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Transmit Antenna Selection for Quadrature Spatial Modulation Systems with Power Allocation

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Abstract

We consider transmit antenna selection combined with power allocation for quadrature spatial modulation (QSM) systems to improve the error rate performance. The Euclidean distance-based joint optimization criterion is presented for transmit antenna selection and power allocation in QSM. It requires an exhaustive search and thus high computational complexity. Thus its reduced-complexity algorithm is proposed with a strategy of decoupling, which is employed to successively find transmit antennas and power allocation factors. First, transmit antennas are selected without considering power allocation. After selecting transmit antennas, power allocation factors are determined. Simulation results demonstrate considerable performance gains with lower complexity for transmit antenna selected QSM systems with power allocation, which can be achieved with limited rate feedback.

Keywords: *Quadrature Spatial Modulation (QSM), Power Allocation, Euclidean Distance, Maximum Likelihood (ML) Receiver, Multiple Input Multiple Output (MIMO)*

1. INTRODUCTION

Spatial modulation (SM) transmission is a multiple input multiple output (MIMO) technique with low receiver complexity [1]. The index of one active transmit antenna is employed to convey an additional information bits. Even if the SM has an advantage capable of achieving high spectral efficiency with relatively low-complexity, a new quadrature spatial modulation (QSM) transmission scheme has been recently developed to increase the spectral efficiency of the conventional SM systems [5]. The QSM systems exploit two orthogonal spatial dimensions to transmit the real and imaginary parts of a signal constellation symbol. Both SM and QSM transmission schemes can avoid inter-channel interference at the receiver.

To improve the performance of the conventional SM systems, transmit antenna selection techniques have been presented [9]. In [13], power allocation (PA) schemes have been considered to relieve the unfavorable effects of channel fading. On the other hand, various transmit antenna selection (AS) approaches have been examined to enhance the error performance of QSM systems [16]. In [18], the QSM systems combined with

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a power allocation scheme have been recently studied to improve the system performance with limited feedback. Each of transmit antenna selection and power allocation offers error performance advantages.

In this paper, we consider QSM systems with both transmit antenna selection and power allocation. To improve error performance of QSM systems, joint optimization of transmit antenna selection and power allocation is performed on a basis of Euclidean distance criterion. However, the minimum Euclidean distance optimization problem with an exhaustive search for joint transmit antenna selection and power allocation requires huge computational complexity. To reduce the complexity, we propose a decoupled transmit antenna selection and power allocation algorithm. First of all, it selects a subset of transmit antennas with an assumption of equal power. Then, power allocation for the selected transmit antennas is carried out with a limited feedback. It is assumed that channel side information is known at the receiver. The indices of subsets of the selected transmit antennas and power allocation factors are then sent to the transmitter through a limited feedback link. It is shown that the QSM system with the proposed transmit antenna selection and power allocation schemes outperforms that with only transmit antenna selection and that with only power allocation. It is analyzed that the decomposed transmit antenna selection and power allocation can significantly lower the complexity of the joint estimation.

2. SYSTEM MODEL

Figure 1 shows the system model of QSM employing transmit antenna selection combined with power allocation. A total of $\log_2\left(N_S^2 M\right)$ information source bits enter the QSM transmitter. Here N_S denotes the number of selected transmit antennas. A complex data symbol s is selected from an M-QAM constellation set S according to the first $\log_2 M$ bits. This symbol is expressed as $s = s_R + js_Q$, where s_R and s_Q, respectively, are real and imaginary parts of the M-QAM symbol s. Then s_R and js_Q are independently transmitted from the l_R th and l_Q th transmit antennas using SM principle, respectively, where $l_R, l_Q = \{1, 2, \cdots, N_S\}$ are independently determined according to the remaining two $\log_2 N_S$ bits. The resultant QSM symbol vector is weighted by the power allocation factors, which are generated by obeying uniform distribution.

