Hybrid M-QAM with Adaptive Modulation and Selection Combining in MIMO Systems

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Abstract. In this paper, we propose a hybrid M-ary Quadrature Amplitude Modulation (M-QAM) transmission scheme that jointly uses adaptive modulation and selection combining for singular value decomposition (SVD)-based multiple-input multiple-output (MIMO) systems (AMSC-MIMO). We derive exact closed-form expressions of the performance of the proposed scheme in terms of the average spectral efficiency and the outage probability. Numerical results show that the proposed hybrid M-QAM scheme offers higher spectral efficiency and lower outage probability than the conventional adaptive modulation in MIMO systems.

Keywords: Adaptive Modulation, Variable Rate Variable Power, Selection Combining, MIMO.

1 Introduction

In order to meet the growing demand for mobile multimedia services, most of the recent wireless communication systems employ various techniques that can alleviate the adverse effect of fading channel and enhance data rate and link reliability. Diversity combining (DC) schemes are well-known techniques that can reduce the multi-path fading effect and improve the reliability of communication channels by transmitting the signal over multiple independently fading channels and coherently combining them at the receiver [1]. On the other hand, by using multiple antennas at the transmitter and receiver, multiple-input multiple-output (MIMO) technology provides powerful performance-enhancing capabilities [2,3], one of whose attractive features is the spatial-multiplexing gain over single-input single-output (SISO) systems. By taking advantage of the frequency selectivity and the time variation of fading channels, adaptive modulation (AM) is often adopted in order to increase the spectral efficiency while still meeting the bit error rate (BER) and the average transmit power constraints [4,5]. It has been shown that we can achieve higher spectral efficiency by applying AM in MIMO system (AM-MIMO) [6]. Apart from AM-MIMO, there are efforts to combine AM jointly with DC to improve both the link reliability and the spectral efficiency [7,8]. For example, [7] proposes a hybrid scheme to increase the spectral

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efficiency of multi-channel systems by using maximal ratio combining (MRC) scheme jointly with discrete-rate adaptation. Although the MRC is optimal in the sense of output SNR, its complexity is the highest among other conventional diversity combining schemes since it requires to know the channel status of all the branches between the transmitter and receiver. To reduce the complexity, suboptimal schemes such as selection combining (SC) are often adopted with the sacrifice of the performance [9,10].

In this paper, we introduce a hybrid M-ary quadrature amplitude modulation (M-QAM) with adaptive modulation and selection combining in MIMO systems (AMSC-MIMO). The distinctive feature of AMSC-MIMO is that, while applying discrete-rate adaptation to each sub-channel of a MIMO system, it examines sub-channels whose eigenvalue gains are below the cutoff threshold, selects a sub-channel with the largest gain among them, and jointly determines the data rate and transmit power of the selected sub-channel. Note that, under suitable channel conditions, e.g., rich scattering environment, a MIMO channel can be decomposed into parallel sub-channels by singular value decomposition (SVD) and space-time pre-processing at the transmitter and receiver. In addition to the spatial multiplexing gain of SVD-based MIMO channel, the proposed scheme can exploit both the diversity gain and power loading gain to enhance the overall spectral efficiency in low SNR region, by selecting a sub-channel whose eigenvalue gain is the best among sub-channels below the threshold and enhancing the transmit power of the selected sub-channel enough to meet the required BER performance. We show in the paper that the proposed scheme increases the link gain as well as the spectral efficiency comparing to the conventional AM-MIMO scheme. In our study of the proposed scheme, we carry out performance analysis in terms of the average spectral efficiency and the outage probability assuming perfect channel state information (CSI) at both the transmitter and receiver, and then we validate our analysis from the numerical results.

This paper is organized as follows. In Section II, the channel model and the system operations under consideration are described. The performance analysis of the proposed scheme is in Sections III, and the numerical results are presented in Section IV. Finally in Section V, a brief conclusion is provided.

2 System Description

We consider a point-to-point communication model of the wireless system that has multiple transmit and receive antennas at both the transmitter and receiver.

