Multi-Antenna Selection for Double Spatial Modulation

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Abstract. In this paper, to exploit the spatial domain of transmit antennas (TAs) for the transmit diversity gain in the double spatial modulation (DSM) system, a new scheme of multi-antenna selection for DSM (MAS-DSM) is designed. In the MAS-DSM system, the number of TAs are grouped into \( n \) groups, each of which corresponds to an sub-system of DSM. More specifically, a transmitted spatial vector is constructed by two spatial vectors (SVs). For the achievability of transmit diversity gain, one of the two SVs is obtained by using \( n \) antenna index (AI) vectors to modulate a data symbol, another of them is obtained by multiplying with a rotation angle after another \( n \) AI vectors to modulate another data symbol. Finally, the spectral efficiency and the average bit error ratio (BER) are analyzed. Simulation results by using Monte Carlo demonstrate that the proposed MAS-DSM system has better BER performance compared with the conventional spatial modulation schemes in wireless communication network.

Keywords: Transmit diversity gain; multi-antenna selection; double spatial modulation (DSM); antenna index (AI); bit error ratio (BER).

1. Introduction
Generalized spatial modulation (GSM) reported in [1-3] is developed for achieving the transmit diversity of system, the activated transmit antenna (TA) in which simultaneously transmits the same version of one conventional modulated symbol (e.g. QAM/PSK) with more than one active TAs at one time slot. GSM not only achieves the transmit diversity gain but also relax the relation of both the antenna index information bits and the number of TAs. However, the spectral efficiency is only \( \left\lfloor \log_2 C_{N_t}^{n_a} \right\rfloor + \log_2 N \), where \( N_t \), \( n_a \), \( N \) denotes the number of TAs and the active TAs, the modulation order, respectively.

By making fully use of the property of the spatial dimension in the constellation symbol, quadrature spatial modulation (QSM) reported in [4], extends the spatial dimension to the in-phase and quadrature dimension. The real and quadrature part of a data symbol are modulated by an antenna activated by an in-phase vector and another antenna activated by a quadrature vector, respectively. Compared with SM [5], QSM can transmit more \( \log_2 N_t \) bits per a transmitted vector symbol. For further achieving the spectral efficiency, double spatial modulation (DSM) is proposed in [6] and provides two-fold spectral efficiency compared to classical SM. In fact, with the aid of a rotation angle, two independent SM transmission vectors are superimposed. To improve the system performance against the high channel correlation in massive MIMO systems, grouping GSM (gGSM) is proposed in [7]. Recently, based on
the design concept of both SM and QSM, quadrature index modulation with three dimension constellation [8] (QIM-TDC) is proposed to enhance the spectral efficiency and to enhance the reliability of wireless communication system by the design of three-dimension (3D) constellation. However, based on the above researches, the transmit diversity is not better considered for the better performance and too many TAs are inactivated.

In this paper, for further achieving the transmit diversity, a new design, which is called multi-antenna selection for DSM (MAS-DSM), is proposed to further lower bit error ratio (BER) performance. In the proposed MAS-DSM system, the TAs are divided into multiple groups, which are used to transmit the two conventional modulated symbols with the aid of a rotation angle. Furthermore, the spectral efficiency and the average bit error ratio (BER) are provided. Finally, simulation results and comparisons show that the proposed MAS-DSM outperforms those existing transmission schemes in terms of the average BER performance.

2. System Model

2.1. MAS-DSM transmitter

The transmitter of the MAS-DSM system has \( N_t \) TAs, as shown in Fig.1.

![Fig. 1 MAS-DSM Transmitter](image)

In the MAS-DSM scheme, the number of \( N_t \) TAs is grouped into \( n \) groups, each group of which has \( N_t/n \) TAs, only one of which are used for the transmission of the modulated symbol. Through the Bits Splitter, The \( m \) incoming data bits are grouped into two categories as follows:

The first group includes two parts of \( I_{M1}^1 \) and \( I_{M2}^2 \). The two parts of \( I_{M1}^1 \) and \( I_{M2}^2 \), each containing \( \log_2 M \) information bits, are respectively used to modulate two data symbol \( s_i \) and \( s_k \), where \( s_i \in \{s_1, s_2, \ldots, s_i, \ldots, s_M\} \) and \( s_k \in \{s_1, s_2, \ldots, s_k, \ldots, s_M\} \) drawn from arbitrary constellation diagram such as \( M \)-QAM/PSK.

