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TRANSMIT ANTENNA SELECTION SCHEMES FOR DOUBLE SPATIAL MODULATION

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ABSTRACT

Double spatial modulation (DSM) is a transmission technique which has been recently proposed for multiple-input multiple-output (MIMO) communication systems. DSM has a higher spectral efficiency compared with classical spatial modulation (SM), as it doubles the number of active transmit antennas. In this paper, transmit antenna selection (TAS) is applied to DSM in order to enhance the bit error rate (BER) performance. In particular, we integrate two sub-optimal TAS algorithms to DSM; namely, capacity-optimized antenna selection (COAS) and antenna selection based on amplitude and antenna correlation (A-C-AS). Simulation results of these two algorithms are presented and compared with the optimal Euclidean distance-optimized antenna selection (EDAS) using MATLAB software. Our results show a complexity-performance trade-off. Although there is a negligible loss of BER, our algorithms are much less complex than EDAS.

KEYWORDS

Antenna selection, Double spatial modulation, Transmit diversity, Spectral efficiency, Bit error rate.

1. INTRODUCTION

In MIMO systems, spatial multiplexing is used to serve the need for higher data rates in wireless communications. It utilizes multiple transmitting antennas in order to convey the data simultaneously [1]. One popular example for spatial multiplexing in MIMO is the vertical Bell lab layered space-time (VBLAST) scheme [2]-[3]. VBLAST achieves a high data rate, but suffers from inter-channel interference (ICI) and high receiver complexity.

To overcome the pitfalls of the VBLAST, spatial modulation (SM) is another transmission scheme that overcomes the problem of the ICI and has a lower receiver complexity than the VBLAST [4]-[5]. SM is a member of the index modulation family which attracted an increased attention in the past decade [6]-[8]. Although SM improves the spectral efficiency of MIMO systems, it does not achieve the same data rate of the VBLAST. Therefore, the improvement of spectral efficiency under SM has been achieved through several schemes [6]. Examples of the recent schemes of SM include quadrature spatial modulation (QSM) [9] and double spatial modulation (DSM) [10]. QSM retains the benefits of SM, but with an improved spectral efficiency. The basic idea of QSM is to split the in-phase and quadrature components of the amplitude/ phase modulation (APM) symbol and map them separately to the antenna set [9]. Meanwhile, DSM allows transmitting two modulated symbols at the same time. DSM provides considerably better error performance than QSM [10]. Moreover, the spectral efficiency of the classical SM is a half of the spectral efficiency of the DSM scheme for the same number of transmit antennas and modulation order, M.

Despite the several advantages of SM-MIMO systems, combining transmit diversity with these systems is not straightforward [11]. Antenna selection schemes (TASs) can be used to introduce transmit diversity for SM systems [12]-[15]. In [12], a tree search antenna selection scheme (TSAS) for SM systems is introduced to reduce the high complexity of EDAS scheme. In [13], a low complexity TAS algorithm based also on Euclidian distance is presented. Several sub-optimal TAS schemes are used to enhance the performance of QSM in [14]. The performance is compared with the optimal EDAS. The suboptimal schemes have much lower complexity compared with EDAS with a reasonable deterioration in bit error rate (BER) performance [15]. Up to the author knowledge, the performance of antenna selection schemes has not been studied with DSM.

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The contribution of this paper is to introduce transmit diversity for the DSM. Moreover, it studies the impacts of antenna selection algorithms on DSM. The performance of the applied TAS algorithms is analyzed in terms of both computational complexity and BER probability.

The paper is organized as follows: Section 2 describes the DSM transmission technique. Different TAS schemes are discussed in Section 3. Monte-Carlo simulation results and comparisons are provided in Section 4 and the paper's conclusions are given in Section 5.

2. DSM Transceiver

In the DSM transceiver shown in Figure 1 and Figure 2, the input binary bits $m = \log_2(N_t^2 M^2)$ are split into two equal parts by a primary splitter, each containing $\log_2(N_t M)$ bits, where N_t and M are the total number of transmit antennas and constellation size, respectively. Consequently, each part selects its own information symbol and the position of the active transmit antenna. Therefore, the $\log_2(N_t M)$ bits are split into two sets of bits by a secondary splitter. The first set of bits, $\log_2(N_t)$, determines the location of an active transmit antenna, whilst the second set of bits, $\log_2(M)$, determines the corresponding transmit symbol from M-ary signal constellation.

