mathbf{H}_{ij}$ are orthogonal to each other for all cases because of the orthogonality of Alamouti's STBC. Therefore, no inter channel interference (ICI) happens in STBC-SM scheme as in the SM case. We have c equivalent channel matrices $\mathbf{H}_{ij}^l$, $0 \leq l \leq c-1$, and for the lth combination, the receiver determines the ML estimates of s_1 and s_2 using the decomposition as follows resulting from the orthogonality of $\mathbf{h}_{l1}$ and $\mathbf{h}_{l2}$:

$$\tilde{s}_{l1} = \arg \min_{s_1 \in \gamma} \left\| \mathbf{Y} - \sqrt{\frac{\rho}{\mu}} \mathbf{h}_{l1} s_1 \right\|^2 \tag{11}$$

$$\tilde{s}_{l2} = \arg \min_{s_2 \in \gamma} \left\| \mathbf{Y} - \sqrt{\frac{\rho}{\mu}} \mathbf{h}_{l2} s_2 \right\|^2 \tag{12}$$

where $H_l = \begin{bmatrix} \mathbf{h}_{l1} & \mathbf{h}_{l2} \end{bmatrix}$, $0 \leq l \leq c-1$ and $\mathbf{h}_{lj}, j = 1, 2$, is a $2N_r \times 1$ column vector, γ is the set of the modulated signal constellation. The associated minimum ML metrics $\tilde{m}_{1l}$ and $\tilde{m}_{12}$ for $\tilde{s}_{1l}$ and $\tilde{s}_{12}$ are:

$$\tilde{m}_{l1} = \arg \min_{l \in N_t} \left\| \mathbf{Y} - \sqrt{\frac{\rho}{\mu}} \mathbf{h}_{l1} \tilde{s}_{1l} \right\|^2 \tag{13}$$

$$\tilde{m}_{l2} = \arg \min_{l \in N_t} \left\| \mathbf{Y} - \sqrt{\frac{\rho}{\mu}} \mathbf{h}_{l2} \tilde{s}_{2l} \right\|^2 \tag{14}$$

The summation $m_l = m_{l1} + m_{l2}$, $0 \leq l \leq c-1$ gives the total ML metric for the lth combination. The receiver makes a decision by selecting the minimum antenna combination metric as $l = \arg \min_l m_1$ for which $(\tilde{s}_1, \tilde{s}_2) = (\tilde{s}_{\tilde{l}1}, \tilde{s}_{\tilde{l}2})$. As a result, the total number of ML metric calculations in (13) and (14) is decreased from cM^2 to $2cM$, yielding a linear decoding complexity [4]. Then the estimated symbols $(\tilde{s}_1, \tilde{s}_2)$ and estimated antenna pairs $\tilde{l}$ are used to recover the input bits using demapping process depending on the look-up table utilized at the transmitter. The block diagram of STBC-SM receiver is illustrated in Figure 2.
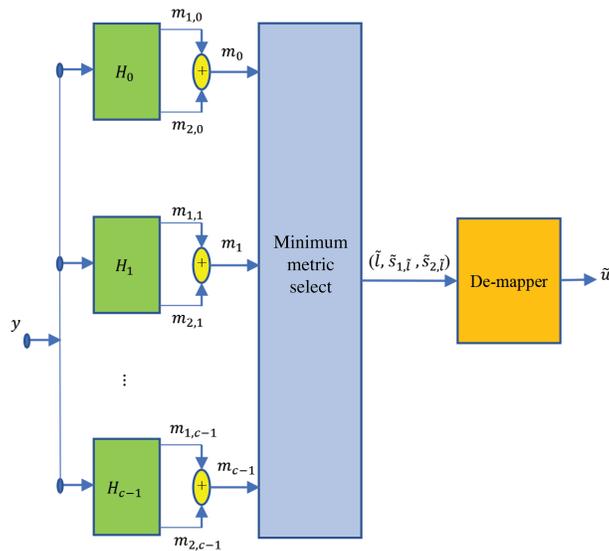
Figure 2. Block diagram of STBC-SM receiver.