The second group includes \( n \) parts of the antenna index (AI) bits \( I_{AI1}^1, \ldots, I_{AI1}^n \) and \( I_{AI2}^1, \ldots, I_{AI2}^n \). The \( n \) parts of \( I_{AI1}^1, \ldots, I_{AI1}^n \), each containing \( \log_2 (N_t/n) \) information bits, are respectively mapped into
the AI vectors of \( \mathbf{v}_{\alpha}^1, \ldots, \mathbf{v}_{\alpha}^n \), and then respectively used to activate one out of \( N_i/n \) TAs in each group for transmitting the same data symbol \( s_j \). Similarly, The \( n \) parts of \( \mathbf{I}_{\alpha_1}, \ldots, \mathbf{I}_{\alpha_n} \), each containing \( \log_2(N_i/n) \) information bits, are respectively mapped into the AI vectors of \( \tilde{\mathbf{v}}_{\beta_1}^1, \ldots, \tilde{\mathbf{v}}_{\beta_n}^n \), and then used to activate one out of \( N_i/n \) TAs in each group for transmitting the same data symbol \( \tilde{s}_k \). Note that \( \mathbf{v}_{\alpha}^n, \mathbf{v}_{\beta}^n, \alpha^\xi, \beta^\xi \in \{1, 2, \ldots, N_i/n\} \) are from the \( \alpha^\xi, \beta^\xi \)-th column vectors of a identity matrix with \( N_i/n \times N_i/n \) dimensions, where \( \omega, \xi \in \{1, 2, \ldots, n\} \).

In Fig.1, with the aid of a rotation angle, a transmitted spatial vector \( \mathbf{V} \) is constructed by two spatial vectors such as \( \mathbf{S}_1 \) and \( \mathbf{S}_2 \). For the spatial vector \( \mathbf{S}_i(\mathbf{S}_j) \), it is obtained by modulating the data symbol \( s_j(\tilde{s}_k) \) on the active transmit antennas activated by \( n \) parts of \( \mathbf{v}_{\alpha}^1, \ldots, \mathbf{v}_{\alpha}^n(\tilde{\mathbf{v}}_{\beta}^1, \ldots, \tilde{\mathbf{v}}_{\beta}^n) \). Hence, the expression of the spatial vector \( \mathbf{S}_1 \) and \( \mathbf{S}_2 \) may be as follows:

\[
\mathbf{S}_1 = \left[ s_j \cdot \mathbf{v}_{\alpha}^1 \quad \cdots \quad s_j \cdot \mathbf{v}_{\alpha}^n \right]^T, \quad \mathbf{S}_2 = \left[ s_k \cdot \tilde{\mathbf{v}}_{\beta}^1 \quad \cdots \quad s_k \cdot \tilde{\mathbf{v}}_{\beta}^n \right]^T
\]

(1)

According to the basic principle of DSM, before resulting in the transmitted spatial vector \( \mathbf{V} \), a rotation angle \( \theta \) is considered, the value of the angle \( \theta \) may be \( 90^\circ, 45^\circ, 30^\circ \) for BPSK, 4QAM, 8QAM constellations.

Accordingly, the normalized transmitted spatial vector \( \tilde{\mathbf{V}} \) is given as

\[
\tilde{\mathbf{V}} = \frac{\mathbf{S}_1 + e^{j\theta} \cdot \mathbf{S}_2}{\sqrt{n \cdot (E_{av} + \tilde{E}_{av})}} = \frac{1}{\sqrt{\mu}} \left( \begin{bmatrix} s_j \cdot \mathbf{v}_{\alpha}^1 \\ \vdots \\ s_j \cdot \mathbf{v}_{\alpha}^n \end{bmatrix} + e^{j\theta} \cdot \begin{bmatrix} s_k \cdot \tilde{\mathbf{v}}_{\beta}^1 \\ \vdots \\ s_k \cdot \tilde{\mathbf{v}}_{\beta}^n \end{bmatrix} \right)
\]

(2)

where \( \mu = n \cdot (E_{av} + \tilde{E}_{av}) \), \( E_{av}, \tilde{E}_{av} \) denotes the average energy of the spatial vector \( \mathbf{S}_1, \mathbf{S}_2 \), respectively.

