Generalized Spatial Modulation with Transmit Antenna Grouping for Correlated Channels

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***Abstract*—In this paper, an effective generalized spatial modulation (GenSM) scheme with transmit antenna grouping is proposed to overcome the performance degradation caused by correlated channels. In the proposed scheme, the transmit antennas are divided into several equal-sized groups, and spatial modulation (SM) is carried out to select one active antenna in each group independently. It is quite different from the conventional GenSM which jointly selects active antenna set. Apart from the straightforward block grouping method, which collects the adjacent antennas to the same group, interleaved grouping is also introduced. It can maximize the average distance between the antennas in the same group, since the channel correlation depends on it. To evaluate the performance, a closed-form expression of the average bit error probability (ABEP) upper bound is derived for all proposed grouping methods and Monte-Carlo simulations are conducted to verify the analysis and reveal the performance gain of the proposed scheme in terms of bit error rate (BER) in comparison with conventional GenSM and SM.**

I. Introduction

Spatial modulation (SM) [1] is a novel multiple-input-multiple-output (MIMO) technique which maps the information bits not only to the constellation symbols but also to the active transmit antenna indices. In this way, SM possesses the advantage of i) spatial multiplexing gain with the activation of a single transmit antenna; ii) relaxed inter-antenna synchronization (IAS) at the transmitter; iii) low-complexity single stream tranceiver design and iv) enhanced energy efficiency brought by single radio frequency (RF) chain. Thus, SM could be suitable for solving challenges in wireless communications [2]-[4].

One shortage of conventional SM is that the spectrum efficiency of SM increases logarithmically with the transmit antenna number. When the number of transmit antennas is large, the data rate of SM is lower than the other conventional spatial multiplexing techniques. Additionally, in order to choose the active antenna index according to the information bits, the number of transmit antennas is strictly constrainted to integer power of two, which brings limitations to the configuration of SM in practice. To overcome these problems, generalized spatial modulation (GenSM) is proposed in [5], [6]. Unlike SM, GenSM allows multiple active transmit antennas to transmit the same constellation symbol. Thus, more bits can be modulated to the active antenna indices and the restriction of the transmit antenna number is also removed. In this way, GenSM can achieve flexible trade-off between spectrum efficiency and system complexity while maintaining relatively high energy efficiency with no more RF chains. As a consequence, GenSM is also considered to be more practical in massive MIMO scenarios where the transmitter is equipped with a large number of antennas. GenSM has attracted considerable attention and has been investigate in some recent studies. In [7], with the vertical bell labs layered space-time (V-BLAST) like architecture, the proposed GenSM scheme could achieve higher multiplexing gain. Authors of [8] present a general upper bounding framework for the average bit error probability (ABEP) of GenSM and use it to optimize system configuration. In [9], by using an optimum combination of number of transmit antennas and number of transmit RF chains, GenSM could perform better than spatial multiplexing. In [10], an upper bound on the ABEP and low-complexity algorithms for signal detection and channel estimation are proposed for GenSM in large-scale multiuser MIMO systems.

Channel correlation is a common phenomenon in wireless communications. Although some of the MIMO techniques make full use of it and achieve the advantage of, e.g., beamforming gain, for most of the conventional MIMO techniques which pursue spatial diversity or multiplexing gains, channel correlation causes performance degradation [11]-[13]. In massive MIMO systems, where hundreds of antennas are placed in limited space, the problem of channel correlation can be much more severe. Until now, some recent works have emerged to analyze the influence of the channel correlation on GenSM. The authors of [14] analyze the performance of GenSM and S-M assuming channel estimation errors and correlated Rayleigh and Rician fading channels. In [15], a very tight upper bound on the ABEP for GenSM in correlated fading channels is derived and a design criterion for optimization is presented. The above mentioned studies reveal the performance penalty brought by channel correlation and bring about the urgent need to improve the robustness of GenSM against correlated channels. Although an optimization strategy is proposed in [15], it is done by exhaustive search and provides no practical intuition.