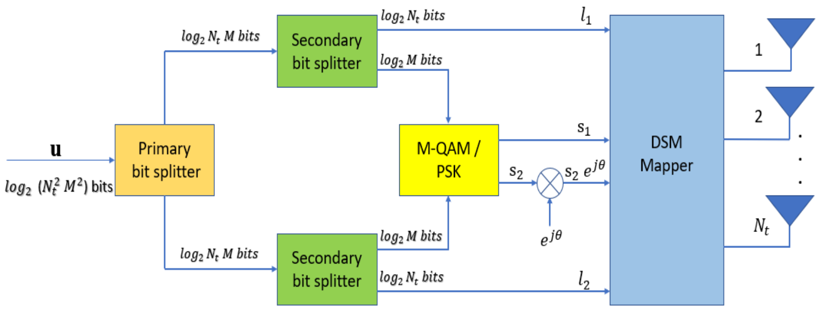

Figure 1. Block diagram of DSM transmitter.

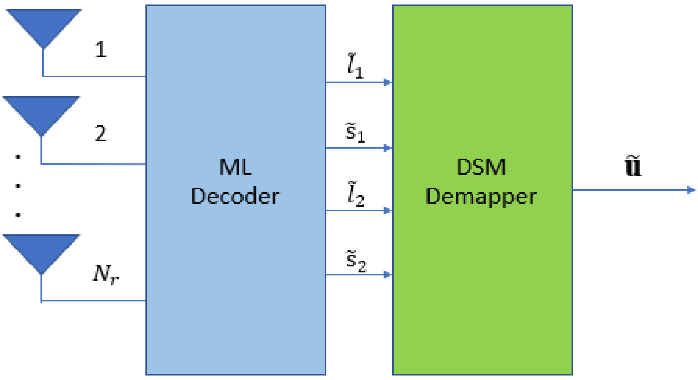

Figure 2. Block diagram of DSM receiver.

A DSM transmission vector is constructed by the superposition of two independent SM transmission vectors [10]. One of the information symbols s_1 is sent through its corresponding activated transmit antenna l_1, while the second information symbol s_2 is sent through the second active antenna l_2 with a rotation angle θ. The rotation angle θ is optimized for M-ary signal constellation to distinguish the two information symbols from each other and to decrease the BER [10].

Therefore, under DSM, the transmitted vector $\mathbf{s}$ of size of $N_t \times 1$ is given by [10]. Generally, the spectral efficiency of DSM is given as follows [10]:

$$\mathbf{s} = \left[0 \cdots 0 \ \underbrace{s_1}_{l_1} \ 0 \cdots 0 \ \underbrace{s_2\, e^{j\theta}}_{l_2} \ 0 \cdots 0 \right]^T \tag{1}$$

$$m = \log_2(N_t^2) + \log_2(M^2), \tag{2}$$

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The received vector $\mathbf{y}$, of size $N_r \times 1$, can be expressed as:

$$\mathbf{y} = \mathbf{Hs} + \mathbf{n} = \mathbf{h}_{l_1} s_1 + \mathbf{h}_{l_2} s_2 e^{j\theta} + \mathbf{n} \tag{3}$$

where, $\mathbf{H}$ is the channel matrix that has a size of $N_r \times N_t$, $\mathbf{h}_{l_1}$ and $\mathbf{h}_{l_2}$ are the l_1^{th} and l_2^{th} column vectors of $\mathbf{H}$, respectively and $\mathbf{n}$ is an additive white Gaussian noise vector with zero mean and a variance of σ^2. Moreover, the channel state information (CSI) is assumed to be fully known at the receiver side. Based on this formulation, we use the maximum likelihood (ML) detector, which is known to provide the optimum bit error rate (BER) performance for DSM. ML detector considers all potential realizations of the antenna indices, l_1 and l_2 and M-ary constellation symbols s_1 and s_2 to estimate $\tilde{l}_1$ and $\tilde{l}_2$ together with $\tilde{s}_1$ and $\tilde{s}_2$. This is achieved by searching over $N_t^2 M^2$ decision metrics and selecting the ones that satisfy the following cost function:

$$(\tilde{s}_1, \tilde{s}_2, \tilde{l}_1, \tilde{l}_2) = \arg \min_{s_1, s_2, l_1, l_2} \left\| \mathbf{y} - (\mathbf{h}_{l_1} s_1 + \mathbf{h}_{l_2} s_2 e^{j\theta}) \right\|^2 \tag{4}$$

3. Antenna Selection

Spatial modulation systems have many advantages, including: few radio frequency (RF) chains, ICI avoidance and low receiver complexity. However, accommodating transmit diversity into these systems is not straightforward [11]. One way to do that, though, is to use antenna selection (AS). The block diagram of TAS with DSM-MIMO systems is shown in Figure 3. Based on the channel estimation at the receiver, the best L_t out of N_t antennas are selected using one of the TAS schemes. After that, the DSM explained in Figure 2 is applied to the L_t transmit antennas instead of the total N_t transmit antennas.