**Example:** Consider the MAS-DSM system with \( N_i = 6 \), \( n = 3 \), thus the rule of bit to AI vector may be \( \{0 \rightarrow [1 0]^T, 1 \rightarrow [0 1]^T\} \). 4QAM for \( s_j \) and \( \tilde{s}_k \), the rule of bits to symbol is that

\( \{00 \rightarrow 1 + j, 01 \rightarrow 1 + j, 10 \rightarrow 1 + j, 11 \rightarrow 1 + j\} \) Let \( m = [11010101] \) denote \( \mathbf{i}_m^1, \mathbf{i}_m^2, \mathbf{i}_m^3 \), a possible input information bit sequence to be transmitted by the transmitter of the MAS-DSM system.

From the above information bit sequence \( m \), the first \( I_m^1 \) bits are mapped into a 4QAM symbol \( 1 \rightarrow j \). The \( [i_m^1, i_m^2, i_m^3] \) bits are used to select the AI vector \( \mathbf{v}_1^j = [0 1]^T, \mathbf{v}_2^j = [1 0]^T, \mathbf{v}_3^j = [0 1]^T \) from the column vectors of a \( 2 \times 2 \) dimensional identity matrix, respectively. The next \( I_m^2 \) bits are mapped into a 4QAM symbol \( 1 \rightarrow -j \). The \( [i_m^1, i_m^2, i_m^3] \) bits are used to select the AI vector \( \tilde{\mathbf{v}}_1^j = [0 1]^T, \tilde{\mathbf{v}}_2^j = [1 0]^T, \tilde{\mathbf{v}}_3^j = [0 1]^T \) from the column vectors of a \( 2 \times 2 \) dimensional identity matrix, respectively.
Therefore, for this input information bit sequence, the corresponding the normalized transmitted spatial vector $\hat{\mathbf{v}}$ may be given by

$$\hat{\mathbf{v}} = \mathbf{S}_1 + e^\phi \cdot \mathbf{S}_2 = \frac{1}{\sqrt{n}} \left( \frac{1}{\sqrt{2}} \right) \left( \mathbf{S}_1 + e^{i\phi} \cdot \mathbf{S}_2 \right)$$

(3)

Where $\mathbf{S}_1 = [0, -1 - j, -1 - j, 0, 0, -1 - j]^T$, $\mathbf{S}_2 = [-1 + j, 0, 0, -1 + j, 0]^T$.

2.2. MAS-DSM Receiver

The resulting spatial vector $\hat{\mathbf{v}}$ symbol are transmitted over the flat Rayleigh channel and the additive white Gaussian noise. Thus, the received signal vector $\mathbf{r} \in \mathbb{C}^{N_c \times 1}$ may be given as

$$\mathbf{r} = \mathbf{H} \mathbf{v} + \mathbf{w} = \mathbf{H} \left( \frac{\mathbf{S}_1 + e^{i\phi} \cdot \mathbf{S}_2}{\sqrt{n} \left( E_{av} + \mathbf{E}_{av} \right)} \right) + \mathbf{w}$$

(4)

where $\mathbf{H} \in \mathbb{C}^{N_t \times N_t}$ is a channel matrix with $N_t \times N_t$ dimension, whose each entry $h_{l,\lambda}$, $l \in \{1, 2, \ldots, N_t\}$, $\lambda \in \{1, 2, \ldots, N_t\}$ is an independent and identically distributed (i.i.d) complex Gaussian random variable having a mean zero and a variance one. Similarly, $\mathbf{w} \in \mathbb{C}^{N_c \times 1}$ is assumed to be an i.i.d complex Gaussian random variable having a mean zero and a variance $\sigma_w^2$.