To this end, in this paper, we propose a novel GenSM scheme with transmit antenna grouping. The essential idea of our scheme is to divide the transmit antennas into groups and each group selects one active antenna according to its own space bits[1] independently to carry the constellation symbols. This is quite different from the conventional GenSM scheme which jointly selects the active antenna set according to all the space bits. In this way, the influence of the error detection of some active antennas can be restricted to certain space bits, instead of leading to catastrophical error as in conventional GenSM. Apart from the straightforward idea of block grouping which collects the adjacent antennas to the same group, a more robust method, termed interleaved grouping, is also proposed to minimize the correlation among transmit antennas in the same group and further improves the performance. We also derive a tight upper bound on the ABEP for the proposed scheme with both grouping methods and conduct Monte Carlo simulations to verify the performance gain of our scheme against conventional GenSM/SM under correlated channels.

The rest of the paper is organized as follows. Section II introduces the system model of the proposed scheme. Section III derives a tight upper bound of the ABEP. Results of Monte Carlo simulations and analysis are given in Section IV. Finally, Section V concludes the paper.

II. System Model

Consider a point-to-point narrow-band MIMO system with N_t transmit antennas and N_r receive antennas. The received signal $\mathbf{y}$ can be expressed in matrix expression as

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

where $\mathbf{x} \in \mathbb{C}^{N_t \times 1}$ denotes the signals from each transmit antenna. $\mathbf{n} \in \mathbb{C}^{N_r \times 1}$ is the additive white Gaussian noise (AWGN) matrix with its elements being identical and independently distributed (i.i.d.) random values distributing as $\mathcal{CN}(0, \sigma_n^2)$. $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix between the transmit and receive antennas, which will be discussed later in this section.

A. Conventional GenSM

In conventional GenSM scheme, more than one transmit antennas are active at each time instant. Assuming the active antenna number is N_a, $\lfloor \log_2 \binom{N_t}{N_a} \rfloor$ space bits, therefore can be chosen to determine the active antenna set, where $\binom{\cdot}{\cdot}$ denotes the binomial coefficient and $\lfloor \cdot \rfloor$ represents the floor operation. Up to now, there are two different GenSM schemes to organize the constellation symbols sent by the active antennas. One is to send parallel symbol flows from the active antennas in the same way as V-BLAST scheme [7]. The other is to send an identical constellation symbol from all the active antennas simultaneously [15]. We note that while the former strategy achieves improved data rate from both the increased space bits and the multiple data flows transmitted by the additional active antennas, it also suffers from severe ICI especially when the channels are strongly correlated. Thus, to better illustrate the influence of correlated channels on the grouping method, we choose the later one as the reference GenSM scheme. However, we would like to address that the generalization of the proposed scheme to the V-BLAST-like one is straightforward and will be talked about in our future works. According to the reference GenSM scheme, an M-ary phase shift keying (M-PSK) constellation symbol will be transmitted from the active antennas, carrying $\eta_s = \log_2 M$ constellation bits. The spectrum efficiency of conventional GenSM in terms of bps/Hz is given by

$$\eta_{GenSM} = \lfloor \log_2 \binom{N_t}{N_a} \rfloor + \eta_s. \tag{2}$$

B. Proposed Scheme

Due to the limited size of the wireless communication terminals, the transmit/receive antennas are usually placed in cramped spaces, which leads to high correlation of the channel coefficients among the antenna elements. This is quite a challenge for the system design. Specifically, for GenSM/SM, information is carried by the indices of active transmit antennas. When the transmitter suffers from high antenna correlation, the resolution of the active transmit antenna indices at the receiver will be severely degraded, which will result in error detection. Thus, in this paper, we focus on mitigating the influence of transmit antenna correlation and propose GenSM with transmit antenna grouping.

