Double Spatial Modulation with Transmit Antenna Group for Communication Signal Transmission

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Abstract. In this paper, to make use of the idle transmit antennas for the improvement of multiplexing gain and the spectral efficiency, a new design of double spatial modulation (DSM) with transmit antenna group (DSM-TG) is proposed. More specifically, all of transmit antennas are grouped into $G$ groups, each group implements a DSM system independently. Then, by using the vector combiner, $G$ groups of DSM symbol vectors are constructed into a transmitted spatial vector. Furthermore, the average bit error ratio is analyzed. Finally, to make a fair comparison, simulation results are presented for the transmission of same data rate, and show the proposed DSM-TG achieves the better bit error rate (BER) performance gain as compared with other spatial modulation schemes.

Keywords: Multiplexing gain, spectral efficiency, double spatial modulation (DSM), transmit antenna group, bit error ratio (BER).

1. Introduction

Index modulation (IM) technologies, which enhances the spectral efficiency by exploiting the index domain such as transmit antenna selection, time slot, frequency, have been widely nominated to play a significant role in the next generation of wireless communications system. Compared with Spatial Multiplexing (SMX), IM relaxes the inter-channel interference and inter-antenna synchronization.

In order to enhance the higher spectral efficiency, generalized spatial modulation (GSM) [1-3] is developed for the number of antenna index vectors by allowing two or more transmit antennas (TAs) to be simultaneously activated. On the combination of antenna index domain with constellation domain, quadrature spatial modulation (QSM) [4] is proposed to utilize two selected antenna index vectors including one non-zero element to modulate the real and quadrature parts of a data symbol, respectively. Furthermore, by using a rotation angle, two independent SM [5] vector symbols are superimposed into a transmitted spatial vector (TSV). Thus, double spatial modulation (DSM) [6] provides two-fold spectral efficiency compared to classical SM.

To improve the spectral efficiency and bit error ratio (BER) performance of wireless communication, GSM with transmit antenna grouping [7] is proposed by grouping of transmit antennas and quadrature index modulation with three dimension constellation (QIM-TDC) reported in [8] is proposed by designing three-dimension (3D) constellation. Furthermore, using code index modulation (CIM) to carry extra index information bits, for instance, CIM aided SM (CIM-SM) [9].
In this paper, in order to further achieving the higher spectral efficiency and to further enhancing the BER performance by making use of the idle transmit antennas, a new scheme, referred as DSM with transmit antenna group (DSM-TG), is proposed. In the DSM-TG system, all of the TAs are divided into multiple groups, each group is used to transmit a DSM vector symbol independently. Furthermore, the average pairwise error probability (PEP) is provided. Finally, simulation results by Monte Carlo method demonstrate the DSM-TG system outperforms other schemes (e.g. GSM, QSM, QIM-TDC, CIM-SM) in terms of the average bit error ratio performance.

2. System Model
Consider a MIMO system which consist of $N_t$ TAs and $N_r$ receiver antennas, as shown in Fig.1. With the aid of the antenna index modulator and the symbol modulator, the bits stream of $B$ are mapped into a spatial vector $S \in C^{N_t \times 1}$. Then, the spatial vector $S$ is transmitted over the wireless communication complex channel matrix $H$ and experiences the additive white Gaussian noise $n$. Therefore, the received vector signal $y$ can be expressed as:

$$y = HS + n$$ \hspace{1cm} (1)

Where $y \in C^{N_r \times 1}$, $H \in C^{N_r \times N_t}$ is a Rayleigh fading channel matrix with $N_t \times N_r$ dimension, whose each entry $h_{i,k}$, $i \in \{1, 2, \cdots, N_r\}, k \in \{1, 2, \cdots, N_t\}$ is an independent and identically distributed (i.i.d) complex Gaussian random variable obeying $CN(0,1)$, $n \in C^{N_r \times 1}$ is assumed to be the complex Gaussian noise vector with zero mean and variance $N_0$.