At the receiver, assuming that the channel state information (CSI) has perfect knowledge, maximum likelihood (ML) detection algorithm is used to recover the original bits. The ML criterion of the MAS-DSM system is defined as

$$[\hat{i}_1, \hat{k}, \hat{\text{I}}_{a1}^1, \ldots, \hat{\text{I}}_{a1}^n, \hat{\text{I}}_{a2}^1, \ldots, \hat{\text{I}}_{a2}^n] = \arg \min_{i_1, k, \text{I}_{a1}^1, \ldots, \text{I}_{a1}^n, \text{I}_{a2}^1, \ldots, \text{I}_{a2}^n} \left\| \mathbf{Y} \cdot \mathbf{H} \left( \frac{\mathbf{S}_1 + e^{i\phi} \cdot \mathbf{S}_2}{\sqrt{n} \left( E_{av} + \mathbf{E}_{av} \right)} \right) \right\|^2$$

(5)

where $\hat{i}_1, \hat{k}$ denote the detected QAM/PSK constellation point indexes, $\hat{\text{I}}_{a1}^1, \ldots, \hat{\text{I}}_{a1}^n$ and $\hat{\text{I}}_{a2}^1, \ldots, \hat{\text{I}}_{a2}^n$ denote the detected antenna index bits.

3. Performance Analysis

3.1. Spectral efficiency

In the above mentioned designing of MAS-DSM, a transmitted symbol can carry the constellation point index bits $I_1^1, I_2^1, \ldots, I_{M}^1, I_1^2, I_2^2, \ldots, I_{M}^2$ and the antenna index bits $\text{I}_{a1}^1, \ldots, \text{I}_{a1}^n, \text{I}_{a2}^1, \ldots, \text{I}_{a2}^n$ in per symbol period. Hence the spectral efficiency of the proposed MAS-DSM can be calculated as

$$\eta = 2 \cdot \log_2 M + 2 \cdot n \cdot \log_2 \frac{N_t}{N} \text{ bps/Hz}$$

(6)

3.2. Average Bit Error Probability

Assumed $\hat{\mathbf{v}}$ is the erroneous detection of $\mathbf{v}$. According to [9], the conditional pairwise error probability (CPEP) can be calculated as
\[ P(\tilde{V} \rightarrow \hat{V} \mid H) = P \left( \left\| Y - HV \right\|^2 > \left\| Y - H\hat{V} \right\|^2 \right) = Q \left( \sqrt{\frac{H(V - \hat{V})}{2\sigma^{2}_e}} \right) = \frac{1}{\pi} \int_{0}^{\infty} \exp \left( -\frac{(V - \hat{V})^2}{4\sigma^{2}_e \cdot \sin^2 \theta} \right) \, d\theta \]  

(7)

where \( Q(\cdot) \) denotes the Gaussian \( Q \) function, \( Q(x) = \frac{1}{\pi} \int_{0}^{x} \exp \left( -\frac{\sin^2 \theta}{2\sin^2 \theta} \right) \). The expectation of the CPEP on the channel response \( H \) can be given by

\[ \bar{P}(\tilde{V} \rightarrow \hat{V}) = E_H \left\{ P(\tilde{V} \rightarrow \hat{V} \mid H) \right\} \]  

(8)

Combing with the \( Q \) function, the expression of expectation of (8) can be calculated as

\[ \bar{P}(\tilde{V} \rightarrow \hat{V}) = \frac{1}{\pi} \int_{0}^{\infty} \left( \frac{\sin^2 \theta}{\sin^2 \theta + \frac{\gamma}{4\sigma^{2}_e}} \right)^{N_i} \, d\theta \]  

(9)

where \( \gamma = \left\| V - \hat{V} \right\|^2 \).

The average bit error ratio (BER) of MAS-DSM, using the union bound technology, can be derived as

\[ P_b = \frac{1}{m2^n} \sum_{\tilde{v}} \sum_{\hat{v}} \bar{P}(\tilde{V} \rightarrow \hat{V}) \cdot e \left( \left\| \tilde{V} \rightarrow \hat{V} \right\| \right) \]  

(10)

where \( e(\tilde{V} \rightarrow \hat{V}) \) denotes the total number of erroneous bits associated with the corresponding PEP event.

4. Performance Results

To validate the superiority of the proposed MAS-DSM system, simulation results using Monte Carlo for the proposed MAS-DSM system with \( N_i = N_e = 8 \) are provided and discussions. Throughout all the simulations, the channel information state is assumed to be perfect.