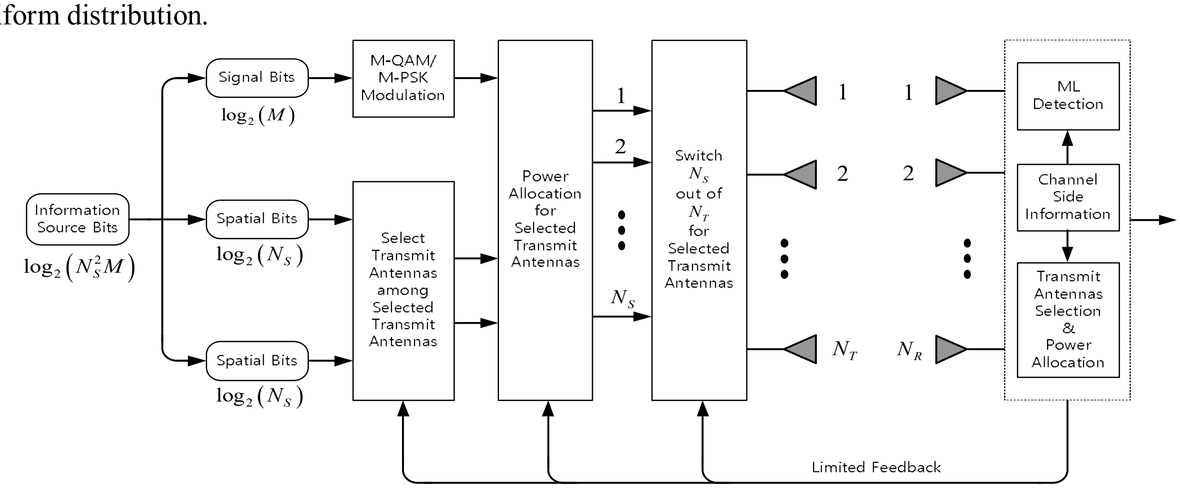

Figure 1. System model of transmit antenna selected QSM scheme with power allocation

This work employs power allocation factors given in Table 1. Note that the number of feedback bits increases as the number of power allocation factor candidates increases. Therefore, the power allocated QSM transmission vector $\mathbf{x} \in C^{N_S \times 1}$ corresponding to the g th power allocation factor candidate can be given as

$$\mathbf{x}^{(g)} = \Big[\ 0,\cdots,0,\underset{\substack{\uparrow \\ l_R\text{th}}}{p_{l_R}^{(g)} s_R},0,\cdots,0,\underset{\substack{\uparrow \\ l_Q\text{th}}}{j\,p_{l_Q}^{(g)} s_Q},0,\cdots,0\ \Big]^T \tag{1}$$

where $p_{l_R}^{(g)}$ and $p_{l_Q}^{(g)}$ are the power weights with a constraint $\sum_{l=1}^{N_S} p_l^{(g)^2} = N_S$ for s_R and js_Q, respectively, transmitted by the l_R th and l_Q th transmit antennas.

Table 1. Power allocation factors for $N_R \times 4$ QSM with 3 bits feedback [18]

Index g	1	2	3	4	5	6	7	8
$p_1^{(g)}$	$\sqrt{0.4}$	$\sqrt{0.8}$	$\sqrt{0.4}$	$\sqrt{1.2}$	$\sqrt{1.2}$	$\sqrt{1.6}$	$\sqrt{1.6}$	$\sqrt{0.8}$
$p_2^{(g)}$	$\sqrt{0.8}$	$\sqrt{0.4}$	$\sqrt{1.2}$	$\sqrt{0.4}$	$\sqrt{1.6}$	$\sqrt{1.2}$	$\sqrt{0.8}$	$\sqrt{1.6}$
$p_3^{(g)}$	$\sqrt{1.2}$	$\sqrt{1.6}$	$\sqrt{1.6}$	$\sqrt{0.8}$	$\sqrt{0.4}$	$\sqrt{0.8}$	$\sqrt{0.4}$	$\sqrt{1.2}$
$p_4^{(g)}$	$\sqrt{1.6}$	$\sqrt{1.2}$	$\sqrt{0.8}$	$\sqrt{1.6}$	$\sqrt{0.8}$	$\sqrt{0.4}$	$\sqrt{1.2}$	$\sqrt{0.4}$

