User Grouping and Power Allocation for Downlink NOMA-Based Quadrature Spatial Modulation

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ABSTRACT Conventional non-orthogonal multiple access (NOMA)-based spatial modulation (SM) systems utilize only the real part of amplitude-phase modulation (APM) symbols for transmission, but quadrature spatial modulation (QSM) can extend this to two orthogonal components to improve the spectral efficiency. In this way, we propose a NOMA-based QSM system in multiple-input multiple-output scenarios, where APM symbols are divided into real and imaginary components for transmission and then these two components are sent by real and imaginary transmit antennas, respectively. To further improve the performance of our proposed system, we also propose a user grouping and a power allocation with relatively low complexity. Different from previous schemes, the user grouping scheme is designed for considering channel conditions, user locations, and channel correlations jointly. Moreover, the power allocation scheme is performed in each group to meet users’ quality-of-service requirements, i.e., target-rate requirements. Simulation results demonstrate the effectiveness of proposed schemes by comparing with existing ones.

INDEX TERMS Quadrature spatial modulation, non-orthogonal multiple access, multiple-input multiple-output, user grouping, power allocation.

I. INTRODUCTION Spatial modulation (SM) in multiple-input multiple-output (MIMO) systems has aroused passions and concerns because it has low system complexity and no inter-antenna interference [1]. In SM systems, the sending symbol is selected by the signal constellation, while the index of transmit antenna (TA) is chosen by the space constellation. In addition, the sending symbol is the amplitude-phase modulation (APM) symbol, which is sent by the chosen only one TA. Different from the conventional transmission mode, quadrature spatial modulation (QSM) has been proposed [2]–[4], where real parts and imaginary parts of APM symbols are separated, and then these two parts are sent by real and imaginary TAs, respectively. In this way, spectral efficiency can be further improved.

Compared with orthogonal multiple access (OMA), non-orthogonal multiple access (NOMA) has achieved a good tradeoff between fairness and spectral efficiency [5]. In NOMA systems, different power allocation coefficients are allocated to users. It ensures that the users can exploit power domain resources at the same time, frequency, code domain. NOMA-based SM (SM-NOMA) systems have been well considered [6]–[8] because they have higher spectral efficiency while maintaining moderate complexity and fairness. However, the performance enhancement of the system is limited by only one chosen TA.

Motivated by these problems, we investigate the combination of NOMA and QSM systems, namely QSM-NOMA systems, which have some advantages. Firstly, APM symbols
can be divided into two orthogonal real and imaginary parts, which means that inter-antenna interference can be also avoided. Secondly, spectral efficiency can be improved by using two orthogonal symbols for transmission. Thirdly, two radio frequency (RF) chains are required at most rather than the same number of RF chains as transmit antennas, and hence the hardware cost of QSM-NOMA systems is lower than that of MIMO-NOMA systems. Moreover, effective user grouping and power allocation schemes should be considered to achieving the performance enhancement in terms of bit error rate (BER) and achievable sum rate (ASR).

A. RELATED WORKS

For user grouping, most of the literature has considered only channel conditions of users. For example, a low-complexity user grouping was investigated by pairing low channel gain users with high channel gain users to increase the sum-throughput, which means that the strongest user and the weakest user should be selected into a group, i.e., a best-near weakest-far (BNWF) user grouping scheme [9]. However, a best-near best-far (BNBF) user grouping scheme was proposed for reducing the outage probability of cooperative networks, which implies that the strongest user and the weakest user should be grouped to different groups [10]. And, an optimal user grouping was designed for downlink NOMA systems to maximize the sum rate, where the strongest user and the weakest user were also not be grouped together [11]. In addition, there were some user grouping based on user locations, where the chordal distance between covariance eigenspaces was first considered to select users [12], and then the average chordal distance (ACD) between statistical-eigenmodes was used to perform user grouping for massive MIMO systems [13]. Furthermore, some literature considered channel correlations between users. For instance, correlation-based user grouping schemes were proposed to estimate inter-user interference and to improve the sum rate as in [14], [15].