To apply TAS, we select some ***columns*** from the channel matrix. The RF switch is controlled by the selection criteria implemented at the receiver. In TAS, the receiver feeds to the transmitter the L_t antenna indices to be utilized at each frame. Therefore, the received signal vector in (3) is modified to:

$$\mathbf{y} = \mathbf{H}_{Tx\_sel} \mathbf{s} + \mathbf{n} = \mathbf{h}_{\dot{l}_1} s_1 + \mathbf{h}_{\dot{l}_2} s_2 e^{j\theta} + \mathbf{n} \tag{5}$$

where, $\mathbf{H}_{sel}$ is the $N_r \times L_t$ modified channel matrix, $\dot{l}_1$ and $\dot{l}_2$ are the antenna indices chosen from L_t transmit antennas to transmit $s_1$and s_2, respectively and $1 \leq \dot{l}_i \leq L_t, i = 1,2$.

For the variety of MIMO techniques, the AS achieves the full diversity inherent in the system at the expense of a small loss in the coding gain in comparison to a full complexity system [17]. Many AS algorithms have been developed in the last decade. We can classify the AS algorithms into two main categories: (i) optimal AS algorithms, including EDAS which requires a high computational complexity at the receiver [14] and (ii) suboptimal AS algorithms which required a lower computational complexity at the receiver.

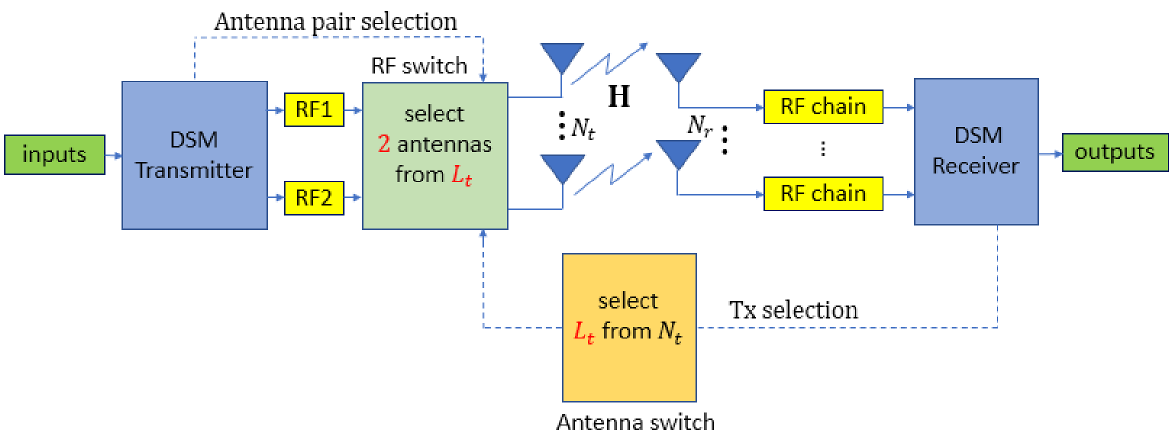

Figure 3. The block diagram of TAS for DSM scheme.

The optimal AS algorithm is the method that uses an exhaustive search of all possible combinations to find the one group that provides the best signal-to-noise ratio (SNR) for diversity or best capacity for spatial multiplexing. Therefore, the optimal AS algorithms require high computational processes at any change in the channel, which in turn leads to the difficulty of implementing these algorithms practically [18].

Since the optimal AS schemes suffer from practical limitations due to the high computational complexity, we will concentrate on using the sub-optimal AS algorithms and compare them with the optimal EDAS.

In this paper, we will focus on two suboptimal AS Algorithms for the DSM scheme. The first algorithm is capacity optimized AS (COAS) and the second is AS based on amplitude and antenna correlation (A-C-AS) [16]. Consider the channel matrix **H** has a size of $N_r \times N_t$. The best set of transmit antennas L_t are selected using one of the AS algorithms (COAS or A-C-AS) and the channel matrix. The selected transmit antennas L_t are used to convey the transmission vector **s** of the DSM.

3.1 Capacity Optimized Antenna Selection (COAS)

The COAS algorithm [16], also called norm-based antenna selection, is an AS algorithm that selects a sub-group of transmitting antennas (L_t) corresponding 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 while imposing a very low computational complexity [16].