2.1 MIMO Channel Model

Assuming frequency-flat and uncorrelated Rayleigh fading over the bandwidth of interest, we consider a MIMO system with n_T transmit and n_R receive antennas and the MIMO channel at a given time instant is represented by the channel matrix $\mathbf{H}$, each entry of which represents the complex Gaussian channel gain between the mth receive and nth transmit antenna pair, say $H_{m,n} \sim \mathcal{CN}(0,1)$. The discrete-time input-output relation over a symbol period is given by

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n}, \tag{1}$$

where $E[\mathbf{nn}^H] = N_0\mathbf{I}_{\mathbf{n_R}}$. We assume a block fading model in which the complex channel gain remains roughly constant over each transmission slot. At each transmission slot, the transmitter sends a frame that consists of a burst of symbols and short guard intervals are periodically inserted into transmitted frames. During these guard intervals, the receiver perfectly estimates the channel state information (CSI) including the channel matrix $\mathbf{H}$ and its statistical information, which is fed back to the transmitter through a reliable link without error and delay. By applying a SVD to $\mathbf{H}$, we can express the MIMO channel as

$$\mathbf{H} = \mathbf{U\Sigma V}, \tag{2}$$

where $\mathbf{U}$ and $\mathbf{V}$ are unitary matrixes with left and right singular vectors of $\mathbf{H}$, respectively, and $\mathbf{\Sigma}$ is an $n_R \times n_T$ diagonal matrix whose main diagonal elements are the singular values of $\mathbf{H}$, $\{\sqrt{\lambda_i}\}_{i=1}^{\mathcal{R}}$. By substituting (2) into (1), we can obtain an equivalent input-output relation as

$$\mathbf{U^H y} = \mathbf{\Sigma V^H x} + \mathbf{U^H n}. \tag{3}$$

From (3), we can see that the MIMO channel is decomposed into $\mathcal{R}$ parallel sub-channels whose power gains are represented by the $\mathcal{R} \times 1$ eigenvalue vector $[\lambda_1, \cdots, \lambda_{\mathcal{R}}]^T$ and input/output symbol vectors are $\acute{\mathbf{x}} = \mathbf{V^H x}$ and $\acute{\mathbf{y}} = \mathbf{U^H y}$, respectively. The received SNR per sub-channel can be written as $\gamma_i = P_i\lambda_i/N_0$, where P_i represents the transmit power per sub-channel. According to the previous works in [11] and [6], any unordered element in the eigenvalue vector, say λ, follows the probability density function (PDF) given as

$$f_\lambda(\lambda) = \frac{1}{\mathcal{R}} \sum_{i=0}^{\mathcal{R}-1} \sum_{j=0}^{i} \sum_{k=0}^{i} \mathit{\Delta}_{j,k}(i,\mathcal{D}) \lambda^{j+k+\mathcal{D}} e^{-\lambda}, \tag{4}$$

where $\mathit{\Delta}_{j,k}(i,\mathcal{D}) = \frac{i!(\mathcal{D}+i)!(-1)^{j+k}}{(i-j)!(i-k)!(\mathcal{D}+j)!(\mathcal{D}+k)!j!k!}$. Based on (4), we can derive its cumulative distribution function (CDF) as

$$\begin{aligned} F_\lambda(x) &= \int_0^x f_\lambda(\lambda) d\lambda \\ &= \frac{1}{\mathcal{R}} \sum_{i=0}^{\mathcal{R}-1} \sum_{j=0}^{i} \sum_{k=0}^{i} \mathit{\Delta}_{j,k}(i,\mathcal{D}) \gamma(j+k+\mathcal{D}+1, x), \end{aligned} \tag{5}$$

where $\gamma(\cdot,\cdot)$ is the lower incomplete Gamma function [12].