For power allocation, the energy efficiency maximization problem was considered in downlink NOMA networks [16], where a non-convex power allocation problem across subchannels was solved by a difference of convex programming. The sum-throughput maximization problem was investigated in uplink and downlink MIMO-NOMA systems [9], where users with different channel conditions were grouped into different clusters firstly, and then obtained their optimal power allocation coefficients by the Lagrangian multiplier method and the Karush-Kuhn-Tucher (KKT) condition. The outage probability minimization problems were studied in cooperative NOMA systems, where power allocation has been investigated for the relay transmission [17], [18]. Furthermore, in cooperative NOMA systems, relay location optimization algorithms were considered to minimize the outage probability [19], a closed-form expression for the throughput under the delay-limited transmission mode was presented [20], and the approximate expression for the ergodic sum rate was derived [21]. The ASR maximization problem was considered in NOMA-millimeter wave systems, where the gradient ascent method and the gradient descent method were presented for power allocation [22]. The robust interference efficiency maximization problem was studied for multicell heterogeneous networks (HetNets), where perfect and imperfect channel state information (CSI) were considered [23]. In addition, a robust resource allocation scheme was investigated for simultaneous wireless information and power transfer (SWIPT)-enabled HetNets, where a min-max probability machine approach was considered [24].

There were several prior works on SM-NOMA systems. The spectral efficiency was studied for SM-NOMA systems in the multiple-input single-output (MISO) scenario, but fixed power allocation and random user grouping were considered [6], [8]. The BER performance was investigated for SM-NOMA systems in the MIMO scenario, where the power allocation was calculated by assuming the same received signal-to-noise ratio (SNR) of the two users after the successive interference cancellation (SIC) procedure [7]. In [25], the SM-NOMA system could be extended to the generalized spatial modulation (GSM) scenario, where a signal detection scheme was studied by block-sparse compressive sensing rather than maximum likelihood (ML) detection. In addition, the impact of dynamic user grouping and power allocation on the performance of GSM-NOMA systems was considered [26]. Furthermore, the combination of NOMA and space shift keying (SSK) was proposed in [27] and the combination of NOMA and generalized space shift keying (GSSK) was studied in [28], where some users were multiplexed using NOMA and others could exploit the spatial domain. The NOMA-SSK/NOMA-GSSK system was extended to the QSM scenario, where the error floor was successfully mitigated by dynamic power allocation [29].

B. MOTIVATION AND CONTRIBUTION

Several existing works have considered for SM-NOMA systems [6]–[8], but most of them mainly focused on random grouping and fixed power allocation. However, with the impact of dynamic user grouping and power allocation, significant performance enhancement could be achieved. Moreover, SM-NOMA systems were rarely analyzed in QSM scenarios, so the APM symbol could be divided into real and imaginary parts to improve spectral efficiency.

Therefore, we propose the QSM-NOMA system. In addition, we can design dynamic user grouping and power allocation for this system. In this manner, users are selected into different groups firstly and then the power allocation is performed in each group, which is a two-step method with relatively low complexity. The main contributions of this paper are outlined as follows:

- A system model of the downlink QSM-NOMA system is proposed, where two real and imaginary parts of APM symbols are sent by real and imaginary transmit antennas, respectively. In addition, all users can exploit both spatial domain and power domain simultaneously rather
than exploiting either spatial domain or power domain as in [29].

- A dynamic user grouping scheme is proposed for downlink QSM-NOMA systems. Most of the prior work has only considered channel conditions, but we consider channel conditions, user locations, and channel correlations. The users with the low ACD are divided into the same group firstly, and then a user will be grouped to a group if there are lower channel correlations between the user and other users within the group.

- A dynamic power allocation scheme is proposed for downlink QSM-NOMA systems. To meet target rates of users, a power allocation problem with various quality-of-service (QoS) requirements is considered, and then all users can obtain their power allocation coefficients in descending order by their channel conditions.

- Simulation results demonstrate the proposed schemes have better performance by comparing with the existing schemes, including the max sum-rate power allocation, the BNWF user grouping, the BNBF user grouping and so on. Compared with other systems, our QSM-NOMA systems have achieved a better tradeoff between spectral efficiency and complexity.

The rest of this paper is organized as follows: Section II presents the system model; Section III and IV discuss proposed user grouping and power allocation schemes, respectively; Section V shows simulation results and performance analysis; Conclusions are drawn in Section VI.