3. Transmit antenna selection (TAS) for STBC-SM scheme

Consider the channel matrix $\mathbf{H}$ has size $N_r \times N_t$. The best set of transmit antennas L_t are selected depending on the AS algorithm (COAS) and the channel matrix. The selected transmit antennas L_t are used by STBC-SM transmitter to convey the symbols of the codeword (transmission matrix). The block diagram of TAS for STBC-SM scheme is demonstrated in Figure 3. The MIMO system needs N_t full radio frequency (RF) chains in the transmitter and N_r complete RF chains in the receiver. Each transmit antenna element needs an RF chain that consists of a digital-to-analog converter, a frequency up-converter, and a power amplifier. Similarly, each receive antenna element requires an RF chain that consists of a low noise amplifier, frequency down-converter, and analog-to-digital converter. Therefore, the complexity of MIMO system will increase as well as the cost of implementation will also increase. One effective way to decrease the number of RF chains is TAS. It mitigates the complexity of MIMO systems. The main goal of TAS is to implement more antennas than RF chains and use only a subset of antennas but maintaining the advantages of MIMO. In TAS, the best L_t out of N_t antennas are selected. In MIMO systems, to apply TAS, we will select some columns from the channel matrix. The performance of TAS has been discussed from several aspects like capacity for spatial multiplexing systems, and diversity order and coding gain for STC systems. In our paper, we will focus on COAS TAS algorithm for STBC-SM scheme. COAS algorithm, also called a norm-based antenna selection is TAS algorithm that selects a subgroup of antennas L_t which corresponds to the maximum channel amplitudes (columns of channel matrix) from the total number of transmit antennas N_t. The results of many research papers proved that the COAS algorithm was capable of enhancing the error performance of variety MIMO systems, whilst maintaining a very low computational complexity. The COAS algorithm can be applied as follows: **Step 1**: Calculate the Frobenius norm of each column vector in the channel matrix $\mathbf{H}$:

$$\|\mathbf{h}_i\|_F^2 \quad 1 \leq i \leq N_t \tag{15}$$

Step 2: Rearrange the column vectors of the channel matrix $\mathbf{H}$ in descending order to get:

$$\mathbf{H}_A = \left[\|\mathbf{h}_1\|_F^2 \geq \|\mathbf{h}_2\|_F^2 \geq \cdots \geq \|\mathbf{h}_{N_t}\|_F^2 \right] \tag{16}$$

Step 3: Choose the highest L_t channel gain vectors to form the $L_t \times N_r$ channel gain matrix $\mathbf{H}_{sel}$.
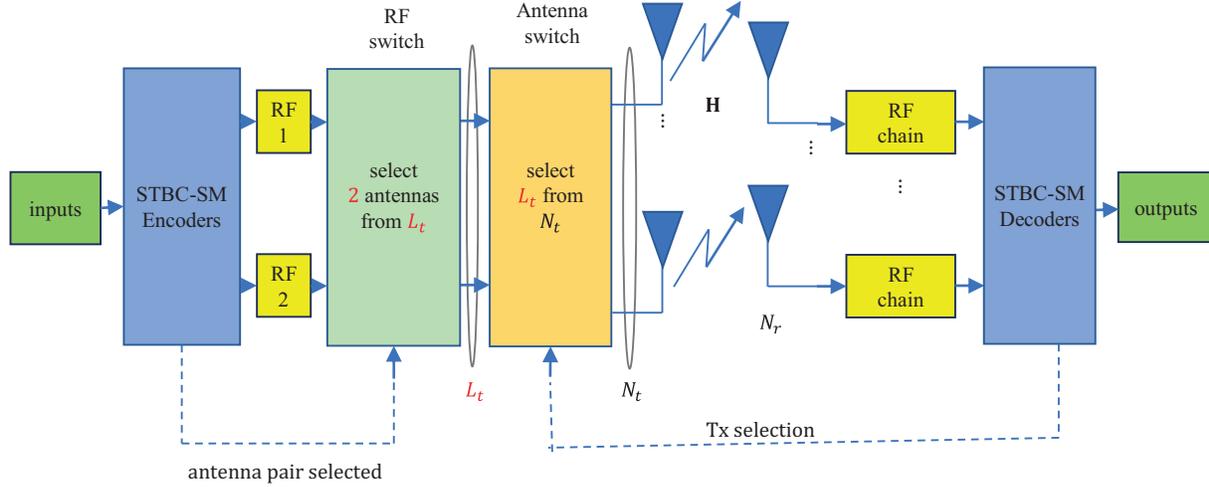
Figure 3. The block diagram of TAS with STBC-SM scheme.