2.2 Mode of Operation

To enhance the spectral efficiency of the MIMO system, the transmitter adjusts data rate of each sub-channel to the instantaneous CSI. Throughout this paper, we adopt uncoded M-QAM with discrete-rate adaptation in each sub-channel and transmit power is subject to the total transmit power constraint, $P_T = \sum_{i=1}^{\mathcal{R}} P_i$. For discrete-rate adaptation, we assume the equal power allocation for every sub-channel, $P_i = P_T/\mathcal{R}$, and the received SNR range of each sub-channel is separated into $\mathcal{N}$ regions, $\{\gamma_{T_n}\}_{n=1}^{\mathcal{N}}$, each of which is associated with M_n. For uncoded M-QAM with square constellation set, $M_n = 2^{2n}$ where $n = 1, \cdots, \mathcal{N}$, and $SE_n = 2n$ bits are transmitter per symbol. When the transmission mode M_n for the ith sub-channel with $\gamma_{T_n} \leq \gamma_i < \gamma_{T_{n+1}}$ is given, the instantaneous BER can be approximated as [13]

$$BER(M_n, \gamma_i) \simeq c_1 e^{-\frac{c_2 \gamma_i}{M_n - 1}}, \tag{6}$$

where positive real values of c_1 and c_2 are set according to the BER bounds. As an example, $c_1 = 0.2$ and $c_2 = 1.6$ for $BER_T \leq 10^{-3}$ and $M_n \geq 4$. We assume that the instantaneous BER of a sub-channel is subject to an instantaneous BER constraint, $BER(M_n, \gamma_i) \leq BER_T$. Based on (6), we can obtain the required eigenvalue gain, or equivalently, the received SNR to satisfy the instantaneous BER constraint. For a given BER_T, the switching threshold for M_n-QAM can be obtained from (6) as

$$\gamma_{T_n} = \frac{M_n - 1}{K}, n = 1, \cdots, \mathcal{N}, \tag{7}$$

where $K = \frac{c_2}{\ln(c_1/BER_T)}$. Using the above definition of the received SNR per sub-channel and (7), we can write the eigenvalue gain corresponding to each switching threshold as

$$\lambda_{T_n} = \frac{N_0 \gamma_{T_n}}{P_i} = \frac{M_n - 1}{\bar{\gamma} K}, n = 1, \cdots, \mathcal{N}, \tag{8}$$

where $\bar{\gamma} = P_i/N_0$ and we define $\gamma_T = \gamma_{T_1}$ and $\lambda_T = \lambda_{T_1}$, respectively, as the cutoff threshold.

In this paper, we compare two different adaptive modulation schemes in MIMO systems, 1) the conventional AM-MIMO and 2) the proposed AMSC-MIMO, respectively.

Conventional AM-MIMO. According to the conventional M-QAM with AM-MIMO in [6], discrete-rate adaptation is applied to each sub-channel independently. While evaluating the condition of each sub-channel, the transmitter stops transmitting data stream when the received SNR of a sub-channel is below the cutoff threshold or, equivalently, $\lambda_i < \lambda_T$. We denote the sub-channel as a cutoff channel. When the received SNR of a cutoff channel is higher than the threshold, the transmitter resumes data transmission on that sub-channel. In low SNR regime, it is possible that a majority of sub-channels remain cutoff when the MIMO channel suffers from deep fading; as a result, overall spectral efficiency of AM-MIMO system is reduced significantly since the cutoff channels are just wasted without data transmission.

Proposed AMSC-MIMO. The objective of the proposed scheme is to increase overall spectral efficiency of MIMO system by maintaining appropriate data rate of cutoff channels to meet the instantaneous BER and the average transmit power constraints. To accomplish the objective, AMSC-MIMO combines discrete-rate adaptation and SC over cutoff channels. The detailed operation of AMSC-MIMO is as follows.