Transmit Antenna Selection (TAS) Based on COAS

The COAS algorithm can be applied as follows [16]:

Step 1: Calculate the Frobenius norm of each column **H**,

$$\|\mathbf{h}_i\|_F^2, \quad i = 1, 2, \dots, N_t \tag{6}$$

Step 2: Re-arrange in descending order the columns,

$$\mathbf{H}_\mathrm{A} = \left[\|\mathbf{h}_1\|_F^2 \geq \|\mathbf{h}_2\|_F^2 \geq \cdots \geq \left\|\mathbf{h}_{N_t}\right\|_F^2\right] \tag{7}$$

Step 3: Choose the highest L_t channel gain vectors to form the $L_t \times N_r$ channel gain matrix $\mathbf{H}_{Tx\_sel}$.

3.2 Antenna Selection Based on Amplitude and Antenna Correlation (A-C-AS)

The A-C-AS algorithm is an AS algorithm based on the combination of two selection criteria: channel amplitude and antenna correlation. The correlation-based algorithm was introduced in [19]. TAS based on amplitude and antenna correlation (A-C-TAS) was first suggested for the SM by [16]. This scheme selects $L_t + 1$ transmit antennas that have the largest channel amplitudes from N_t total transmitting antennas. Thereafter, the correlations for all $\binom{L_t+1}{2}$ transmit antenna pairs are calculated. The transmit antenna pair that corresponds to the largest correlation is selected and the channel that has smaller channel gains within the selected pair is rejected. The A-C-AS scheme has shown a significant improvement in BER at low computational complexity. The smaller the correlation between transmitting antennas, the better the overall system performance [19].

Transmit Antenna Selection (TAS) Based on A-C (A-C-TAS)

The A-C-TAS algorithm can be applied as follows [19]:

Step 1: Calculate the Frobenius norm of each column vector in the channel matrix **H**,

$$\|\mathbf{h}_i\|_F^2, \quad i = 1, 2, \dots, N_t \tag{8}$$

Step 2: Choose the $N_c = L_t + 1$ transmit antennas based on the largest norms of the column vectors,

$$\mathbf{H}_{N_c} = \left[\|\mathbf{h}_1\|_F^2 \geq \|\mathbf{h}_2\|_F^2 \geq \cdots \geq \left\|\mathbf{h}_{N_c}\right\|_F^2\right] \tag{9}$$

Step 3: Determine all possible enumerations of the channel gain vector pairs. The total number of possible vector pairs is given by $N_A = \binom{N_c}{2}$. Each pair will have the form (h_x, h_y).

Step 4: Calculate the angle of correlation θ between both vectors of a vector pair. For each vector pair, θ can be calculated as:

$$\theta_z = \cos^{-1}\left(\frac{|\mathbf{h}_x^H \mathbf{h}_y|}{\|\mathbf{h}_x\|_F \ \|\mathbf{h}_y\|_F}\right), \quad z = 1, 2, \ldots, N_A. \tag{10}$$

The angle of correlation for each pair is stored in $\mathbf{A}_\theta$,

$$\mathbf{A}_\theta = \left[\theta_1 \ \theta_2 \ \ldots \ \theta_{N_A}\right] \tag{11}$$

Step 5: Choose the largest correlation pair which has the smallest angle and reject the smaller of the two-channel gain vectors. This forms the $L_t \times N_r$ channel gain matrix $\mathbf{H}_{Tx\_sel}$.

3.3 Transmit Antenna Selection (TAS) Based on EDAS

Yang et al. [20] has introduced EDAS as the optimal AS for spatial modulation. The bit error performance of the SM scheme is improved significantly by maximizing the minimum Euclidian distance (ED) between all possible pairs of transmit antennas. The minimum ED for DSM is defined as:

$$ED_{min} = \underset{s_i, \hat{s}_i, l_i, \hat{l}_i, i=1,2}{\arg\min} \left\|\mathbf{h}_{l_1} s_1 + \mathbf{h}_{l_2} s_2 e^{j\theta} - (\mathbf{h}_{\hat{l}_1} \hat{s}_1 + \mathbf{h}_{\hat{l}_2} \hat{s}_2 e^{j\theta})\right\|^2, \tag{12}$$

where, $\mathbf{v_1} = \mathbf{h}_{l_1} s_1 + \mathbf{h}_{l_2} s_2 e^{j\theta}$ and $\mathbf{v_2} = \mathbf{h}_{\hat{l}_1} \hat{s}_1 + \mathbf{h}_{\hat{l}_2} \hat{s}_2 e^{j\theta}$ is a pair of transmitted vectors and $\mathbf{v_1} \neq \mathbf{v_2}$. The EDAS can be applied on the DSM scheme by maximizing the Euclidian distance between all possible transmit vector pairs from the selected antenna sets. The L_t antennas that maximize ED_{min} in (12) are chosen for the EDAS transmission.

