# Low-complexity transmit antenna selection for spatial modulation

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A low-complexity transmit antenna selection (TAS) scheme is proposed for spatial modulation systems to provide a better trade-off between computational complexity and system performance. The proposed scheme can achieve a performance similar to the optimal TAS scheme in the low SNR region, but with much lower complexity compared with existing schemes in the literature.

*Introduction:* Spatial modulation (SM) [1–3] has been proposed as an efficient and low-complexity implementation of MIMO wireless systems. In SM-MIMO, only one transmit antenna is activated at each single time instant. At the SM receiver, the maximum-likelihood (ML) detection algorithm [4] was proposed to obtain optimal system performance. To further enhance system performance with limited feedback, link adaptation schemes that change transceiver parameters have been developed such as in [5–7]. Among the current link adaptation schemes, transmit antenna selection (TAS) [6, 7] is a class of efficient schemes, which fully exploits extra antenna resources for improving performance.

For SM-MIMO link adaptation schemes including TAS, the optimal criterion is to design the link by maximising the minimum Euclid distance (ED) among the legitimate transmit vectors [5, 6]. However, the ED-based criterion results in large complexity due to exhaustive search. In [7–9], some simplified ED-based algorithms of lower complexity were proposed. To further reduce the complexity of ED-based algorithms, some candidate TAS criteria were developed such as in [7, 10, 11]. More specifically, a capacity optimised antenna selection (COAS) [7] was proposed, where the antennas with the maximum Frobenius norm of the columns in the channel matrix are selected. COAS is of low complexity and its performance is not comparable to those based on the ED criteria. On the other hand, motivated by Tang *et al.* [12] which is concerned with the angles between the transmit vectors, the correlation of the angles is considered as a new TAS criterion in [10, 11]. For example, antenna selection based on antenna correlation (AS-AC) was developed in [11]. However, the computational complexity for searching the best antenna correlation in [11] is excessive, and the performance is still not comparable to those algorithms based on the optimal criterion.

In this Letter, a new TAS criterion is proposed in consideration of not only the Frobenius norm of the columns in the channel matrix, but also the angles between the column vectors. A low-complexity searching algorithm is developed to efficiently select the best antenna set for transmission. It is shown that the proposed scheme is capable of achieving a more elegant trade-off between complexity and performance compared with current TAS schemes.

*System and signal model:* Consider a SM-MIMO system with $N_t$ transmit and $N_r$ receive antennas over the flat Rayleigh fading channel. If $L$ transmit antennas are selected out of the $N_t$ ones, the selected antenna subset is determined by a TAS criterion at the receiver side. The receiver decides the selected subset $C_i^{L\times 1} \in S, i = 0, 1, \ldots, I$, where $S$ is the set of all possible $I = C_{N_t}^L$ subsets of the transmit antennas. Then the receiver will inform the transmitter of the indices of the selected antenna subset.

At each time slot, data bits are mapped onto the transmit vector as $x = s_m e_l \in C^{L\times 1}$, where the complex-valued $s_m$, $m = 0, 1, \ldots, M-1$, is chosen from the $M$-ary quadrature amplitude modulation ($M$-QAM) constellation and

$$e_l = \left[\overbrace{0, \ldots, 0}^{l-1}, 1, 0, \ldots, 0\right]^{\mathrm{T}} \in C^{L\times 1}, \; l = 0, 1, \ldots, L-1 \qquad (1)$$

is selected from the $L$-dimensional vector space. In general, the transmit vector, which represents $\log_2 LM$ bits, is transmitted over $L$ transmit antennas.

At the receiver, the received signal vector can be expressed as

$$\boldsymbol{y} = \boldsymbol{H}(i)\boldsymbol{x} + \boldsymbol{n} \qquad (2)$$

where $\boldsymbol{H}(i)$ is the channel matrix with $i = 0, 1, \ldots, I$, and the channel fading coefficient between the $l$th transmit and the $j$th receive antenna, denoted by $h_{jl}$, is assumed to be independent and identically distributed (i.i.d.) complex Gaussian random variables with zero mean and unit variance, i.e. $h_{jl} \sim CN(0, 1)$. The $N_r$-dimensional noise vector $\boldsymbol{n}$ contains Gaussian random variables obeying $CN(0, \sigma^2)$, where $\sigma^2$ is the noise power of the noise. Using the ML detection algorithm, the optimal estimate of the transmit symbol vector can be given by

$$\hat{x} = \arg\min_{x\in\Lambda} \left\|\boldsymbol{y} - \boldsymbol{H}(i)x\right\|_{\mathrm{F}}^2 \qquad (3)$$

where $\Lambda$ is the set of all the possible transmitted symbols.