1. Initially, the transmitter allocates equal power $P_i^* = P_i$ for every sub-channel in the MIMO system. While performing slotted transmit operation, the transmitter obtains the perfect CSI during guard periods and determines λ_i of each sub-channel. If $\lambda_i \geq \lambda_T$, the sub-channel is treated just as in AM-MIMO and is ready for transmission right away. Otherwise, it is categorized into *cutoff channel* and is not selected for transmission.
2. Among the remaining cutoff channels, the transmitter sorts them in order of the eigenvalue gain and selects one with the highest eigenvalue gain, $\lambda_1 = \max\{\lambda_i\}_{i=1}^{\mathcal{C}}$, as the candidate channel.
3. The transmitter recursively raises the transmit power of the candidate channel by borrowing the transmit power from the last of the ordered cutoff channels, e.g., $P_1^* = P_1^* + P_{\mathcal{C}}$ and sets $P_{\mathcal{C}} = 0$ and $\mathcal{C} = \mathcal{C} - 1$, until it consumes all the remaining power of cutoff channels or until the raised power satisfies the instantaneous BER constraint, or equivalently, $P_1^* \lambda_1 / N_0 \geq \gamma_T$. In the latter case, the candidate channel is removed from the cutoff channel list and is selected for transmission with the adjusted power, P_1^*, and the transmitter repeats previous steps from 2) and selects another candidate channel among the remaining cutoff channels. In the former case, the transmitter terminates finding a candidate channel and stops further processing the cutoff channels.

From the steps above, we can observe that the proposed scheme attempts to increase the number of sub-channels that are capable of transmitting data streams, while the total transmit power still meets the constraint, $\sum_{i=1}^{\mathcal{R}} P_i \leq P_T$.

3 Performance Analysis

In this section, we obtain closed-form expressions for the performance of the proposed AMSC-MIMO in terms of the average spectral efficiency and the outage probability. For the convenience of the analysis hereafter, we assume the initial transmit power of every sub-channel is normalized as $P_i = P_T/\mathcal{R} = 1$ and, accordingly, $\bar{\gamma} = 1/N_0$ and $\gamma_i = \lambda_i / N_0$.

3.1 Eigenvalue Gain Distribution of a Candidate Channel

According to the operation of the proposed AMSC-MIMO, the ith candidate channel is defined as a cutoff channel whose eigenvalue gain denoted as $\lambda_{\mathcal{C},i}$ is the ith one among $\mathcal{C}$ cutoff channels. Thus, $\lambda_{\mathcal{C},i}$ is the $(\mathcal{C}-i+1)$th order statistic whose CDF is given by [14]

$$F_{\mathcal{C},i}(x) = \sum_{j=\mathcal{C}-i+1}^{\mathcal{C}} \binom{\mathcal{C}}{j} F_\lambda(x)^j \{1 - F_\lambda(x)\}^{\mathcal{C}-j}. \tag{9}$$

We can also obtain the PDF of the order statistic, $\lambda_{\mathcal{C},i}$, given as [14]

$$\begin{aligned} f_{\mathcal{C},i}(x) &= \frac{d}{dx} F_{\mathcal{C},i}(x) \\ &= \frac{F_\lambda(x)^{\mathcal{C}-i}\{1 - F_\lambda(x)\}^{i-1}}{B(\mathcal{C}-i+1, i)} f_\lambda(x), \end{aligned} \tag{10}$$

where $B(\cdot,\cdot)$ is the beta function [12].

Let us define an event $E_{\mathcal{C},i} = \{\frac{\lambda_T}{P_i^*} \le \lambda_{\mathcal{C},i} < \frac{\lambda_T}{P_i^*-1} | \lambda_{\mathcal{C},i} < \lambda_T\}$, and denote $\lambda_{\mathcal{C},i}^{CCH} = \{P_i^* \lambda_{\mathcal{C},i} | E_{\mathcal{C},i}\}$ as the adjusted gain of the ith candidate channel. Then, we can derive the CDF of $\lambda_{\mathcal{C},i}^{CCH}$ as