It is assumed that N_T transmit antennas and N_R receive antennas are available. Thus, the $N_R \times N_T$ complex channel gain matrix is characterized by $\mathbf{H}_T$, whose elements are independent and identically distributed (i.i.d.) with $CN(0,1)$. Here $CN(0,\sigma^2)$ denotes circularly symmetric complex Gaussian distribution with zero mean and variance of σ^2. Based on the channel matrix $\mathbf{H}_T$ and the transmit antenna selection algorithm combined with power allocation, both a set of $N_S\,(<N_T)$ transmit antennas and the best power allocation factors are selected at the receiver side. The receiver sends via a low-bandwidth feedback link to the transmitter the indices of the selected transmit antenna subset $A_q \in \Omega$, $q = 1,2,\cdots,N_P$, where Ω is the set of all possible $N_P = \binom{N_T}{N_S}$ transmit antenna subsets and the allocated power weight set $B^{(g)}$, $g \in G(=\{1,2,\cdots,N_G\})$, where N_G is the number of the power allocation factor candidates given in Table 1.

The $N_R \times 1$ received signal vector can be defined as

$$\mathbf{y}^{(g)} = \mathbf{H}^{(q)}\mathbf{x}^{(g)} + \mathbf{w} = \mathbf{h}_{(l_R)} p_{l_R}^{(g)} s_R + j\mathbf{h}_{(l_Q)} p_{l_Q}^{(g)} s_Q + \mathbf{w} \tag{2}$$

where $\mathbf{H}^{(q)}$ denotes the $N_R \times N_S$ channel submatrix associated with the transmit antenna subset, of the full channel matrix $\mathbf{H}_T$. It can be constructed as $\mathbf{H}^{(q)} = \left[\ \mathbf{h}_{(1)}\ \mathbf{h}_{(2)}\ \cdots\ \mathbf{h}_{(N_S)}\ \right]$ where the lower index (l) in $\mathbf{h}_{(l)}$, $l = 1,2,\cdots,N_S$, represents the columns of the $N_R \times N_T$ full channel matrix $\mathbf{H}_T$ corresponding to selected transmit antennas and thus (l) could become one of $(1,2,\cdots,N_T)$. $\mathbf{h}_{(l_R)}$ and $\mathbf{h}_{(l_Q)}$, respectively, represent the l_R th and l_Q th columns of an $N_R \times N_S$ channel gain matrix $\mathbf{H}^{(q)}$. Here $\mathbf{w} \in C^{N_R \times 1}$ is the noise vector whose elements distributed with $CN\left(0, N_0\right)$.

3. JOINT TRANSMIT ANTENNA SELECTION AND POWER ALLOCATION

To select N_S antennas among N_T transmit antennas and the power allocation factors, the minimum Euclidean distance (ED) $d_{\min}$ among all possible power allocated QSM transmit vectors is used to maximize the error performance bound of maximum-likelihood (ML) detection. That is, the decision metric is calculated as

$$\left[q_{ED}, g_{ED}\right] = \underset{A_q \in \Omega, g \in G}{\arg\max} \left\{ \min_{\mathbf{x}_u^{(g)} \neq \mathbf{x}_v^{(g)} \in X} \left\| \mathbf{H}^{(q)} \left(\mathbf{x}_u^{(g)} - \mathbf{x}_v^{(g)} \right) \right\|_F^2 \right\} \tag{3}$$

where X is the set of all possible power allocated QSM transmit symbol vectors. The ED-based antenna selection and power allocation with exhaustive search (ED-AS-PA-ES) of (3) can be expressed as

$$\left[q_{ED}, g_{ED}\right] = \underset{A_q \in \Omega, G \in Q}{\arg\max} \left\{ \min \mathbf{D}(q, g) \right\} \tag{4}$$

where $\mathbf{D}(q,g)$ is an $N_S \times N_S$ square matrix computed by an $N_R \times N_S$ submatrix $\mathbf{H}^{(q)}$ and the set of all possible QSM transmission symbol vectors. For $m = n$, the (m,n) th element of $\mathbf{D}(q,g)$ can be written as

$$D_{m,n}(q,g) = \min_{\substack{u \neq v \\ m_R(=m)=n_R(=n) \\ m_Q=1,2,\cdots,N_S \\ n_Q=m_Q,m_Q+1,\cdots,N_S}} \left\| \mathbf{h}_{(m_R)} p_{m_R}^{(g)} s_{u,R} + j\mathbf{h}_{(m_Q)} p_{m_Q}^{(g)} s_{u,Q} - \mathbf{h}_{(n_R)} p_{n_R}^{(g)} s_{v,R} - j\mathbf{h}_{(n_Q)} p_{n_Q}^{(g)} s_{v,Q} \right\|_F^2 \tag{5}$$