The RF switch in Figure 3 is controlled by the selection criteria implemented at the receiver. In TAS, the receiver tells the transmitter which indices of the L_t out of N_t transmit antennas to be utilized at each frame through an existing limited feedback link between the receiver and the transmitter. As only the indices of the selected antennas are to be fedback, few bits are required. On the transmitter side and based on the selected antennas indices, the antenna switch selects the best L_t antennas from N_t total transmitter antennas and RF switch selects two antennas from the selected L_t based on the transmitted codeword. The main drawback of TAS is the need for new bandwidth and different frequency for the feedback link, but compared to the benefits that can be achieved from the TAS, this drawback can be overlooked.

Assume $P(\mathbf{X}_i \to \mathbf{X}_j | \mathbf{H})$ is the conditional pairwise error probability (PEP) of decoding STBC-SM matrix $\mathbf{X}_j$ given that the STBC-SM matrix $\mathbf{X}_i$ is sent for a given channel $\mathbf{H}$, where $i \neq j$. The upper bound for the conditional pairwise error probability (PEP) of STBC-SM scheme is calculated as follows [21]:

$$P(\mathbf{X}_i \to \mathbf{X}_j | \mathbf{H}) = Q\left(\sqrt{\frac{\rho \|\mathbf{H}\mathbf{E}_{i,j}\|_F^2}{2N_t}}\right) \leq \exp\left(-\frac{\rho \|\mathbf{H}\mathbf{E}_{i,j}\|_F^2}{4N_t}\right) \tag{17}$$

where ρ is the average SNR at each receive antenna, $\mathbf{E}_{i,j}$ is the error matrix $(\mathbf{X}_i - \mathbf{X}_j)$ and N_t is the total transmit antennas. When AS algorithms are used with STBC-SM, L_t antennas have been selected from the total number of transmit antennas N_t which correspond to select L_t columns from the channel matrix $\mathbf{H}$. The channel matrix after the antenna selection is denoted as $\mathbf{H}_{sel} = \mathbf{H}_{N_r \times L_t}$. The conditional PEP of STBC-SM scheme is modified to,

$$P(X_i \to X_j | \mathbf{H}) = Q\left(\sqrt{\frac{\rho \|\mathbf{H}_{sel}\mathbf{E}_{i,j}\|_F^2}{2L_t}}\right) \leq \exp\left(\frac{\rho \|\mathbf{H}_{sel}\mathbf{E}_{i,j}\|_F^2}{4L_t}\right) \tag{18}$$

Note that, the minimization of the upper bound occurs when we maximize the term $\|\mathbf{H}_{sel}\mathbf{E}_{i,j}\|_F^2$ in (18).

Therefore, the selected antennas should be selected to maximize the term $\|\mathbf{H}_{sel}\mathbf{E}_{i,j}\|_F^2$. That is,

$$
\begin{aligned}
(A_1, A_2, \cdots, A_{L_t}) &= \underset{A_1,A_2,\cdots,A_{L_t} \in S}{\arg\max} \|\mathbf{H}_{\left(A_1,A_2,\cdots,A_{L_t}\right)}\mathbf{E}_{i,j}\|_F^2 \\
&= \underset{A_1,A_2,\cdots,A_{L_t} \in S}{\arg\max} \operatorname{tr}\left[\mathbf{H}_{\left(A_1,A_2,\cdots,A_{L_t}\right)}\mathbf{E}_{i,j}\mathbf{E}_{i,j}^H\mathbf{H}_{\left(A_1,A_2,\cdots,A_{L_t}\right)}^H\right] \\
&= \underset{A_1,A_2,\cdots,A_{L_t} \in S}{\arg\max} \operatorname{tr}\left[\mathbf{H}_{\left(A_1,A_2,\cdots,A_{L_t}\right)}\mathbf{H}_{\left(A_1,A_2,\cdots,A_{L_t}\right)}^H\right] \\
&= \underset{A_1,A_2,\cdots,A_{L_t} \in S}{\arg\max} \|\mathbf{H}_{\left(A_1,A_2,\cdots,A_{L_t}\right)}\|_F^2
\end{aligned}
\tag{19}
$$

where $S = \binom{N_t}{L_t}$ is the group of all potential antenna compositions where L_t is number the of selected antennas.