**Notation:** $(\cdot)^H$ is the conjugate transpose operation, $tr(\cdot)$ denotes the trace operation, $\|\cdot\|^2$ is the second-order norm operation, $\binom{n}{k}$ denotes the binomial coefficient of $[n, k]$, $\mathbb{C}$ is a complex number field, $\mathbb{Z}$ denotes an integer field, and $\mathcal{C}\mathcal{N}(\mu, \sigma)$ is complex Gaussian distribution with mean $\mu$ and variance $\sigma^2$.

**II. SYSTEM MODEL**

A single-cell downlink QSM-NOMA system is proposed, where there are $T$ groups and each group has $K$ users. In this way, there are total $N = KT$ users and the $l$th user of the $i$th group is expressed by $u_i^l$, where $i \in \{1, 2, \ldots, K\}$, $l \in \{1, 2, \ldots, T\}$. Moreover, the BS as the transmitter is equipped with $N_t$ TAs, and each user as the receiver has $N_r$ receive antennas. Furthermore, NOMA is implemented within each group and OMA is used for different groups to eliminate the inter-group interference as in [6], [8]. Taking the $i$th group as an example, the GMSN system model is shown in Fig. 1.

In the QSM-NOMA system, both the Rayleigh fading and the path loss are considered, and $H_{\gamma}^i = d_{\gamma,i}^{-\alpha}H_{\gamma}^i \in \mathbb{C}^{N_r \times N_t}$, where $H_i^l$ is the channel matrix of $u_i^l$, $d_{\gamma,i}$ is the distance between the BS and $u_i^l$, and the path loss exponent is indicated by $\alpha$ [10]. $H_{\gamma}^i$ is the Rayleigh fading coefficient from the BS to $u_i^l$ with its entries that are independent and identically distributed (i.i.d.) as $\mathcal{C}\mathcal{N}(0, 1)$ [7]. Furthermore, system symbols are presented in Table 1.

In addition, the input bit of $u_i^l$ is $\log_2(N_t) + \log_2(N_r) + \log_2(M)$. According to the principle of QSM, the first $\log_2(N_r)$ bit is utilized for selecting the index of the real (in-phase) TA $j_{\gamma,i}^l$, the second $\log_2(N_t)$ bit is used for selecting the index of the imaginary (quadrature) TA $j_{\gamma,Q}^l$. Thus, the transmit antenna combination (TAC) of $u_i^l$ is $\mathbf{J}_i^l = \left[ j_{\gamma,i}^l, j_{\gamma,Q}^l \right]^T \in \mathbb{Z}^{2 \times 1}$. Moreover, the remaining $\log_2(M)$ bit is utilized for determining the APM symbol, which is expanded to real (in-phase) and imaginary (quadrature) components. In this way, these two orthogonal components can be sent by real and imaginary TAs.\(^1\)

\(^1\)The impact of antenna selection on the performance is beyond the scope of this paper, which will be further considered in our future work.
Therefore, the sending symbol of $u_i^1$ is defined as:

$$s_i^1 = s^1_{i,i} + js^1_{i,Q},$$

where $s^1_{i,i} \in \mathbb{C}^{1 \times 1}$ denotes the sending symbol of $u_i^1$, $s^1_{i,Q}$ and $s^1_{i,Q} \in \mathbb{Z}^{1 \times 1}$ are the in-phase and quadrature component of the sending symbol of $u_i^1$, named as the in-phase symbol and the quadrature symbol of $u_i^1$, respectively.

Without loss of generality, it is assumed that $\|H_i^1\|^2 > \|H_i^2\|^2 > \cdots > \|H_i^K\|^2$, where $H_1, H_2, H_3, \ldots, H_K \in \mathbb{C}^{N_r \times N_t}$ are the channel matrix of $u_1^1, u_2^1, u_3^1$, and $u_K^1$, respectively. Thus, the first user is closer to the base station (BS) than other users, and then the BS will allocate less power to the first user as in [9], [30].