3.4 Computational Complexity for the AS Algorithms

We will evaluate the computational complexity for both AS algorithms in terms of the number of real multiplications (RM) and real addition (RA). Note that a complex multiplication is equivalent to 4 RM and 2 RA, $((a + jb) * (c + jd) = (a * c - b * d) + j\,(b * c + a * d))$, while a complex addition is equivalent to 2 RA, $((a + jb) + (c + jd) = (a + c) + j\,(b + d))$ [21]. A similar approach of computational complexity analysis used in [15] is adopted in the following sub-sections.

Computational Complexity for COAS

The Frobenius norm in (6) needs N_r complex multiplication and $(N_r - 1)$ complex addition for each column vector in the channel matrix **H**. Then, the total number of real operations for each column equals, N_r (4 RM + 2 RA) + $(N_r - 1)$(2 RA) = 8 $N_r - 2$.
These operations are done N_t times. Therefore, the required number of real operations to compute is given by:

$$\mathcal{C}_{\text{COAS-TAS}} = N_t(8\, N_r - 2) \tag{13}$$

Computational Complexity for A-C-TAS

The Frobenius norm in (8) needs $N_t(8\, N_r - 2)$. The numerator in (10) requires N_r complex multiplication + $(N_r - 1)$ complex addition and 2 RM + 1 RA for evaluating the absolute value. So, the number of real operations for numerator equals N_r (4 RM + 2 RA) + $(N_r - 1)$(2 RA) + 2 RM + 1 RA = 8 $N_r + 1$.

In the denominator of (10), each Frobenius norm requires N_r complex multiplications, $(N_r - 1)$ complex additions and the multiplication of two Frobenius norms requires 1 RM. So, the number of real operations for denominator equals 2 (N_r (4 RM + 2 RA) + $(N_r - 1)$(2 RA)) + 1 RM = 16 $N_r - 3$.

Hence**,** the total number of real operations in (9) equals (8 N_r +1) + (16 N_r – 3) = (24 N_r – 2). These operations are done $\binom{N_c}{2}$ times. Therefore, the required number of real operations to compute ((8) and (10)) is given by:

$$\mathcal{C}_{\text{A-C-TAS}} = N_t(8\, N_r - 2) + \binom{N_c}{2}(24 N_r - 2) \tag{14}$$

Computational Complexity for EDAS

The absolute value in Equation (11) and the summation of the resulted vector [1: N_r] need (2 RM+1 RA) N_r and RA ($N_r - 1$), respectively. So, the number of real operations for the absolute value equals (2 RM+2 RA) N_r - 1 RA= $4N_r - 1$.

The term $\mathbf{h}_{l_1} s_1 + \mathbf{h}_{l_2} s_2 e^{j\theta} - (\mathbf{h}_{\hat{l}_1} \hat{s}_1 + \mathbf{h}_{\hat{l}_2} \hat{s}_2 e^{j\theta})$ needs (4 complex multiplications, 1 complex addition and 2 complex subtractions) N_r. So, the number of real operations for this term equals (4(4 RM+2 RA)+2 RA+2(2 RA)) N_r =30 N_r.

An exhaustive search of (11) requires that the ED be calculated for all symbol combinations of s_i and $\hat{s}_i$, such that $s_i \neq \hat{s}_i$. This requires $M^2(M^2 - 1)(34\, N_r - 1)$.

EDAS-DSM must then be done for each of the $\binom{N_t}{L_t}$ transmit antenna subsets. Also, the EDAS-DSM must be performed for each antenna pair within each antenna subset; i.e., EDAS-DSM must be executed a total of $\binom{L_t}{2}\binom{N_t}{L_t}$ times.

Therefore, the required number of real operations to compute (12) is given by,

$$C_{\text{ED-TAS}} = [(M^4 - M^2)(34\, N_r - 1)] \binom{L_t}{2}\binom{N_t}{L_t} \quad (15)$$

3.5 Performance Analysis of DSM with TAS

The conditional pairwise error probability (PEP) for DSM is given by [10], [12]:

$$\mathrm{P}(x \to \hat{x}) = Q\left(d_{min}/\sigma\sqrt{2}\right) \quad (16)$$

where, $Q(.)$ is the tail distribution function of the standard normal distribution, $x = \mathbf{h}_{l_1} s_1 + \mathbf{h}_{l_2} s_2 e^{j\theta}$ is the transmitted vector which has been detected incorrectly as $\hat{x} = \mathbf{h}_{\hat{l}_1} \hat{s}_1 + \mathbf{h}_{\hat{l}_2} \hat{s}_2 e^{j\theta}$ and d_{min} is the minimum Euclidian distance between all transmitted vectors.