The main idea of the proposed scheme is to separate the transmit antennas into equal-sized groups and conduct SM independently. Assuming that every N_g antennas are collected together as a transmit antenna group, the total N_t transmit antennas can be divided into $N_a = N_t/N_g$ groups. To perform SM in each group, N_a is restricted to be integer power of 2. Then, the modulation process of the proposed scheme can be described as follows. Firstly, $N_a\lfloor \log_2 N_g \rfloor$ bits are fed to N_a SM modulators to determine the single active antenna in each antenna group. Then, an M-PSK symbol is decided by another η_s bits, which will be transmitted by the active antennas. The block diagram of the transmitter structure with $N_t = 8, N_a = 2$ is given in Fig. 1 for reference. Accordingly, the spectrum efficiency of the proposed scheme in terms of bps/Hz can be represented by

$$\eta_{proposed} = N_a \times \lfloor \log_2 \binom{N_g}{1} \rfloor + \eta_s. \tag{3}$$

As can be seen from (3), the data rate provided by space bits in the proposed scheme becomes $N_a \times \lfloor \log_2 \binom{N_g}{1} \rfloor$ as compared with the conventional GenSM scheme. An interesting phenomenon worth noting is that the number of space bits of the conventional GenSM and the proposed scheme are the same when $N_a = 2$, because the relation

[1] In this paper, space bits refer to the information bits used to select the active antenna(s) in GenSM/SM. The information bits determining the constellation symbols are named constellation bits correspondingly.

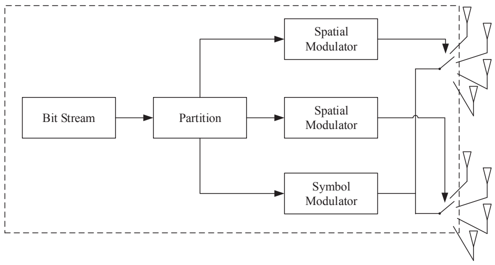

Fig. 1. Block diagram of the transmitter of GenSM with transmit antenna grouping ($N_t = 8, N_a = 2$).

$2\times\lfloor\log_2\binom{N_g}{1}\rfloor = \lfloor\log_2\binom{2\times N_g}{2}\rfloor$ holds for arbitrary N_g, which means if the number of the active antennas equals two, the proposed scheme does not suffer from any data rate loss.

1) Grouping Methods: In this paper, we propose two different antenna grouping methods, namely block grouping and interleaved grouping, which are suitable for linear antenna arrays at the transmitter. In order to clarify the two methods, we take $T_1, T_2, \cdots, T_{N_t}$ to represent the transmit antennas from the beginning to the end of the linear array.

In block grouping, transmit antennas are spatially separated into several blocks, which means that each group has transmit antennas adjacent to each other. To clarify it in a mathematical way, the i^{th} group consists of $T_{(i-1)\times N_a+1}, T_{(i-1)\times N_a+2}, \cdots, T_{i\times N_a}$. Since correlation is usually relevant to distance between antennas, we note that block grouping provides no correlation degradation as compared with conventional GenSM. However, by separating the space bits and projecting them to antenna groups, the number of error space bits is reduced when wrong detection of the active antenna set occurs. Thus, block grouping can provide constant performance gain even when channel correlation doesn't exist.

Interleaved grouping, however, is specially designed for correlation channels to further boost the performance of block grouping. For interleaved grouping, the antennas in the same group are designed to have the maximum distance among each other, which means that the antennas of each group are distributed in the whole linear array evenly. Mathematically, the i^{th} group consists of $T_i, T_{i+N_a}, T_{i+2\times N_a}, \cdots, T_{i+(N_g-1)\times N_a}$. Since the channel correlation is usually relevant to distance, by maximize the distance between antennas in the same group, interleaved grouping is able to minimize the antenna correlation within each group.

An example of the two grouping methods for $N_t = 8, N_a = 2$ is given in Fig. 2, where the block grouping method gathers T_1, T_2, T_3, T_4 to group 1 and T_5, T_6, T_7, T_8 to group 2, while the interleaved grouping method takes T_1, T_3, T_5, T_7 to form group 1 and T_2, T_4, T_6, T_8 for group 2.