*Conventional antenna selection algorithm for SM:* First, the ED-based TAS is mentioned because of its excellent performance. For SM-MIMO with ML detection, the performance of the receiver is dominated by the minimum Euclidean distance, which is defined as

$$d_{\min}(\boldsymbol{H}(i)) = \min_{x_j, x_k\in\Lambda, x_j\neq x_k} \left\|\boldsymbol{H}(i)(x_j - x_k)\right\|_{\mathrm{F}}^2 \qquad (4)$$

Then, the optimal TAS scheme is to select the antenna subset which maximises the minimum Euclidean distance as follows:

$$\hat{\boldsymbol{H}}_p = \arg\max_{p\in P} \mathrm{d}_{\min}(\boldsymbol{H}_p) \qquad (5)$$

where $P$ is the candidate subsets of all the possible transmit antenna combinations. This criterion gives the optimal performance in terms of bit error rate. However, the optimal TAS scheme necessitates exhaustive search resulting in prohibitive computational complexity, especially for large QAM constellations. Several simplified ED-based TAS algorithms have been developed to reduce complexity such as the Euclid distance optimised antenna selection (EDAS) [7], EDAS reduced-low-complexity (EDAS-RLC) [8] and singular value decomposition reduced-low-complexity (SVD-EDAS) schemes [9]. The COAS algorithm was proposed in [7], where the antennas corresponding to the columns of the channel matrix with the maximum Frobenius norm are selected. The algorithm can be expressed as

$$p = \arg\max_{\forall i, l\in\{1,2,\ldots,N_t\}} \left\|\boldsymbol{h}_l(i)\right\|_{\mathrm{F}}^2 \qquad (6)$$

where $\boldsymbol{h}_l(i)$ is the $l$th column of matrix $\boldsymbol{H}(i)$. COAS is of much lower complexity, although its performance is not comparable to its ED-based counterparts.

**Table 1:** Proposed TAS algorithm

1: $\Theta = \varnothing$, $\Gamma = \{1, 2, \ldots, N_t\}$
2: for $j = 1 : N_t$
  $\alpha_j = \|\mathbf{h}_j\|_F^2$
  *end*
3: $p_1 = \arg\max_{i\in\Gamma} \alpha_i$
4: for $n = 2 : L$
  $\Theta = \Theta + \{p_{n-1}\}$
  $\Gamma = \Gamma - \{p_{n-1}\}$
  for all $i \in \Gamma$
    $\beta_{p_{n-1},i} = arc\cos \frac{|\langle \mathbf{h}_i, \mathbf{h}_{p_{n-1}}\rangle|}{\|\mathbf{h}_i\|\|\mathbf{h}_{p_{n-1}}\|}$
    $\beta_i = \arg\max_{j\in\Theta} \beta_{j,i}$
    $w_i = \|\mathbf{h}_i\|\beta_i$
  end
  $p_n = \arg\max_{i\in\Gamma} w_i$
  end
5: $\Theta = \Theta + \{p_L\}$
6: return $\Theta$

*Proposed TAS scheme:* It is a challenging issue to design a TAS criterion offering a balanced trade-off between performance and complexity. In this Letter, based on the traditional COAS and angle-based criteria, a hybrid TAS criterion is proposed in consideration of both the norms and the angles of the transmit SM-MIMO signal vectors.

The proposed criterion aims at selecting the optimised channel matrix which increases the angles of the transmit vectors as well as the channel gains. First, the angle of transmit vectors $\boldsymbol{h}_j$ and $\boldsymbol{h}_k$ is described as the cosine similarity of it as

$$\cos\beta_{j,k} = \frac{|\boldsymbol{h}_j^{\mathrm{H}}\boldsymbol{h}_k|}{||\boldsymbol{h}_j||_{\mathrm{F}}||\boldsymbol{h}_k||_{\mathrm{F}}} \qquad (7)$$

Then, the proposed criterion can be described as

$$p = \arg\max_{\forall i}\left(\min_{\forall j,k,j\neq k}\left(\|h_j(i)\|_F^2\|h_k(i)\|_F^2\beta_{j,k}(i)\right)\right) \quad (8)$$

As can be seen from (8), an exhaustive search is still desired to solve for the best antenna subset. To alleviate the complexity issue, a low-complexity searching algorithm is also developed in this Letter to select the preferred antennas one by one. Two sets Θ and Γ are defined to represent the selected and the overall antenna indices, respectively. Initially, the cardinals of the two sets are set to $|\Theta| = 0$ and $|\Gamma| = N_t$. In the first step, the first selected antenna is the column with the largest Frobenius norm, and is then added it to Θ. Then, there are still $N_t - 1$ remaining elements in Γ. Furthermore, in the $n$th ($n > 2$) step, we compute the angles between the $(n-1)$th antennas in Θ and the remaining antennas in Γ, and choose the antenna satisfying

$$p_n = \arg\max_{k\in\Gamma}\left(\left(\min_{j\in\Theta}\beta_{j,k}\right)\|h_k\|_F\right) \quad (9)$$

Then $p_n$ is added to Θ. The above procedures continue until $n = L$. The proposed scheme is summarised in Table 1.