2.1. The Proposed Scheme
In this paper, we consider the transmitter of the DSM-TG system, as illustrated in Fig.1. In the DSM-TG scheme, assumed that we divided all of $N_t$ TAs into $G$ groups, each of which includes $N_g = N_t/G$, $g \in \{1, 2, \cdots, G\}$ TAs, which need to be restricted to be integer of power of 2. Thus, the number of the spatial index bits conveyed by the each group is $2 \cdot \log_2 \left( N_t/G \right)$. Also, since
a DSM system simultaneously convey two different constellation symbols with the same modulation order, hence the spectral efficiency of DSM-TG with \( G \) groups can be expressed by

\[
\eta = 2G \cdot \log_2 \left( N_g \right) + 2G \cdot \log_2 M
\]

As shown in Fig.1, through the S/P Splitter, bits stream \( B \) are divided into \( G \) blocks of \( B_g = B/G \) bits stream. The operation events within different subblocks are identical to forming a DSM symbol, and it is sufficient to introduce a subblock of forming a vector symbol.

Without loss of generality, in a subblock of \( B_g \) information bits, we further divided \( B_g \) bits stream into three parts of data information bits: \( I_{A}^{g}, I_{A}^{g}, I_{M}^{g} \). Through the Antenna Index Modulator, \( I_{A}^{g}, I_{A}^{g}, I_{M}^{g} \) data bits, each of which contains \( \log_2 \left( N_g \right) \) information bits, are respectively mapped into two antenna index vectors \( \mathbf{v}_{\kappa}^{g} \) and \( \mathbf{v}_{\xi}^{g} \), where \( \mathbf{v}_{\kappa}^{g}, \mathbf{v}_{\xi}^{g} \) are respectively from the \( \kappa, \xi \)-th column vectors of an identity matrix \( I \) with \( N_g \times N_g \) dimension, where \( \kappa, \xi \in \{1, 2, \cdots, N_g\} \). Moreover, the Symbol Modulator maps \( I_{M} \) containing \( 2 \cdot \log_2 M \) bits into two constellation symbols \( x_{1}^{g} \) and \( x_{2}^{g} \), which are independently drawn from the conventional QAM/PSK constellation. Before feeding into the DSM-g group, by using a rotation angle \( \theta \), whose values are respectively 90°, 45°, 30° for BPSK, 4QAM, 8PSK constellations, the data symbol \( x_{2}^{g} \) need to rotate \( \theta \) degree, namely \( x_{2}^{g} \cdot e^{j \theta} \).

Furtherly, according to the core idea of DSM, the expression of a DSM vector symbol \( \mathbf{S}_{g} \) in the \( g \) subblock may be as follows:

\[
\mathbf{S}_{g} = x_{1}^{g} \cdot \mathbf{v}_{\kappa}^{g} + x_{2}^{g} \cdot e^{j \theta} \cdot \mathbf{v}_{\xi}^{g}
\]

Finally, in the Vector Combiner, Concatenating these \( G \) groups of \( \mathbf{S}_{g} \) the creates a transmitted spatial vector \( \mathbf{V}_{tv} \), which is expressed as

\[
\mathbf{V}_{tv} = \left[ \mathbf{S}_{1}, \mathbf{S}_{2}, \cdots, \mathbf{S}_{g}, \cdots, \mathbf{S}_{G} \right]^T
\]

Before transmission, since the transmit power follows \( P = 1 \), the transmitted spatial vector \( \mathbf{V}_{tv} \) need to be normalized as \( \mathbf{V}_{tv}^E = \mathbf{V}_{tv} / E_{av} \), where \( E_{av} = \sum_{d=1}^{G} \left( 2E_{av}^{x_{1}^{g}} + 2E_{av}^{x_{2}^{g}} \right) \) is the average energy for the transmitted spatial vector \( \mathbf{V}_{tv}^E \).