2) ML-Optimum Detector: Assuming perfect channel state information (CSI) at the receiver, the optimal maximum-likelihood (ML) detector for GenSM with transmit grouping can be written as

$$[\check{a}_1, \check{a}_2, \cdots, \check{a}_{N_a}, \check{s}] = \underset{\substack{\check{a}_i \in \text{ group } i \\ \check{s} \in M\text{-PSK}}}{\arg\min} \left\{ \left|\left|\mathbf{y} - \mathbf{H}\check{\mathbf{x}}\right|\right|_F^2 \right\}, \quad (4)$$

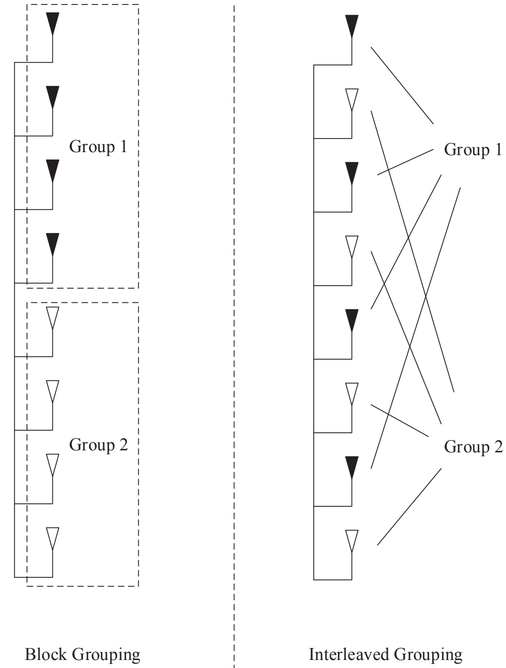

Fig. 2. Two grouping schemes ($N_t = 8, N_a = 2$).

where $\check{a}_i$ represents the detected index of the active transmit antenna in the group i, $\check{s}$ denotes the detected M-PSK and $\check{\mathbf{x}}$ is the detected GenSM symbol which can be characterized by $\check{a}_i$ and $\check{s}$. $||\cdot||_F$ stands for the Frobenius norm.

C. Spatial Correlation Channel Model

In this paper, the Kronecker model [16] is utilized to model the spatial correlated channels between transmitter and receiver for its straightforward mathematical description and acceptable accuracy. The correlated channel is given by

$$\mathbf{H} = \mathbf{R}_r^{\frac{1}{2}}\mathbf{G}\mathbf{R}_t^{\frac{1}{2}}, \quad (5)$$

where $\mathbf{G} \in \mathbb{C}^{N_r\times N_t}$ is the uncorrelated channel matrix, whose elements are i.i.d random values following $\mathcal{CN}(0,1)$, $\mathbf{R}_r \in \mathbb{C}^{N_r\times N_r}$ is the receiver correlation matrix and $\mathbf{R}_t \in \mathbb{C}^{N_t\times N_t}$ is the transmitter correlation matrix. Since the performance of the GenSM scheme is mainly influenced by the transmitter-side correlation, in this paper, we decide to ignore the correlation at the receiver side by simply setting $\mathbf{R}_r = \mathbf{I}_{N_r}$, where $\mathbf{I}_{N_r}$ is the identical matrix of size N_r, i.e., no correlation among receive antennas [13]. Thus, the correlated channel can be simplified as

$$\mathbf{H} = \mathbf{G}\mathbf{R}_t^{\frac{1}{2}}. \quad (6)$$

The correlation between two transmit antennas is assumed to decay exponentially with distance, i.e., $Corr(T_i, T_j) = \rho^{|i-j|}$ where $0 \leq \rho \leq 1$ is the exponential correlation parameter. Thus, the correlation matrix can be written as

$$\mathbf{R}_t = \begin{bmatrix} 1 & \rho & \rho^2 & \cdots & \rho^{N_t-1} \\ \vdots & \ddots & \ddots & \ddots & \rho \\ \rho^{N_t-1} & \cdots & \rho^2 & \rho & 1 \end{bmatrix}. \quad (7)$$

As can be observed from the channel model, the maximization of the distance among certain transmit antennas is able to minimize the correlation of the corresponding channel coefficients, which stands for the performance gain to be shown later of our interleaved grouping scheme against conventional GenSM.