In case of transmit antenna selection, $l_1, l_2, \hat{l}_1$ and $\hat{l}_2\ \epsilon [1, L_t]$ and the selected antenna set, L_t are chosen to maximize d_{min} in case of EDAS; whereas applying either COAS or A-C-TAS is expected to increase d_{min}. Therefore, considering (15), applying TAS leads to a decrease in the PEP for the same σ in TAS schemes.

4. Simulation Results

The simulation result represents the average BER performance versus the average SNR at each receive antenna for different spectral efficiencies (4, 6 and 8 b/s/Hz). The optimum rotation angles for BPSK, 4-QAM are found as 90º and 45º, respectively [10].

All performance comparisons are measured at a BER equal to 10^{-5}. It has been assumed that all MATLAB simulations are performed over quasi-static Rayleigh fading channels. Additionally, it is assumed that the CSI is well known at receiver and the feedback link between the receiver and the transmitter is error-free. Furthermore, an optimal ML detection has been used at the receiver side.

Figure 4 shows the BER performance of the two sub-optimal TAS algorithms (COAS and A-C-AS) on DSM with spectral efficiency 4 b/s/Hz, different numbers of total transmit antennas N_t and the selected transmit antennas L_t equal 2. Both algorithms have been compared to each other.

The performance of COAS-DSM and A-C-AS-DSM schemes outperforms the conventional DSM (BPSK, $N_t = 2$) scheme with 1.5 dB and 4 dB, respectively when $N_t = 4$. However, this gain can be further improved by increasing N_t. Hence, when N_t is increased to 8, COAS-DSM and A-C-AS-DSM exhibit a 2.5 dB and 5.5 dB gains over the classical DSM. It is noted that by increasing N_t, the overall BER performance of AS scheme also increases. Furthermore, for a BER of 10^{-5}, A-C-AS-DSM outperforms COAS-DSM by 2.5 dB and 3 dB when $N_t = 4$ and 8, respectively. The optimal EDAS-DSM has a gain of 6.8 dB over DSM (BPSK, $N_t = 2$) . It outperforms the A-C-AS-DSM (BPSK, $N_t = 8$, $L_t = 2$) by 1.5 dB, but at the cost of high computational complexity.

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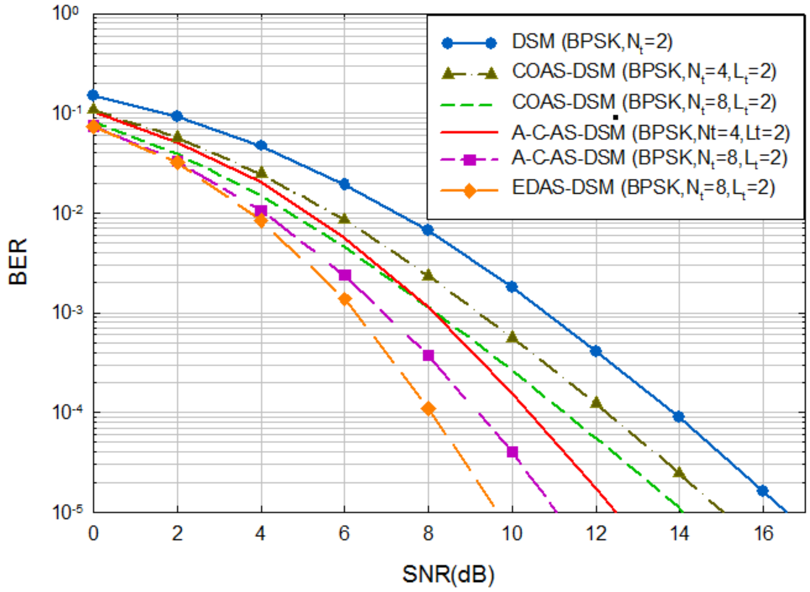

Figure 4. BER performance of TAS for DSM for 4 bits/s/Hz and $N_r = 4$.

Figure 5 illustrates the BER performance COAS and A-C-AS on DSM with spectral efficiency 6 b/s/Hz, different numbers of total transmit antennas N_t *and* the selected transmit antennas $L_t = 2$.