For further explanation of DSM-TG working principle, an example is given in what follows. Assuming \( N_{t} = 8 \), \( G = 2 \) and 4QAM and BPSK constellation, the rule of antenna index bit stream to an antenna index vector may be \( \{00 \rightarrow [1 0 0 0]^T, 01 \rightarrow [0 1 0 0]^T, 10 \rightarrow [0 0 1 0]^T, 11 \rightarrow [0 0 0 1]^T\} \), the rule of symbol index bits into a constellation point symbol may be \( \{00 \rightarrow 1 + j, 01 \rightarrow -1 - j, 10 \rightarrow -1 + j, 11 \rightarrow 1 - j\} \).
Let \( B = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \) denoting a possible input bits stream be mapped into a TSV of DSM-TG. For the first subblock \( B_1 \) information bit stream, \( I_{M}^{13}, I_{M}^{12} \) bits are modulated into two 4QAM symbols \( \mathbf{v}_{21}^{13} = [0 1 0 0]^T \), \( \mathbf{v}_{31}^{21} = [0 0 1 0]^T \) from an identity matrix with 4×4 dimensions, respectively. Similarly, \( I_{M}^{23}, I_{M}^{22} \) bits are modulated into two 4QAM symbols \( x_1^2 = -1, x_2^2 = 1 \), respectively. \( I_{A}^{3} \) \( I_{A}^{4} \) bits are used to select the 2,3-th column vectors \( \mathbf{v}_{2} = [0 1 0 0]^T \), \( \mathbf{v}_{3} = [0 0 1 0]^T \) from an identity matrix with 4×4 dimensions, respectively.

According to the Eq.(3),
\[
\begin{align*}
S_1 &= [0 -1+j 0 0]^T + [0 0 1 + j 0]^T \cdot e^{j\theta_1} = [0 -1+j (1 + j) \cdot e^{j\theta_1} 0]^T , \\
S_2 &= [0 0 0 -1]^T + [1 0 0 0]^T \cdot e^{j\theta_2} = [e^{j\theta_2} 0 0 -1]^T ,
\end{align*}
\]
where \( \theta_1 = \frac{\pi}{4}, \theta_2 = \frac{\pi}{2} \).

Hence, for bits stream \( B \), the normalized TSV \( \mathbf{v}_{tv}^E \) is given by
\[
\begin{align*}
\mathbf{v}_{tv}^E &= [S_1, S_2, \ldots, S_{G}]^T \\
&= [S_1, S_2]^T, \quad \text{here } G = 2 \\
&= [0 -1+j (1 + j) \cdot e^{j\theta_1} 0 0 -1]^T
\end{align*}
\]

2.2. ML Detector
Assuming at the receiver the channel knowledge is perfect, the constellation symbol index bits and the spatial index bits are jointly detected using the maximum likelihood (ML) detection algorithm recover the original bits, as follows:
\[
[\hat{x}_1, \hat{x}_2, \hat{\kappa}_1, \hat{\kappa}_2; \ldots; \hat{x}_1, \hat{x}_2, \hat{\kappa}_1, \hat{\kappa}_2] = \arg \min_{\mathbf{v}_{tv}} \| \mathbf{Y} - \mathbf{H} \mathbf{S} \|_2 \quad (6)
\]

Where \( \hat{x}_1, \hat{x}_2, \hat{\kappa}_1, \hat{\kappa}_2 \) denote the detected two symbols and two spatial index numbers corresponding the \( g \)-th DSM system, respectively.

3. Average Bit Error Probability
In this section, the average pairwise error probability (APEP) is presented. According to the theory of [9], an upper bound on the APEP for the bits stream \( B \) can be computed as follows:
\[
\text{APEP} \leq \frac{1}{B^2} \sum_{V_n} \sum_{V_{tv}} P(\mathbf{V}_{tv}^E \rightarrow \hat{\mathbf{V}}_{tv}^E) \cdot e\left(\mathbf{V}_{tv}^E \rightarrow \hat{\mathbf{V}}_{tv}^E\right) \quad (7)
\]