III. Performance analysis of the average bit error probability

In this section, we derive a closed-form expression of the upper bound for the ABEP of the proposed scheme by using the well known union bounding technique [17]. Assuming normalized transmit power, i.e., $E_s = \mathbb{E}\left[||\mathbf{x}||_F^2\right] = 1$, where $\mathbb{E}\{\cdot\}$ denotes the expectation operator, and defining the signal-to-noise-ratio (SNR) to be $E_s/\sigma_n^2 = 1/\sigma_n^2$, the ABEP can be bounded by

$$\text{ABEP} \le \frac{1}{2^\eta} \sum_{s,a} \sum_{\check{s},\check{a}} \frac{N\left(s,a;\check{s},\check{a}\right) P\left(s \to \check{s}, a \to \check{a}\right)}{\eta}, \tag{8}$$

where a denotes the ensemble of indices of active antennas, i.e., $a = \{a_1, a_2, \cdots, a_{N_a}\}$, $P\left(s \to \check{s}, a \to \check{a}\right)$ stands for the pairwise error probability (PEP) of deciding on $\check{s}, \check{a}$ when s, a is actually transmitted and $N\left(s,a;\check{s},\check{a}\right)$ refers to the number of bits in error between s, a and $\check{s}, \check{a}$. According to the ML criterion in (4), the PEP is given as

$$\begin{aligned} P\left(s \to \check{s}, a \to \check{a}\right) &= P\left(\mathbf{x} \to \check{\mathbf{x}}\right) \\ &= P\left(\left|\left|\mathbf{y} - \mathbf{H}\mathbf{x}\right|\right|_F^2 \ge \left|\left|\mathbf{y} - \mathbf{H}\check{\mathbf{x}}\right|\right|_F^2\right). \end{aligned} \tag{9}$$

We note that the format of the signals $\mathbf{x}$ and $\check{\mathbf{x}}$ in (9) is exactly the same as that in the conventional GenSM. Thus, the result of Eq.(13) in [14] can be introduced to our derivation with some variations. The PEP from [Eq.(13), 14] can be written as

$$\begin{aligned} & P\left(s \to \check{s}, a \to \check{a}\right) \\ \le & \frac{1}{2} \frac{\exp\left(-\frac{1}{2\sqrt{2}\sigma_n^2} \mathbf{u}_{\tilde{\mathbf{H}}}^H \mathbf{\Lambda} \left(\mathbf{I} + \frac{1}{2\sqrt{2}\sigma_n^2} \mathbf{L}_{\tilde{\mathbf{H}}} \mathbf{\Lambda}\right)^{-1} \mathbf{u}_{\tilde{\mathbf{H}}}\right)}{\left|\mathbf{I} + \frac{1}{2\sqrt{2}\sigma_n^2} \mathbf{L}_{\tilde{\mathbf{H}}} \mathbf{\Lambda}\right|}, \end{aligned} \tag{10}$$

where in our case, $\mathbf{u}_{\tilde{\mathbf{H}}} = 0$ because of Raleigh fading, $\mathbf{\Lambda} = \mathbf{I}_{N_r} \otimes \Psi\Psi^H$, where $\Psi = (\check{\mathbf{x}} - \mathbf{x})$ and $(\cdot)^H$ represents the Hermitian transposition, $\mathbf{L}_{\tilde{\mathbf{H}}} = \mathbf{R}_r \otimes \mathbf{R}_t = \mathbf{I}_{N_r} \otimes \mathbf{R}_t$ with $\otimes$ denoting the Kronecker product. $|\cdot|$ is the determinant. Thus, (10) can be simplified as

$$P\left(s \to \check{s}, a \to \check{a}\right) \le \frac{1}{2} \frac{1}{\left|\mathbf{I} + \frac{1}{2\sqrt{2}\sigma_n^2} \mathbf{R_t} \Psi \Psi^H\right|^{N_r}}, \tag{11}$$

Plugging (11) into (8), we obtain

$$\text{ABEP} \le \frac{1}{2^{\eta+1}\eta} \sum_{s,a} \sum_{\check{s},\check{a}} \frac{N\left(s,a;\check{s},\check{a}\right)}{\left|\mathbf{I} + \frac{1}{2\sqrt{2}\sigma_n^2} \mathbf{R_t} \Psi \Psi^H\right|^{N_r}}. \tag{12}$$

We note that by varying the set of a and $\check{a}$, (11) is suitable for both proposed grouping methods. As will be validated and discussed in the simulations, the upper bound of BER of the proposed scheme in (12) is very close to the numerical results when the SNR is relatively high.