We eliminate the error matrix term in (18) because of the error matrix has the property $\mathbf{E}_{i,j}\mathbf{E}_{i,j}^H = \alpha\mathbf{I}$, due to the orthogonality of the Alamouti code (STBC), where α is constant.

As shown above, in order to minimize the error rate in equation (17), the highest norms of the channel matrix $\mathbf{H}$ columns are chosen to produce $\mathbf{H}_{sel}$ matrix. This results in the choice of the antennas group that achieve the highest SNR at the receiver. This has been demonstrated when we used the COAS algorithm with the STBC-SM scheme. Furthermore, in [4], [22], it was proven that the Alamouti code and STBC-SM are very robust against channel correlation compared to the classical spatial modulation (SM).

4. Simulation results of TAS for STBC-SM

In this section, the MATLAB simulation results of the COAS AS scheme for STBC-SM have been presented. For each case, the simulation result represents the average BER performance versus the average SNR at each receive antenna. All performance comparisons are measured at a BER equals 10^{-5}. It has been assumed that all MATLAB simulations are performed over quasi-static Rayleigh fading channels. Additionally, the CSI is assumed to be well known at the receiver and an error-free link is available between the transmitter and the receiver. Furthermore, the optimal ML detection has been employed. Figure 4 demonstrates the BER performance of the sub-optimal AS algorithm (COAS) on STBC-SM (QPSK, N_t=6 then 8 , N_r=1) when the number of selected transmit antennas is L_t=4. The results have been compared with the classical STBC-SM (QPSK, N_t=4, N_r=1). The performance of COAS-STBC-SM scheme outperforms the conventional STBC-SM (QPSK, N_t=4, N_r=1) with 3 dB, when N_t=6 . However, this gain can be further improved by increasing N_t. When N_t is increased to 8, COAS-STBC-SM exhibits 3.8 dB gain over the conventional STBC-SM (QPSK, N_t=4, N_r=1). It is noted that by increasing the value of N_t, the overall BER performance of AS scheme will increase.

Figure 5 depicts the behavior of the suboptimal AS algorithm (COAS) on STBC-SM (QPSK, N_t= 8 ,N_r=1) when the number of selected transmit antennas is L_t=4. The results have been compared with classical STBC-SM (BPSK, N_t=8, N_r=1), both systems are similar in the number of transmitting antennas N_t=8 as well as the spectral efficiency (3 bits/s/Hz). The codewords of STBC-SM with 8 transmitting antennas and
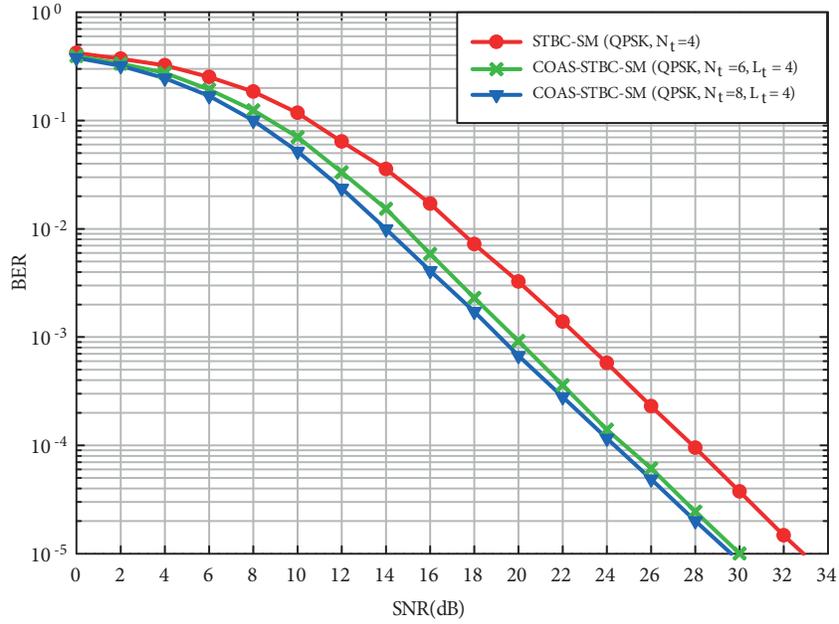
Figure 4. BER performance of TAS with 3 bits/s/Hz STBC-SM for $N_r=1$.