where $m = m_R = 1,2,\cdots,N_S$. $s_{z,R}$ and $s_{z,Q}$, $z = u,v$, denote real and imaginary parts of a symbol s_z, respectively. For $m < n$, $D_{m,n}(q,g)$ can be given as

$$D_{m,n}(q,g) = \min_{\substack{m_R(=m)\neq n_R(=n) \\ m_Q=1,2,\cdots,N_S \\ n_Q=m_Q,m_Q+1,\cdots,N_S}} \left\| \mathbf{h}_{(m_R)} p_{m_R}^{(g)} s_{u,R} + j\mathbf{h}_{(m_Q)} p_{m_Q}^{(g)} s_{u,Q} - \mathbf{h}_{(n_R)} p_{n_R}^{(g)} s_{v,R} - j\mathbf{h}_{(n_Q)} p_{n_Q}^{(g)} s_{v,Q} \right\|_F^2 \tag{6}$$

where $m = m_R = 1,2,\cdots,N_S$, $m_Q = 1,2,\cdots,N_S$, $n = n_R = m+1, m+2,\cdots,N_S$, and $n_Q = m_Q, m_Q+1,\cdots,N_S$.

The computational complexity analysis can be carried out in terms of the number of floating point operations, similar to [16]. Instead of complex multiplications, real multiplications are reflected in complexity computation. The computational complexity of the ED-AS-PA-ES imposed by (4) is approximated by

$$C_{ED-AS-PA-ES} = N_G C_{N_S}^{N_T} \left(C_2^{N_S} + N_S \right)^2 \left(12N_R + 10 \right) M^2 \tag{7}$$

where $C_{N_b}^{N_a}$ denotes the number of N_b combinations from N_a elements.

4. DECOUPLED TRANSMIT ANTENNA SELECTION AND POWER ALLOCATION ALGORITHM

The ED-AS-PA-ES requires the high computational complexity. In this regard, a transmit antenna selection and power allocation algorithm with reduced complexity needs to be developed. The proposed algorithm is based on decoupling transmit antenna selection and power allocation to reduce the overall complexity of the joint antenna selection and power allocation. To begin with, transmit antennas are selected without considering power allocation. Then, based on the selected transmit antennas, power allocation factors are determined.

For transmit antenna selection first, this work employs capacity optimized antenna selection (CO-AS) presented in [9] although any antenna selection method can be used. CO-AS algorithm offering a very low computational complexity selects a subset of N_S antennas by finding N_S transmit antenna indices corresponding to the N_S maximum values in the set $\{T_k\}$, where $T_k = \|\mathbf{h}_k\|_F^2$, $k = 1,2,\cdots,N_T$. Here $\mathbf{h}_k$ is the *k*th column vector of the $N_R \times N_T$ full channel matrix $\mathbf{H}_T$.

The next step is to choose transmit power allocation factors based on the $N_R \times N_S$ channel submatrix $\mathbf{H}^{(\hat{q})}$, $\hat{q} = 1,2,\cdots,N_P$, associated with the transmit antennas selected from the CO-AS algorithm. Given the selected transmit antennas, the ED-based power allocation with exhaustive search of (4) is rewritten as [16]

$$g_{PA-ED} = \arg\max_{G \in Q} \{\min \mathbf{D}(\hat{q},g)\} \tag{8}$$

where $\mathbf{D}(\hat{q},g)$ is an $N_S \times N_S$ square matrix computed by a submatrix $\mathbf{H}^{(\hat{q})}$ and all possible QSM symbol vectors. This power allocation approach has considerable computational complexity.