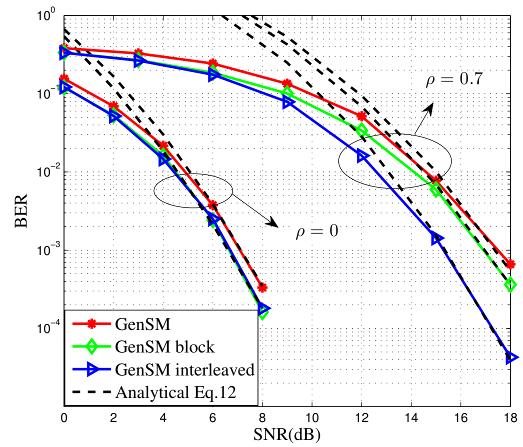

Fig. 3. BER versus the SNR for conventional GenSM, GenSM with block grouping and interleaved grouping for $N_t = 16, N_r = 8, N_a = 2, \rho = 0$ or $0.7, \eta = 7$.

IV. Simulation Results

In this section, Monte-Carlo simulations are conducted to examine the BER performance of the proposed scheme in comparison with conventional GenSM and SM.

Fig. 3 compares the BER performance of the two proposed schemes and conventional GenSM with the system setup of $\{N_t = 16, N_a = 2, N_r = 8, \rho = 0 \text{ or } 0.7\}$. BPSK is utilized for all schemes to achieve the data rate of η =7 bps/Hz. The analytical results in Section III are also drawn in the figure for verifications. As can be observed from the figure, the analytical results matches the simulation in high SNR regions for both the two proposed schemes, which demonstrates improved BER performance as compared with conventional GenSM. For block grouping when $\rho = 0.7$, the performance gain is about 0.5dB throughout the considered SNR region. For interleaved grouping when $\rho = 0.7$, the benefit is further improved to about 2dB. For $\rho = 0$, i.e., no correlation, the performance gain of interleaved grouping is the same as that of block grouping which is about 0.5dB. As discussed before and verified by the simulations, we can draw the conclusion that simply splitting the transmit antenna array into groups is enough to improve the performance. However, due to the fact that the antennas in each group is still strongly correlated as in conventional GenSM, which makes it hard for the receiver to make decisions, the performance improvement is limited. For interleaved grouping, by further separating the transmit antennas in the same group, apart from the benefits brought by grouping, the Euclidean distance between different active antenna sets is also enlarged, which further improves the detection of the space bits. Thus, the performance can be significantly boosted.

Next, we evaluate the performance versus the variation of the receive antenna numbers N_r in Fig. 4. The same system setup of $\{N_t = 16, N_a = 2, \rho = 0.7, \text{BPSK}\}$ as in Fig. 3 is used in the simulation. As can be observed from Fig. 4, we

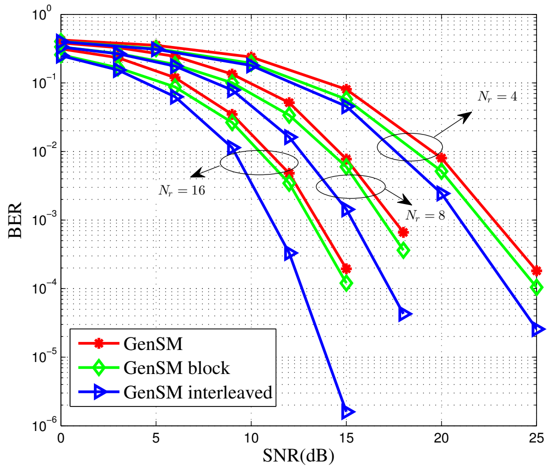

Fig. 4. BER versus the SNR for conventional GenSM, GenSM with block grouping and interleaved grouping with different N_r for $N_t = 16, N_a = 2, \rho = 0.7, \eta = 7$.