$$\begin{aligned} F_{\mathcal{C},i}^{CCH}(x) &= \frac{\Pr[\lambda_{\mathcal{C},i} < \frac{x}{P_i^*}, \frac{\lambda_T}{P_i^*} \le \lambda_{\mathcal{C},i} < \frac{\lambda_T}{P_i^*-1}]}{\Pr[E_{\mathcal{C},i}]} \\ &= \begin{cases} 0, & x < \lambda_T \\ \frac{F_{\mathcal{C},i}(\frac{x}{P_i^*}) - F_{\mathcal{C},i}(\frac{\lambda_T}{P_i^*})}{\widetilde{P}}, & \lambda_T \le x < \mathcal{G}_i \lambda_T \\ 1, & \mathcal{G}_i \lambda_T \le x \end{cases}, \end{aligned} \tag{11}$$

where $\widetilde{P} = \Pr[E_{\mathcal{C},i}]$, and $\mathcal{G}_i = \frac{P_i^*}{P_i^*-1}$. Differentiating (11) with respect to x and using (4), we can obtain the PDF of $\lambda_{\mathcal{C},i}^{CCH}$, given as

$$f_{\mathcal{C},i}^{CCH}(x) = \begin{cases} \frac{1}{\widetilde{P} P_i^*} f_{\mathcal{C},i}(\frac{x}{P_i^*}), & \lambda_T \le x < \mathcal{G}_i \lambda_T \\ 0, & \text{elsewhere} \end{cases} \tag{12}$$

3.2 Spectral Efficiency

The average spectral efficiency of the proposed AMSC-MIMO system is derived as follows. At first we can write the average spectral efficiency as

$$\overline{SE}^{AMSC} = \sum_{\mathcal{C}=0}^{\mathcal{R}} SE_{\mathcal{R},\mathcal{C}} P_{\mathcal{R},\mathcal{C}}, \tag{13}$$

where $P_{\mathcal{R},\mathcal{C}}$ is the probability that there are $\mathcal{C}$-cutoff channels, and $SE_{\mathcal{R},\mathcal{C}}$ is its spectral efficiency, which can be shown as

$$P_{\mathcal{R},\mathcal{C}} = \binom{\mathcal{R}}{\mathcal{C}} F_\lambda(\lambda_T)^{\mathcal{C}} (1 - F_\lambda(\lambda_T))^{\mathcal{R}-\mathcal{C}}, \tag{14}$$

and

$$SE_{\mathcal{R},\mathcal{C}} = \sum_{k=0}^{\lfloor \frac{\mathcal{C}}{2} \rfloor} P_{\mathcal{C}}(k, \mathbf{p}_k) SE_{\mathcal{C}}(k, \mathbf{p}_k), \tag{15}$$

respectively. Note that $P_{\mathcal{C}}(k, \mathbf{p}_k)$ and $SE_{\mathcal{C}}(k, \mathbf{p}_k)$ in (15) represent the probability and the spectral efficiency of the event when k candidate channels are selected among $\mathcal{C}$ cutoff channels ($k \leq \mathcal{C}/2$), respectively. We denote $\mathbf{p}_k$ as a vector whose element represents the adjusted transmit power of a candidate channel. The vector $\mathbf{p}_k$ is drawn from a set that contains all the possible combinations of powers as its elements. For i.i.d cutoff channels, the probability, $P_{\mathcal{C}}(k, \mathbf{p}_k)$, can be derived as

$$\begin{aligned} P_{\mathcal{C}}(k, \mathbf{p}_k) &= \Pr[P_1^* \lambda_{\mathcal{C},1} \geq \lambda_T, \ldots, P_k^* \lambda_{\mathcal{C},k} \geq \lambda_T, \\ &\quad (P_1^* - 1)\lambda_{\mathcal{C},1} < \lambda_T, \ldots, (P_k^* - 1)\lambda_{\mathcal{C},k} < \lambda_T, \\ &\quad (\mathcal{C} - \mathcal{P}(k))\lambda_{\mathcal{C},k+1} < \lambda_T | \lambda_{\mathcal{C},1} < \lambda_T, \ldots, \\ &\quad \lambda_{\mathcal{C},k+1} < \lambda_T] \\ &= \left(\prod_{i=1}^{k} \frac{F_{\mathcal{C},i}(\frac{\lambda_T}{P_i^* - 1}) \; - \; F_{\mathcal{C},i}(\frac{\lambda_T}{P_i^*})}{F_{\mathcal{C},i}(\lambda_T)} \right) \\ &\quad \times \frac{F_{\mathcal{C},k+1}(\frac{\lambda_T}{\mathcal{C} - \mathcal{P}(k)})}{F_{\mathcal{C},k+1}(\lambda_T)}, \end{aligned} \tag{16}$$