For this reason, the ED-AS algorithm with reduced complexity proposed in [9] is applied to this power allocation scheme to lower the computational complexity of (8). Under a condition that the symbols $s_{v,R}$ and $s_{v,Q}$ are given, the matrix $\mathbf{D}(\hat{q},g)$ is redefined as a new matrix $\mathbf{\Psi}(\hat{q},g)$. Then the power allocation problem can be transformed to

$$g_{PA-RC} = \arg\max_{G \in Q} \{\min \mathbf{\Psi}(\hat{q},g)\} \tag{9}$$

By following the methods in [9] and [16], the elements of (5) and (6) for the index $\hat{q}$ can be rewritten as

$$\Psi_{m,n}(\hat{q},g) = \min_{\substack{u \neq v \\ m_R(=m)=n_R(=n) \\ m_Q=1,2,\cdots,N_S \\ n_Q=m_Q,m_Q+1,\cdots,N_S}} \hat{\mathbf{s}}^T \tilde{\mathbf{\Xi}}_{(m,n)}(\hat{q},g)\hat{\mathbf{s}}, \quad m = n \tag{10}$$

$$\Psi_{m,n}(\hat{q},g) = \min_{\substack{m_R(=m)\neq n_R(=n) \\ m_Q=1,2,\cdots,N_S \\ n_Q=m_Q,m_Q+1,\cdots,N_S}} \hat{\mathbf{s}}^T \tilde{\mathbf{\Xi}}_{(m,n)}(\hat{q},g)\hat{\mathbf{s}}, \quad m < n \tag{11}$$

where $\Psi_{m,n}(\hat{q},g)$ is the (m,n) th element of $\mathbf{\Psi}(\hat{q},g)$ and

$$\hat{\mathbf{s}}^T \tilde{\mathbf{\Xi}}_{(m,n)}(\hat{q},g)\,\hat{\mathbf{s}} = \left\| \hat{\mathbf{h}}_{(m_R)} p_{m_R}^{(g)} s_{u,R} + j\hat{\mathbf{h}}_{(m_I)} p_{m_I}^{(g)} s_{u,Q} - \hat{\mathbf{h}}_{(n_R)} p_{n_R}^{(g)} s_{v,R} - j\hat{\mathbf{h}}_{(n_I)} p_{n_I}^{(g)} s_{v,Q} \right\|_F^2 \tag{12}$$

$$\hat{\mathbf{s}} = \begin{bmatrix} \hat{s}_{u,R} & \hat{s}_{u,Q} & -s_{v,R} & -s_{v,Q} \end{bmatrix}^T \tag{13}$$

$$\hat{s}_{u,Q} = E_Q\left(r_1\right) = E_Q\left(\frac{\tilde{h}_{23}^{(m,n)}(\hat{q},g)s_{v,R} + \tilde{h}_{24}^{(m,n)}(\hat{q},g)s_{v,Q}}{\tilde{h}_{22}^{(m,n)}(\hat{q},g)} \right) \tag{14}$$

$$\hat{s}_{u,R} = E_R\left(r_2\right) = E_R\left(\frac{-\tilde{h}_{12}^{(m,n)}(\hat{q},g)\hat{s}_{u,Q} + \tilde{h}_{13}^{(m,n)}(\hat{q},g)s_{v,R} + \tilde{h}_{14}^{(m,n)}(\hat{q},g)s_{v,Q}}{\tilde{h}_{11}^{(m,n)}(\hat{q},g)} \right) \tag{15}$$

where $\hat{\mathbf{h}}_{(l)}$ is the column vector of the channel submatrix $\mathbf{H}^{(\hat{q})}$ corresponding to the selected transmit antennas and $E_Q\left(r_1\right)$ and $E_R\left(r_2\right)$ indicates the operation that demodulates r_1 and r_2, respectively, to its nearest point of $\mathrm{Im}(X)$ and $\mathrm{Re}(X)$. Then the symbol $\hat{s}_u$ is given as $\hat{s}_u = E_R\left(r_1\right) + jE_Q\left(r_2\right)$. $\tilde{\mathbf{\Xi}}_{(m,n)}(\hat{q},g) = \mathbf{\Xi}_{(m,n)}^H(\hat{q},g)\mathbf{\Xi}_{(m,n)}(\hat{q},g)$ is the 4×4 matrix whose (a,b)th element is denoted by $\tilde{h}_{ab}^{(m,n)}(\hat{q},g)$, $a,b = 1,2,3,4$ with $\tilde{h}_{ab}^{(m,n)}(\hat{q},g) = \tilde{h}_{ba}^{(m,n)}(\hat{q},g)$, $a \neq b$. Here the modified matrix $\mathbf{\Xi}_{(m,n)}(\hat{q},g)$ is defined as