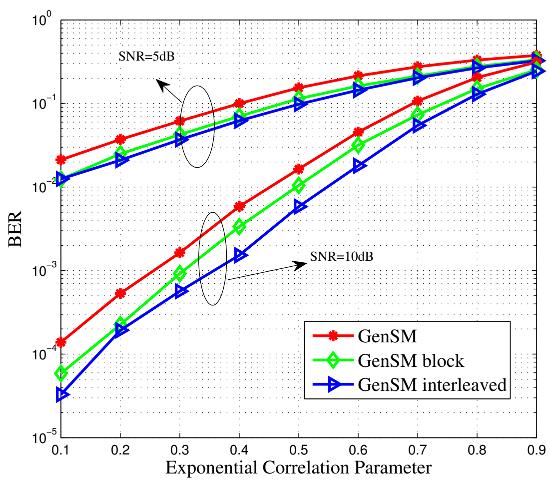

Fig. 5. BER versus the exponential correlation parameter ρ for conventional GenSM, GenSM with block grouping and interleaved grouping for $N_t = 16, N_r = 8, N_a = 2, \eta = 7, \text{SNR} = 5$ or 10dB.

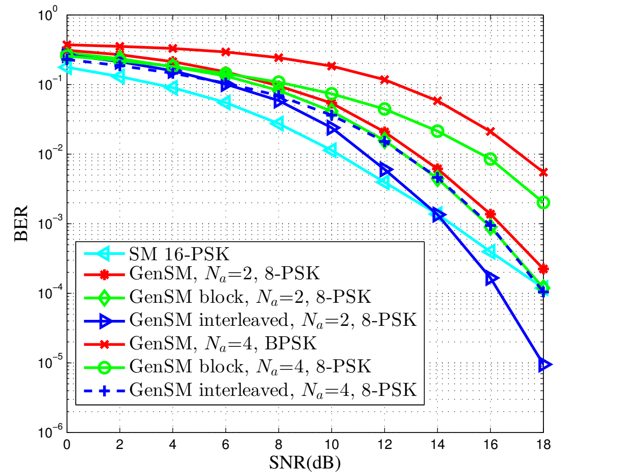

Fig. 6. BER versus the SNR for SM, conventional GenSM, GenSM with block grouping and interleaved grouping with different N_a for $N_t = 8, N_r = 8, \rho = 0.7, \eta = 7$.

can find that the performance gain of our proposed schemes against conventional GenSM remains for all considered N_r. Specially, we notice that the performance improvement of the proposed GenSM with interleaved grouping increases with the receive antenna number. At the target BER of 10^{-3}, the gain of interleaved grouping compared with conventional GenSM is 2dB, 2.5dB, 3dB for $N_r = 4, 8, 16$, respectively. This again demonstrates the priority of our proposed grouping method.

In Fig. 5, we discuss the influence of the exponential correlation parameter ρ under 5dB and 10dB respectively. The system setup is exactly the same as that in Fig. 3. As shown in the figure, the BER performance of the three schemes all degrades when ρ increases. Also, we notice that the improvement in terms of BER brought by our proposed grouping schemes remains constant at the given SNR for a wide range of ρ. However, when ρ is quite small, i.e., channels are nearly uncorrelated, the performance of interleaved grouping is almost the same as that of block grouping. The reason is straightforward. Because the benefits brought by interleaved grouping essentially comes from the reduced correlation within antenna groups. when ρ is quite small, i.e., the channel correlation is moderate, interleaved grouping is simply like block grouping and offers a constant gain brought by grouping just like in Fig. 3.