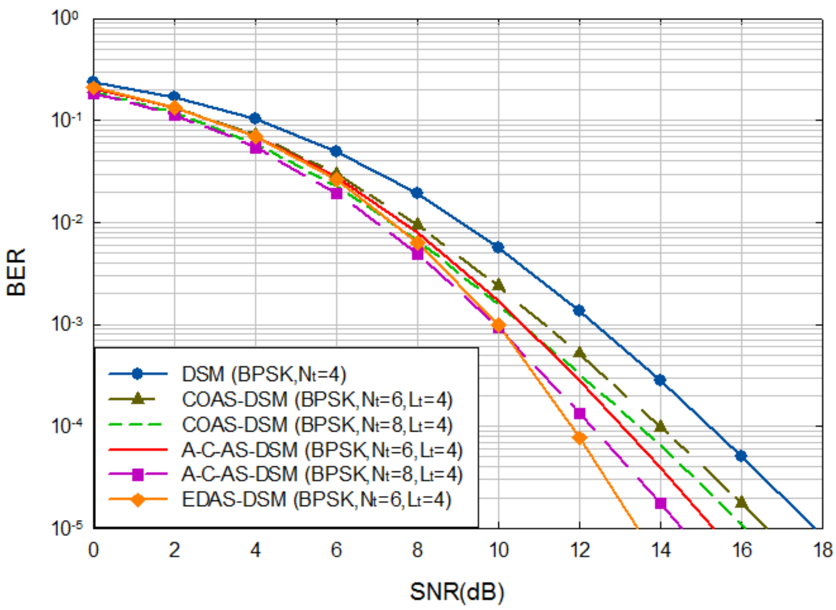

Figure 5. BER performance of TAS for DSM for 6 bits/s/Hz and $\boldsymbol{N_r = 4}$.

The performance of both COAS-DSM and A-C-AS-DSM schemes outperforms the conventional DSM (BPSK, $N_t = 4$) scheme with 1.2 dB and 2.5 dB, respectively when $N_t = 6$. However, this gain can be further improved by increasing N_t. For example, when N_t is increased to 8, COAS-DSM and A-C-AS-DSM exhibit gains of 1.8 dB and 3.3 dB over the conventional DSM.

It is noted that by increasing N_t, the overall BER performance of AS scheme improves. Furthermore, for a BER of 10^{-5}, the A-C-AS-DSM outperforms COAS-DSM by 1.3 dB and 1.5 dB when $N_t = 6$ and 8, respectively.

Finally, EDAS-DSM has an estimated SNR gain of 4.2 dB over DSM for $N_t = 6$. İt outperform the A-C-AS-DSM (BPSK, Nt=6, Lt=4) by 1.9 dB. This comes again at the expense of higher complexity.

Figure 6 presents the results for a 8 × 4 16-QAM QSM and 4-QAM DSM systems with spectral efficiency 8 b/s/Hz, total transmit antennas $N_t = 8$ and the selected transmit antennas $L_t = 4$.

The COAS-DSM and A-C-AS-DSM schemes provide SNR gain of 0.6 dB and 1.8 dB over the conventional DSM (BPSK, $N_t = 8$), respectively. Accordingly, it can be seen that the COAS-DSM and A-C-AS-DSM schemes outperform the conventional DSM scheme, provided that both schemes have the identical spectral efficiency and the identical number of total transmit antennas. Furthermore, for a BER of 10^{-5}, the A-C-AS-DSM outperforms COAS-DSM by 1.2 dB.

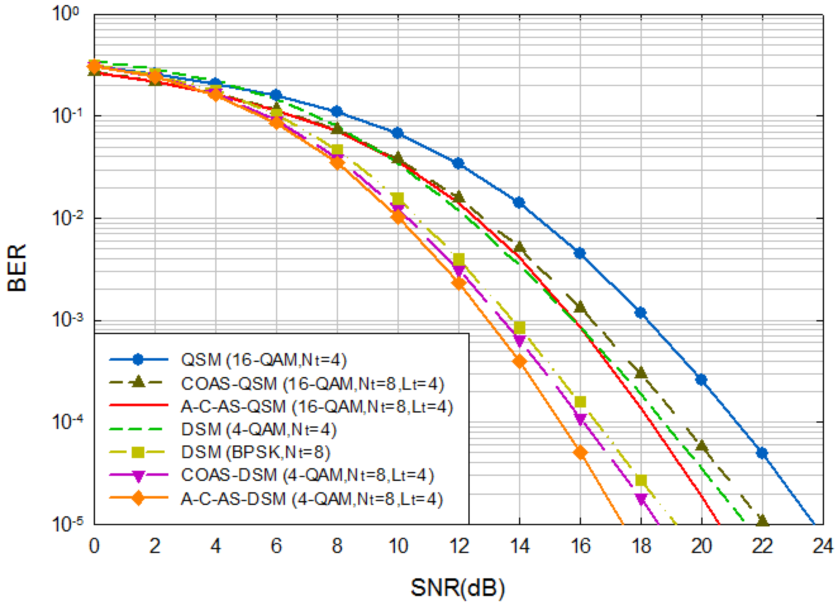

Figure 6. BER performance of TAS for DSM and QSM for 8 bits/s/Hz and $\boldsymbol{N_r = 4}$.