$$\mathbf{\Xi}_{(m,n)}(\hat{q},g) = \begin{bmatrix} \mathrm{Re}\left(\hat{\mathbf{h}}_{(m_R)} p_{m_R}^{(g)}\right) & -\mathrm{Im}\left(\hat{\mathbf{h}}_{(m_Q)} p_{m_Q}^{(g)}\right) & \mathrm{Re}\left(\hat{\mathbf{h}}_{(n_R)} p_{n_R}^{(g)}\right) & -\mathrm{Im}\left(\hat{\mathbf{h}}_{(n_Q)} p_{n_Q}^{(g)}\right) \\ \mathrm{Im}\left(\hat{\mathbf{h}}_{(m_R)} p_{m_R}^{(g)}\right) & \mathrm{Re}\left(\hat{\mathbf{h}}_{(m_Q)} p_{m_Q}^{(g)}\right) & \mathrm{Im}\left(\hat{\mathbf{h}}_{(n_R)} p_{n_R}^{(g)}\right) & \mathrm{Re}\left(\hat{\mathbf{h}}_{(n_Q)} p_{n_Q}^{(g)}\right) \end{bmatrix} \tag{16}$$

Then the power allocation algorithm with reduced complexity can provide the following approximated complexity

$$C_{PA-RC} = N_G\left(C_2^{N_S} + N_S\right)^2\left(12N_S + 10\right)M \tag{17}$$

Note that it offers more benefit than the power allocation algorithm with exhaustive search in terms of complexity, especially when the modulation order is large. Additionally, the rotational symmetry of angle as in [9] and [16] can be exploited to further reduce the complexity. Then the complexity can be obtained as

$$C_{PA-RC} = N_G\left(C_2^{N_S} + N_S\right)^2\left(12N_S + 10\right)\left(M/2\right) \tag{18}$$

Therefore, the total computational complexity of the proposed decoupled antenna selection and power allocation algorithm (called CO-AS-PA-RC) is approximately calculated as

$$C_{CO-AS-PA-RC} = \left(2N_R - 1\right) + N_G\left(C_2^{N_S} + N_S\right)^2\left(12N_S + 10\right)\left(M/2\right) \tag{19}$$

5. SIMULATION RESULTS

This section presents the Matlab simulation results to evaluate the symbol error rate (SER) performance of the proposed transmit antenna selected QSM systems with power allocation under a limited feedback in Rayleigh flat fading channels. For the performance comparison, the following six QSM systems are considered.

(a) QSM system without AS and PA (corresponding to equal transmitted power)

(b) QSM system employing ED-AS with exhaustive search (called QSM-ED-AS-ES), which is presented in [16]. Here, PA is not considered, which means equal transmitted power. The approximated complexity of ED-AS-ES algorithm is given by [16]

$$C_{ED-AS-ES} = C_{N_S}^{N_T} \left(C_2^{N_S} + N_S \right)^2 \left(12 N_R + 2 \right) M^2 \tag{20}$$

Without loss of performance, it can be transformed to the low-complexity version (called ED-AS-LC) [16] with the following complexity.

$$C_{ED-AS-LC} = C_{N_S}^{N_T} \left(C_2^{N_S} + N_S \right)^2 \left(12 N_R + 2 \right) \left(M/2 \right) \tag{21}$$

(c) QSM system using ED-AS with further reduced complexity (called QSM-ED-AS-R), which is presented in [16]. The computational complexity of ED-AS-R algorithm with no PA is approximated by [16]

$$C_{ED-AS-R} = 3 N_T^2 \left(2 N_R - 1 \right) + \left(C_2^{N_T} + N_T \right)^2 51 \left(M/2 \right) \tag{22}$$

(d) QSM system using ED based PA with exhaustive search (called QSM-ED-PA-ES), which is based on [18]. The approximated complexity of ED-PA-ES algorithm is calculated as

$$C_{ED-PA-ES} = N_G \left(C_2^{N_S} + N_S \right)^2 \left(12 N_R + 10 \right) M^2 \tag{23}$$

By the same approach, which is described in [18], employed in deriving (21) and section 4, the ED-PA-ES can be also converted into another algorithm with the following complexity.

$$C_{ED-PA-LC} = N_G \left(C_2^{N_S} + N_S \right)^2 \left(12 N_R + 10 \right) \left(M/2 \right) \tag{24}$$

(e) Proposed transmit antenna selected QSM system with power allocation, which is based on (4) (called QSM-ED-AS-PA-ES)