where $\mathcal{P}(k) = \sum_{i=1}^{k} P_i^*$. The spectral efficiency, $SE_{\mathcal{C}}(k, \mathbf{p}_k)$, is written as

$$SE_{\mathcal{C}}(k, \mathbf{p}_k) = \overline{SE}^{AM} + \sum_{i=1}^{k} SE_{\mathcal{C},i}^{CCH}, \tag{17}$$

where $\overline{SE}^{AM}$ is the average spectral efficiency of the conventional AM-MIMO system with $\mathcal{R} - \mathcal{C}$ independent sub-channels above the cutoff threshold, whose closed form expression has been derived in [6], as

$$\overline{SE}^{AM} = (\mathcal{R} - \mathcal{C}) \sum_{n=1}^{\mathcal{N}} SE_n \left(F_{\lambda}(\lambda_{T_{n+1}}) - F_{\lambda}(\lambda_{T_n}) \right), \tag{18}$$

and $SE_{\mathcal{C},i}^{CCH}$ is the spectral efficiency of the i-th candidate channel with transmit power P_i^*, which can be represented as

$$SE_{\mathcal{C},i}^{CCH} = \sum_{n=1}^{\mathcal{N}} SE_n P_{\mathcal{C},i,n}^{CCH}, \tag{19}$$

where the probability $P_{\mathcal{C},i,n}^{CCH}$ can be derived as

$$\begin{aligned} P_{\mathcal{C},i,n}^{CCH} &= \Pr[\lambda_{T_n} \leq \lambda_{\mathcal{C},i}^{CCH} < \lambda_{T_{n+1}}] \\ &= F_{\mathcal{C},i}^{CCH}(\lambda_{T_{n+1}}) - F_{\mathcal{C},i}^{CCH}(\lambda_{T_n}) \\ &= \begin{cases} 1, n = 1 \\ 0, n \neq 1 \end{cases}. \end{aligned} \tag{20}$$

By substituting (20) to (19), we can prove that the spectral efficiency of every candidate channel is $SE_{\mathcal{C},i}^{CCH} = SE_1$.

3.3 Outage Probability

In the conventional AM-MIMO system, outage event is defined as the case when every eigenvalue gain of the decomposed MIMO channel falls below the cutoff threshold. As a result, the transmitter cannot transmit data stream when the outage event occurs. The outage probability of the conventional AM-MIMO system can be shown as

$$\begin{aligned} P_{out}^{AM} &= \Pr[\lambda_1 < \lambda_T, \cdots, \lambda_{\mathcal{R}} < \lambda_T] \\ &= \{F_\lambda(\lambda_T)\}^{\mathcal{R}}. \end{aligned} \tag{21}$$

In the proposed AMSC-MIMO system, outage event occurs when the largest eigenvalue gain of the decomposed MIMO channel which is multiplied by the adjusted transmit power $P_1^* = \mathcal{R}$ is below the cutoff threshold, given that every independent sub-channel falls below the cutoff threshold. The outage probability of the AMSC-MIMO system can be shown as

$$\begin{aligned} P_{out}^{AMSC} &= \Pr[\max\{\lambda_i\}_{i=1}^{\mathcal{R}} < \frac{\lambda_T}{\mathcal{R}}] \\ &= F_{\mathcal{R},1}\left(\frac{\lambda_T}{\mathcal{R}}\right). \end{aligned} \tag{22}$$