Also, the performance of COAS-DSM and A-C-AS-DSM schemes outperforms the conventional DSM (4-QAM, $N_t = 4$) scheme with 2.2 dB and 4 dB, respectively.

Finally, the conventional DSM (4-QAM, $N_t = 4$) outperforms the conventional QSM (16-QAM, N_t = 4) by 2 dB at 10^{-5}, while the gains for COAS-DSM and A-C-AS-DSM over COAS-QSM and A-C-AS-QSM are 3.3 dB and 3.2 dB, respectively.

The computational complexities for all the simulated cases are given in Table 1. It is clear that the complexity overhead for the antenna selection scheme is very small in case of the COAS scheme. The A-C-AS has a higher overhead which is reasonable with the achieved BER performance. However, the EDAS scheme has a very high computational complexity.

The overhead needed for antenna selection for both QSM and DSM is the same. The DSM has an increase in computation complexity compared to QSM, but it has a better BER performance.

5. CONCLUSIONS

In this paper, two sub-optimal antenna selection algorithms for DSM scheme were introduced. These algorithms are capable of improving the error performance of the DSM transmission scheme while requiring low computational complexities.

The COAS-DSM scheme has a lower computational complexity than the A-C-AS-DSM scheme, because it uses the channel amplitude as the selection criterion only. On the contrary, the A-C-AS-DSM scheme uses channel amplitude and antenna correlation as selection criteria. Therefore, the COAS-DSM gives a smaller improvement in BER performance than A-C-AS-DSM scheme. Still, there is a small loss of BER improvement of the A-C-AS-DSM compared with the optimal EDAS. This is justified by the much lower complexity needed for the A-C-AS-DSM. In other words, there is a trade-off between increasing computational complexity and improving error performance.

Table 1. Computational complexity for DSM and QSM with different antenna selection schemes.

Spectral efficiency	Transmission scheme	Mod. scheme	N_t	L_t	N_r	Real operations	Comp. Overhead (%)
4	DSM	BPSK	2	2	4	1408	0
	COAS-DSM		4	2		1528	7.853403
	COAS-DSM		8	2		1648	14.56311
	A-C-AS-DSM		4	2		1810	22.20994
	A-C-AS-DSM		8	2		1930	27.04663
	EDAS-DSM		8	2		46768	96.98939
6	DSM	BPSK	4	4	4	5632	0
	COAS-DSM		6	4		5812	3.097041
	COAS-DSM		8	4		5872	4.087193
	A-C-AS-DSM		6	4		6094	7.581227
	A-C-AS-DSM		8	4		6154	8.482288
	EDAS-DSM		6	4		151432	96.28084
8	QSM	16-QAM	4	4	4	14336	0
	COAS-QSM		8	4		14576	1.646542
	A-C-AS-QSM		8	4		14858	3.513259
	DSM	BPSK	8	8		22528	0
	DSM	4-QAM	4	4		22528	0
	COAS-DSM		8	4		22768	1.054111
	A-C-AS-DSM		8	4		23050	2.264642

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ملخص البحث:

التعديل الفضائي المزدوج (DSM) عبارة عن تقنية إرسال تم اقتراحها حديثاً لأنظمة الاتصال متعددة المداخل ومتعددة المخارج. وتمتلك هذه التقنية فاعلية طيفية أعلى مقارنة مع التعديل الفضائي الكلاسيكي؛ فهي تعمل على مضاعفة عدد هوائيات الإرسال الفعّالة.

في هذه الورقة، يتم تطبيق اختيار هوائيات الإرسال في التعديل الفضائي المزدوج من أجل تحسين الأداء من حيث معدّل خطأ البِت (BER). وبشكل أكثر تحديداً، نقوم بدمج خوارزميتين في التعديل الفضائي المزدوج؛ هما: اختيار الهوائيات القائم على السعة المثالية (COAS)، و اختيار الهوائيات بناءً على الاتساع والارتباط بين الهوائيات (A-C-AS). وقد تم عرض نتائج المحاكاة للخوارزميتين المذكورتين ومقارنتها مع طريقة اختيار الهوائيات الإقليدية المثالية المسندة الى المسافة المثالية (EDAS) باستخدام برمجية ماتلاب. وتبين النتائج وجود تسوية بين التعقيد والأداء. وعلى الرغم من وجود فقْد طفيف في معدّل خطأ البِت، فإن الخوارزميتين اللتين تم استخدامهما في هذه الدراسة أقل تعقيداً من خوارزمية (EDAS).