(f) Proposed transmit antenna selected QSM system with power allocation, which is based on (19) (called QSM-CO-AS-PA-RC)

The MIMO channel information is assumed to be perfectly known to the ML receiver, which jointly estimates the active antennas indices and the transmitted symbol. The signal to noise ratio (SNR) is defined by the overall signal power transmitted from all the activated antennas divided by the noise variance. The simulation setup is based on 4-QAM with $N_S = 4$ and $N_R = 2$. Thus the spectral efficiency is a fixed data rate of 6 bits per channel use (bpcu). The power allocation factors given in Table 1 are employed for three power allocated QSM systems and thus it requires 3 bits feedback.

Moreover, the computational complexity of each of various QSM systems is numerically evaluated. Assuming $N_S = 4$ and $N_R = 2$ with 4-QAM, Table 2, presenting the number of flops for $N_T = 5$ and $N_T = 6$, shows the complexities of QSM-ED-AS-ES, QSM-ED-AS-LC, QSM-ED-AS-R, QSM-ED-AS-PA-ES, QSM-ED-AS-PA-LC, and QSM-CO-AS-PA-RC. All of them perform transmit antenna selection. In addition, the complexities of QSM-ED-PA-ES and QSM-ED-PA-LC without antenna selection are also given in Table 2. It is shown that the ED-AS-PA-ES algorithm for QSM systems requires a huge complexity compared to the ED-AS-ES because of an additional joint search of power allocation factors. Here the power allocation factor candidates for 3 bits feedback given in Table 1 are employed. In this case, $N_G = 8$. Meanwhile, it can be seen that the proposed CO-AS-PA-RC algorithm for QSM clearly exhibits much lower complexity than the ED-AS-PA-ES and ED-AS-ES while its complexity is similar to that of ED-PA-LC for QSM. Especially for $N_T = 6$, it can achieve a lower complexity than the ED-AS-LC whilst it offer slightly higher than the ED-AS-R. It is observed that the increase in the complexity of CO-AS-PA-RC occurring from $N_T = 5$ to $N_T = 6$ is minor, but the ED-AS-PA-ES and ED-AS-PA-LC have a three-fold larger complexity.

Table 2. Computational complexity for $N_S = 4$, $N_R = 2$, and 4-QAM

	$N_T = 5$	$N_T = 6$
QSM-ED-AS-ES	208,000	624,000
QSM-ED-AS-LC	26,000	78,000
QSM-ED-AS-R	23,175	45,306
QSM-ED-AS-PA-ES	2,176,000	6,528,000
QSM-ED-AS-PA-LC	272,000	816,000
QSM-CO-AS-PA-RC	54,415	54,418
QSM-ED-PA-ES	435,200	
QSM-ED-PA-LC	54,400	

Figure 2 compares the SER performance of various QSM systems controlled by transmit antennas selection or/and power allocation with that of the conventional QSM system. Here $N_T = 5$ is assumed. The simulation results are plotted as a function of E_S/N_0 in decibels, where E_S indicates the QSM signal symbol energy. It is shown that the QSM system using the proposed ED-AS-PA-ES algorithm provides better SER performance than the QSM-ED-AS-ES, QSM-ED-AS-R, and QSM-ED-PA-ES at the expense of complexity. In addition, it is observed that the proposed CO-AS-PA-RC algorithm with reduced complexity also outperforms the QSM-ED-AS-ES, QSM-ED-AS-R, and QSM-ED-PA-ES while it offers a minimal performance loss compared to the ED-AS-PA-ES with huge complexity.