Alamouti s STBC with $c = \lfloor \frac{8}{2} \rfloor_{2^p} = 16$ are shown in (20).

$$
\begin{aligned}
\chi_1 &= (\mathbf{X}_{12}, \mathbf{X}_{34}, \mathbf{X}_{56}, \mathbf{X}_{78}) \\
\chi_2 &= (\mathbf{X}_{23}, \mathbf{X}_{45}, \mathbf{X}_{67}, \mathbf{X}_{18})\, e^{j\theta_2} \\
\chi_3 &= (\mathbf{X}_{13}, \mathbf{X}_{24}, \mathbf{X}_{57}, \mathbf{X}_{68})\, e^{j\theta_3} \\
\chi_4 &= (\mathbf{X}_{15}, \mathbf{X}_{26}, \mathbf{X}_{37}, \mathbf{X}_{48})\, e^{j\theta_4}
\end{aligned}
\tag{20}
$$

where $\mathbf{X}_{ij}$ similar to the notation in (1), and i,j are the antenna indices which are transmitting the Alamouti matrix. The optimized values of θ_2, θ_3, and θ_4, which maximize the coding gain distance CGD amongst all codewords of STBC-SM, are $\pi/8$, $\pi/4$, and $3\pi/8$, respectively [4]. As shown in Figure 4, a substantial enhancement is obtained by the COAS-STBC-SM scheme in comparison to the STBC-SM (BPSK, $N_t=8$, $N_r=1$) scheme where both systems are identical in the total number of transmitting antennas as well as the spectral efficiency. The COAS-STBC-SM method provides a 2.6 dB gain over the STBC-SM (BPSK, $N_t=8$, $N_r=1$). Accordingly, it can be said that the COAS-STBC-SM scheme outperforms the classical STBC-SM scheme provided both schemes have identical spectral efficiency, additionally, both have the same number of total transmitting antennas.

5. Conclusion

In this work, we analyze the performance of a suboptimal antenna selection in STBC-SM system. The COAS algorithm has been chosen because of its simplicity which leads to a low computational complexity [23]. The simulation results indicate that using AS can improve the performance of STBC-SM with a high number of transmit antennas ($N_t \geq 8$). Finally, we can say that the STBC-SM scheme does not need a complicated AS
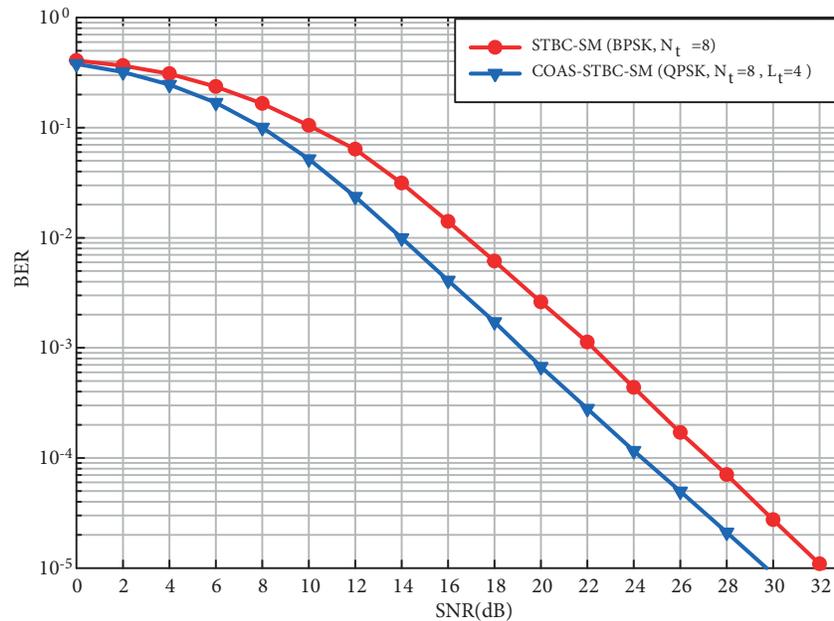
Figure 5. BER performance of TAS for STBC-SM (3 bits/s/Hz) for $N_t = 8$ and $N_r = 1$.

algorithm in order to improve its performance, just we can use the low complexity AS algorithm based on the maximum norm (COAS) which achieved better results compared to the other suboptimal algorithms.

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