Fig. 6 presents the comparison of situations with different number of active transmit antennas. In this case, we use the parameter of $\{N_t = 8, N_a = 1/2/4, N_r = 8, \rho = 0.7\}$ at the data rate of 7bps/Hz, where $N_a = 1$ represents the conventional SM scheme. BPSK, 8-PSK, 16-PSK constellations are used for different schemes to achieve the target data rate. In Fig. 6, we can find that SM performs better than all GenSM schemes when SNR is relatively low. This is because the detection of multiple antenna indices in GenSM schemes are much more vulnerable to the thermal noise than the conventional SM scheme with single active antenna. When the SNR is low, error detections in antennas indices occur more frequently in GenSM schemes, which also leads to the error detection of the constellation symbols. However, when SNR is high, the error detection mainly occurs in the constellation symbol, the lower modulation order therefore helps the GenSM schemes to obtain prior BER performance. Thus, we notice that the performance of GenSM exceeds SM in high SNR region. Also, we note that it is not always better to have more active antennas in GenSM. For example, the performance of GenSM with $N_a = 2$ outperforms that of GenSM with $N_a = 4$ for all three GenSM schemes. This can be explained by the increased correlation among antenna groups.

Finally, in Fig. 7, we focus on practical scenarios where the size of the linear transmit antenna array is fixed, and evaluate the performance of the proposed GenSM scheme with different number of transmit antennas. The comparison is meaningful because usually, the size of the antenna array is limited by the

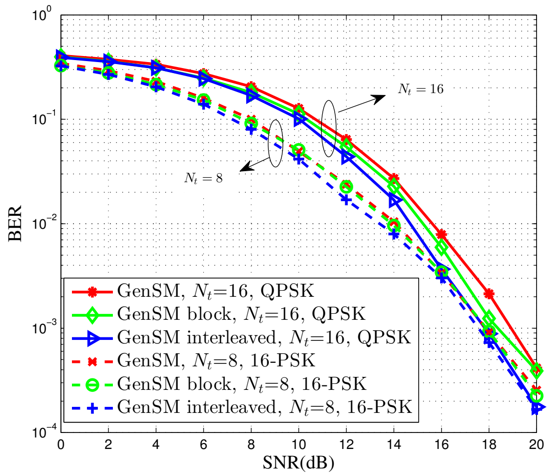

Fig. 7. BER versus the SNR for conventional GenSM, GenSM with block grouping and interleaved grouping with different N_t in equal size for $N_r = 4, N_a = 2, \rho_{16} = 0.5, \rho_8 = 0.25, \eta = 8$.

size of the wireless terminals. The placement of more antennas is therefore at the price of narrowing the separation distance between the antennas, which means stronger inter-antenna correlation. As we assumed in Section II.C, the correlation between two transmit antennas decays exponentially with distance. In the simulations, we consider the system setup of $N_t = 8$ and 16. To simulate the influence of the fixed antenna array size, the distance of adjacent transmit antennas of $N_t = 8$ is set to be double of that of $N_t = 16$. Thus, the correlation exponential parameter of $N_t = 8$ is the square of that of $N_t = 16$, i.e., $\rho_8 = (\rho_{16})^2$. In Fig. 7, without lose of generality, we assume that $\rho_{16} = 0.5, \rho_8 = (\rho_{16})^2 = 0.25$. The data rate is set to be 8 bps/Hz. As can be seen from the figure, the performance gain remains between the proposed grouping methods and conventional GenSM. While $N_t = 8$ outperforms $N_t = 16$ in low SNR region, as SNR increases, the gap narrows and the curves finally converge. The explanation is as follows. When SNR is low, the space bits of $N_t = 16$ are more vulnerable to the noise due to the increased channel correlation. Thus, fewer space bits and moderate correlation for $N_t = 8$ provide better performance. When SNR is high, for the same reason given in the analysis of Fig. 6, lower symbol order for $N_t = 16$ provides the improved performance.

V. Conclusions

In this paper, a novel scheme with transmit antenna grouping was proposed to improve the performance of GenSM/SM under correlated channels. Two grouping methods, namely block grouping and interleaved grouping were proposed either to reduce the ABEP when antenna indices are wrongly detected or to further improve the performance under correlated channels. We analyzed BER performance of the proposed scheme in terms of ABEP and derived a closed-form upper bound. With the method of Monte Carlo simulation, we validated our analysis and revealed the benefits of the proposed GenSM scheme with block and interleaved grouping against GenSM and SM.

Our future work will focus on larger antenna array size, 2-dimensional or 3-dimensional antenna arrays with more practical channel parameters and the optimization of the group size and other system configurations.

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