At the spectral efficiency of 10 bps/Hz, the BER performance versus SNR curves of MAS-DSM with both \( n=2 \) and \( n=4 \), BPSK; SM with 128QAM; GSM with 64QAM; QSM with 16QAM; DSM with 4QAM; ESM with 16QAM; QIM-TDC with 8-3DCI are presented in Fig. 2. It can be observed that the BER performance of MAS-DSM with \( n=2 \) has considerable SNR gains compared with that of MAS-DSM with \( n=4 \). Hence, the number of activated TAs with \( n=2 \) is the best candidate for the MAS-DSM system; the larger the number of activated TAs, the better BER performance may not be. At the spectral efficiency of 10 bps/Hz, compared with other schemes, it can be observed from Fig.2 that the MAS-DSM system using BPSK has significant better BER except QIM-TDC.
Fig. 2 BER comparison of MAS-DSM with other schemes at 10 bps/Hz.

Furthermore, Fig.3 also shows that the BER performance versus SNR curves of MAS-DSM with 4QAM; SM with 512QAM; GSM with 256QAM; QSM with 64QAM; DSM with 8QAM; ESM with 64QAM; QIM-TDC with 32-3DCII at the spectral efficiency of 12 bps/Hz. The simulation results demonstrate that the MAS-DSM system with \( n=2 \) has significantly better performance than all other schemes, and outperforms approximately 13 dB SNR gains over SM, 10 dB SNR gains over GSM, approximately 8 dB SNR gains over QSM, 7 dB SNR gains over DSM, 2.5 dB SNR gains over ESM, 1 dB SNR gains over QIM-TDC at BER value of \( 10^{-4} \).

Fig. 3 BER comparison of MAS-DSM with other schemes at 12 bps/Hz.

5. Conclusion

In this paper, the MAS-DSM system is proposed for achieving the transmit diversity gains by activating the multiple TAs. By activating different number of TAs, we obtain that the larger the number of activated TAs, the better BER performance may not be. Then, compared with other schemes, simulation results using Monte Carlo demonstrates that the MAS-DSM system improves the BER performance at the same configuration. Furthermore, although the BER performance is improved,
the computational complexity of MAS-DSM is not discussed in this paper, which will be next research work.

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References
[1] Jinlin Fu, Chunpin Hou and Wei Xiang, etc, "Generalized spatial modulation system with multiple active transmit antennas," 2010 IEEE Globecom Workshops, Dec. 2010, pp. 839–844.
[2] A. Younis, N. Serafimovski, R. Mesleh, and H. Haas, "Generalised spatial modulation," in Proc. 2010 Signals, Syst. Comput., Nov 2010, pp. 1498–1502.
[3] A. Younis, R. Mesleh, M. D. Renzo, and H. Haas, "Generalised spatial modulation for large-scale MIMO," in Proc. 2014 22nd European Signal Processing Conference (EUSIPCO), Sept. 2014, pp. 346–350.
[4] R. Mesleh, S. S. Ikki, and H. M. Aggoune, "Quadrature spatial modulation," IEEE Trans. Veh. Technol., vol. 64, no. 6, pp. 2738–2742, Jun 2015.
[5] R. Y. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, "Spatial modulation," IEEE Trans. Veh. Technol., vol. 57, no. 4, pp. 2228–2241, July 2008.
[6] Z. Yigit and E. Basar, “Double spatial modulation: A high-rate index modulation scheme for MIMO systems,” in Proc. Int. Symp. Wireless Commun. Syst. (ISWCS), Poznan, Poland, Sept. 2016, pp. 347–351.
[7] W. Qu and M. Zhang, et al., “Generalized spatial modulation with transmit antenna grouping for massive MIMO,” IEEE Access, vol. 5, PP. 26798–26807, 2017.
[8] F. Huang and X. Liu, et al., “Quadrature index modulation with three-dimension constellation,” IEEE Access, vol. 7, PP. 182335-182346, 2019.
[9] Gordon L. Stuber, "Principles of mobile communication," New York, USA: Springer, 3rd edition, 2011.