*Simulation results:* In this Section, we present numerical results to demonstrate the performance of the proposed TAS method. The number of the total transmit, selected antennas and receive antennas are assumed to be $N_t = 6$ or 7, $L = 4$ and $N_r = 3$, respectively. The modulation schemes are QPSK and 16QAM. Throughout our simulations, the frequency-flat Rayleigh fading channel is considered with the channel gain assumed to be perfectly known at the receiver. Moreover, the computational complexity is measured by the number of floating point operations (flops). The proposed algorithm and the comparative schemes mentioned above are shown in Table 1.

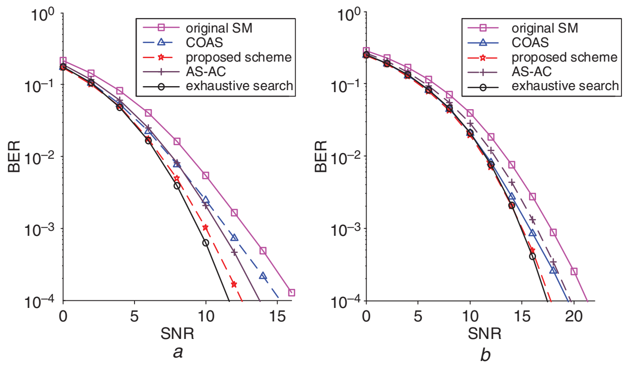


**Fig. 1** *Performance of SM-MIMO employing different TAS schemes with $N_t = 7$, $N_r = 3$, $L = 4$*

*a* QPSK
*b* 16QAM

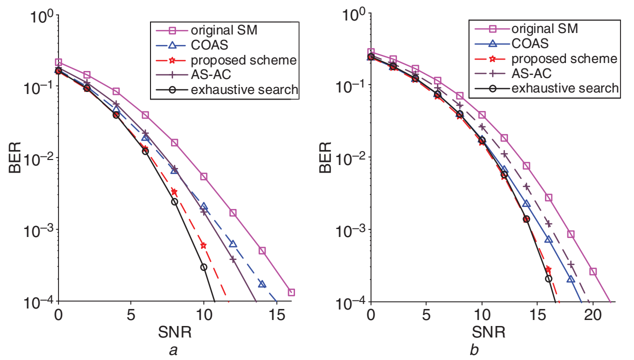


**Fig. 2** *Performance of SM-MIMO employing different TAS schemes with $N_t = 6$, $N_r = 3$, $L = 4$*

*a* QPSK
*b* 16QAM

It can be observed from Figs. 1 and 2 that our proposed TAS method outperforms the other popular TAS schemes applied to the SM system except for the optimum exhaustive search algorithm. Furthermore, the proposed scheme has similar performance as the exhaustive search algorithm with QPSK at low SNRs. When 16QAM is used, the performance of the proposed TAS scheme is close to that of the exhaustive search algorithm. In general, the proposed scheme is capable of striking an elegant balance to bring about a balanced trade-off between system performance and computational complexity. Table 2 shows the computational complexity comparison.

**Table 2:** Computational complexity comparison

| TAS method | Computational complexity (flops) | Example (flops) |
|---|---|---|
| Exhaustive search | $C_{N_t}^2(5N_r - 1)M^2$ | 53 760 |
| EDAS-RLC | $N_t(2N_r - 1) + 64C_{N_t}^2\left(N_r - \frac{2}{3}\right)\frac{M}{2}$ | 17 950 |
| AS-AC | $N_t(2N_r - 1) + (2N_r + 3)C_{N_t}^L C_L^2$ | 840 |
| SVD-EDAS | $N_t(2N_r - 1) + 19C_{N_t}^2\left(N_r - \frac{1}{3}\right)$ | 790 |
| Proposed | $N_t(2N_r - 1) + (2N_r + 3)\left(N_t L - N_t - \frac{L^2 - L}{2}\right)$ | 138 |
| COAS | $N_t(2N_r - 1)$ | 30 |

*Conclusion:* A new TAS criterion for SM-MIMO, which considers the norms and the angles between the transmit signal vectors, is proposed in this Letter. Furthermore, a low-complexity searching algorithm is developed for simplifying the problem of antenna selection. The proposed TAS scheme was found to be able to provide a balanced trade-off between computational complexity and system performance.

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One or more of the Figures in this Letter are available in colour online.

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