4 Numerical Results

Figs. 1 and 2 show the average spectral efficiency and the outage probability of two different M-QAM schemes in 2×2, 4×4 and 6×6 MIMO channels, respectively, as a function of the average SNR per sub-channel, when the target BER is set to 10^{-3}. As the number of transmit and receive antennas increase, we observe higher spatial multiplexing gain from both the conventional AM-MIMO and the proposed AMSC-MIMO. More specifically, we can notice from Fig. 1 that AMSC-MIMO shows significant enhancement of the average spectral efficiency over AM-MIMO in low SNR region, though its curve approaches that of AM-MIMO in high SNR region. From Fig. 2, we can observe that, in 2×2 MIMO channel, the AMSC-MIMO offers approximately 3 dB gain over the AM-MIMO from the perspective of the outage probability, and it offers higher performance gain as the number of antennas increases. For example, we can observe approximately 7 dB gain in 6×6 MIMO channel.

From the numerical results in this section, we can deduce that the above performance enhancements are from the fact that, by exploiting both the spatial diversity gain and the power gain in low SNR region, a candidate channel in the proposed AMSC-MIMO scheme obtains much higher output SNR than the conventional sub-channel in AM-MIMO system does.

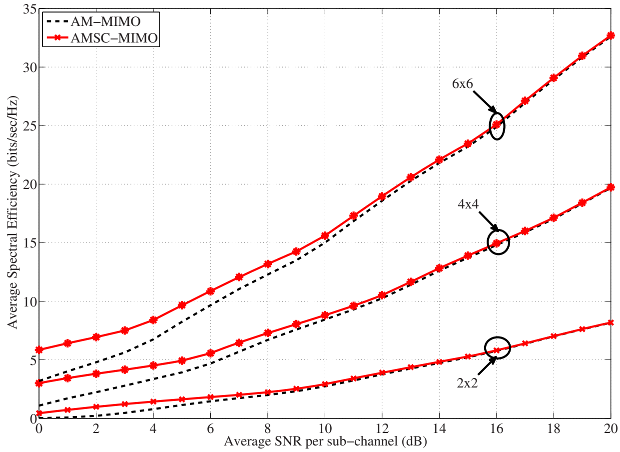

Fig. 1. The comparisons of average spectral efficiency versus the average SNR per sub-channel among the proposed AMSC-MIMO and the conventional AM-MIMO, for 2×2, 4×4 and 6×6 MIMO channels, respectively, when $BER_T = 10^{-3}$

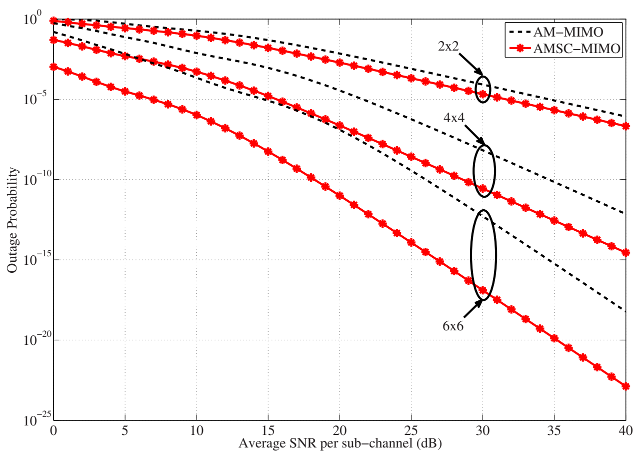

Fig. 2. The comparison of the outage probability versus the average SNR per sub-channel among the proposed AMSC-MIMO and the conventional AM-MIMO, for 2×2, 4×4 and 6×6 MIMO channels, respectively, when $BER_T = 10^{-3}$

5 Conclusion

In this paper, we proposed a hybrid M-QAM scheme that jointly uses discrete-rate adaptation and selection combining in SVD-based MIMO systems, and developed exact closed-form expressions of the performance of the proposed scheme, AMSC-MIMO, assuming perfect CSI. Our numerical results show that by exploiting both the spatial diversity gain and the power gain in low SNR region, the proposed AMSC-MIMO offers higher spectral efficiency and much lower outage probability than the conventional AM-MIMO.

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