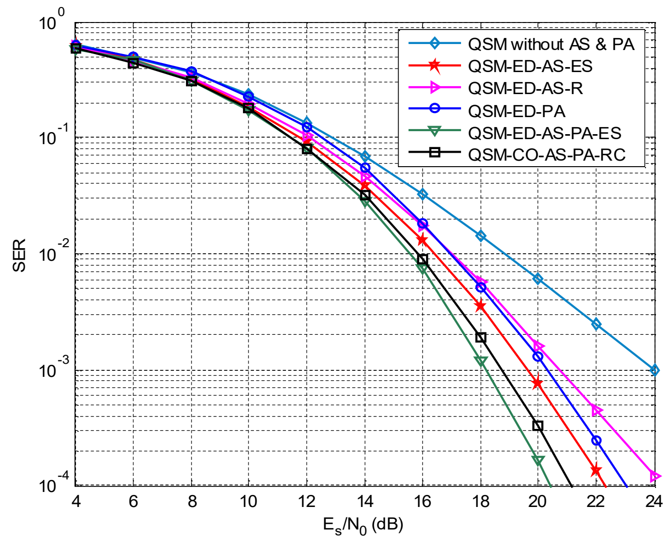

Figure 2. SER of QSM without AS & PA, QSM-ED-AS-ES, QSM-ED-AS-R, QSM-ED-PA, QSM-ED-AS-PA-ES and QSM-CO-AS-PA-RC for $N_T = 5$, $N_S = 4$, and $N_R = 2$

In Figure 3, the SER performances are evaluated under a situation of $N_T = 6$, which can offer more transmit diversity gain than the case in Figure 2. It can be seen that the proposed ED-AS-PA-ES algorithm provides about a 1 dB better SER performance than the ED-AS-ES at SER=10^{-4} and about a 4 dB better SER than the ED-PA-ES and ED-AS-R. On the other hand, the proposed CO-AS-PA-RC algorithm can achieve almost the same SER performance as the ED-AS-ES even if it shows about a 1 dB worse error performance than the ED-AS-PA-ES. It is pointed out that the proposed CO-AS-PA-RC algorithm yields approximately an 11 times smaller complexity than the ED-AS-ES and also imposes about a 119 times reduced complexity than the ED-AS-PA-ES.

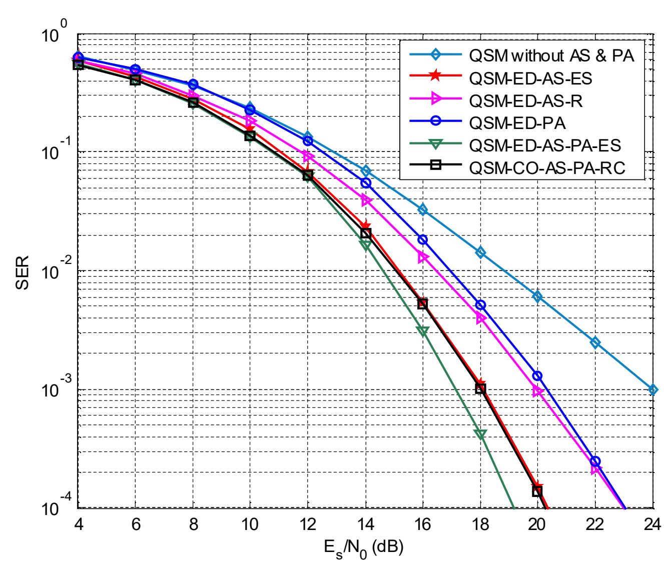

Figure 3. SER of QSM without AS & PA, QSM-ED-AS-ES, QSM-ED-AS-R, QSM-ED-PA, QSM-ED-AS-PA-ES and QSM-CO-AS-PA-RC for $N_T = 6$, $N_S = 4$, and $N_R = 2$

6. CONCLUSIONS

Antenna selection jointly combined with power allocation based on Euclidean distance criterion for QSM systems with limited feedback has been introduced in this paper. It has been demonstrated that the proposed joint optimization algorithm of ED-AS-PA-ES outperforms ED-AS-ES and ED-PA-ES; however this was at the cost of an increased complexity due to its exhaustive search in all possible combinations of antenna subset and power allocation factor candidate. A reduced complexity technique for the ED-AS-PA-ES has been presented by effectively separating antenna selection and power allocation. The proposed CO-AS-PA-RC algorithm performs antenna selection first and then selects power allocation factors. It allows a tremendous reduction in computational complexity compared to the ED-AS-PA-ES and ED-PA-ES. For the QSM system with $N_T = 5$, $N_S = 4$, and $N_R = 2$, the SER performance of the CO-AS-PA-RC is slightly worse than the ED-AS-PA-ES while it exhibits better than the ED-PA-ES. On the other hand, for $N_T = 6$, $N_S = 4$, and $N_R = 2$, the SER results of the CO-AS-PA-RC are almost identical to that of ED-PA-ES whilst they experience error performance loss compared to the ED-AS-PA-ES.

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