Where \( e(\mathbf{V}_{tv}^E \rightarrow \hat{\mathbf{V}}_{tv}^E) \) denotes the total number of erroneous bits associated with the corresponding \( \mathbf{V}_{tv}^E \rightarrow \hat{\mathbf{V}}_{tv}^E \) event., and \( \mathbf{V}_{tv}^E \neq \hat{\mathbf{V}}_{tv}^E \).
For Rayleigh fading channels, based on the theoretical analysis of PEP [9], the expectation of PEP on condition of the channel response $H$ can be given by (8), where $\hat{V}_{tv}^E$ is the erroneous detection of $V_{tv}^E$, 

$$y = \min_{V_{tv}^E \neq V_{tv}^E} \| V_{tv}^E - \hat{V}_{tv}^E \|, \quad Q(\gamma)$$

denotes the Gaussian $Q$ function, $Q(x) = \frac{1}{\sqrt{2\pi}} \int_0^x \exp \left( -\frac{\gamma^2}{2\sin^2 \theta} \right) d\theta$. 

$$P(V_{tv}^E \rightarrow \hat{V}_{tv}^E)_{V_{tv}^E \neq V_{tv}^E} = E_H \left\{ P(V_{tv}^E \rightarrow \hat{V}_{tv}^E | H) \right\}$$

$$= E_H \left[ \frac{1}{\pi} \int_0^\infty \frac{4N_0 \cdot \sin^2 \theta}{4N_0 \cdot \sin^2 \theta + 4N_0 \cdot \| V_{tv}^E - \hat{V}_{tv}^E \|^2} d\theta \right]^{N_r}$$

$$= \left( \frac{1-y}{2} \right)^N \sum_{\lambda=0}^{N_r-1} \left( \frac{1+y}{2} \right)^\lambda$$

4. Performance Results

In this section, to verify the advantage of the DSM-TG system, simulation results with Monte Carlo method are provided and discussions under the condition that the wireless channel belongs to the Rayleigh fading channel and perfect knowledge, $(N_1, N_1) = (8, 8)$. Moreover, in the simulations, the TSV is randomly generated and transmitted over the Rayleigh fading channel, and detected with ML detector at the receiver.

In Fig.2, the BER curves of DSM-TG are evaluated for 12 bps/Hz, and compared with GSM with 4-8QAM and $n=3$, where $n$ is the number of active antennas; QSM with 64QAM; DSM with 8PSK; QIM-TDC with 32-3DCII; ESM with 64QAM; GSM-MIM with (2,1,2,16); CIM-SM with $L=3$ and 8QAM. From Fig. 2, obviously, we observe that DSM-TG has significantly better performance than other schemes (e.g. GSM, QSM, QIM-TDC, CIM-SM) in terms of BER performance. For instance, DSM-TG provides about 9.5 dB SNR gain over QSM at the value of $10^{-4}$.

In Fig.3, at the transmission of 14 bps/Hz, we compare the BER performance of DSM-TG with 2-4QAM, QSM with 256QAM, CIM-SM with $L=3$ and 32QAM, GSM-MIM with (1,1,4,64), GSM with 32QAM and $n=2$, QIM-TDC with 128-3DCII. Also, Fig.3 shows that the BER performance versus SNR curves of DSM-TG is better than other schemes. For instance, DSM-TG outperforms about 8.1 dB SNR gains over QSM, 5 dB SNR gains over CIM-SM, approximately 2 dB SNR gains over GSM-MIM, 1.5 dB SNR gains over QIM-TDC, 1.5 dB SNR gains over GSM at BER value of $10^{-2}$.

5. Conclusions

In this paper, by making use of the idle TAs, we introduced a new design, referred as DSM-TG. In DSM-TG system, all of TAs are divided into multiple groups, each of which implements a DSM system independently, for enhancing the spectral efficiency and achieving the multiplexing gains. Then, the average bit error probability is presented and analyzed. Furthermore, through computer simulation
results, it can be shown that DSM-TG offers significant improvement of BER performance compared with other schemes at the transmission of same data rate. Next, our future research will focus on the detection complexity of DSM-TG, which is not discussed in this paper.

**Figure 2.** Performance comparison of DSM-TG and other schemes with $(N_t, N_r) = (8,8)$.

(a) 12 bps/Hz and (b) 14 bps/Hz.

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