Therefore, the received signal of $u_i^1$ is expressed as:

$$y_i^1 = \sqrt{\beta_i^1 P} \left( H_{i,j_i}^l s^1_{i,i} + jH_{l,j_i,k}^l s^1_{i,Q} \right)$$

$$+ \sum_{k=0}^{K} \sqrt{\frac{\beta_i^k P}{\zeta_i^k}} \left( H_{i,k}^l s^1_{i,i} + jH_{l,k,i}^l s^1_{i,Q} \right) + w_i^l,$$

(2)

where $\beta_i^l$ is the power allocation coefficient of $u_i^l$, $\zeta_i^l$ is the number of active TAs of $u_i^l$, $P$ is the total transmitted power, and $y_i^l \in \mathbb{C}^{N_r \times 1}$ is the received signal of $u_i^l$. $H_{i,j_i}^l$ and $H_{l,j_i,k}^l \in \mathbb{C}^{N_r \times 1}$ are the quadrant and in-phase TA of $u_i^l$, respectively. $H_i^l$ and $H_i^l$ are the quadrature and in-phase component of the channel matrix $H_i$ of $u_i^l$, respectively. Furthermore, $\hat{y}_{i,j_i}^l, \hat{y}_{l,k,i}^l, \hat{y}_{l,j_i,k}^l$ are the estimated TAs and symbols of $u_i^l$.

Then, the modified received signal of $u_i^l$ is demodulated by using the ML detection as in [7] for a fair comparison, which can also be represented as:

$$\hat{y}_{i,j_i}^l, \hat{y}_{l,k,i}^l, \hat{y}_{l,j_i,k}^l = \arg \min_{\hat{y}_{i,j_i}^l, \hat{y}_{l,k,i}^l, \hat{y}_{l,j_i,k}^l} \left( \sum_{k=0}^{K} \frac{\beta_i^k P}{\zeta_i^k} \left( H_{i,k}^l s^1_{i,i} + jH_{l,k,i}^l s^1_{i,Q} \right) \right)^2,$$

(5)

where $g_i^l = H_{i,j_i}^l s^1_{i,i} + jH_{l,j_i,k}^l s^1_{i,Q}$. $\hat{y}_{i,j_i}^l, \hat{y}_{l,k,i}^l, \hat{y}_{l,j_i,k}^l$ are the estimated and possible in-phase TA of $u_i^l$, respectively. $\hat{y}_{i,j_i}^l$ and $\hat{y}_{l,k,i}^l$ are the estimated and possible quadrature TA of $u_i^l$, respectively. $\hat{y}_{l,j_i,k}^l$ is the total transmitted power, $\zeta_i^l$ is the number of active TAs of $u_i^l, \zeta_i^l$ and $\zeta_i^l$ are the estimated and possible in-phase TA of $u_i^l$, respectively. $\zeta_i^l$ and $\zeta_i^l$ are the estimated and possible quadrature symbol of $u_i^l$, respectively. $s^1_{i,i}, s^1_{i,Q} \in \mathbb{C}$, and $\mathbb{Q}$ is the set of all APM symbols.

2) DETECTION OF OTHER USERS

$u_i^l$ with a lower power allocation coefficient is highly affected by users with higher power allocation coefficients, so the SIC procedure is required for $u_i^l$ to remove the interference of these users, where $1 \leq i \leq K - 1$. However, $u_i^l$ still regards the previous $i - 1$ users of the same group as the interference with $\mathcal{C}N(0, \sum_{k=1}^{i-1} \beta_i^k P)$ as in [7]. Therefore, after subtracting the interference of these users from the received signal of $u_i^l$, the modified received signal of $u_i^l$ can be derived as in [7]:

$$\tilde{y}_{i,j_i}^l = y_{i,j_i}^l - \sum_{k=i+1}^{K} \sqrt{\frac{\beta_i^k P}{\zeta_i^k}} \left( H_{i,k}^l s^1_{i,i} + jH_{l,k,i}^l s^1_{i,Q} \right),$$

(4)

where $\tilde{y}_{i,j_i}^l$ and $\tilde{y}_{l,k,i}^l \in \mathbb{C}^{N_r \times 1}$ are the modified received signal and the received signal of $u_i^l$, respectively. $\hat{y}_{i,j_i}^l$ and $\hat{y}_{l,k,i}^l$ are the estimated TAs of $u_i^l$, respectively. Furthermore, $\hat{y}_{i,j_i}^l, \hat{y}_{l,k,i}^l, \hat{y}_{l,j_i,k}^l$ are the estimated TA and symbols of $u_i^l$.

III. USER GROUPING SCHEME

In this section, a low-complexity suboptimal user grouping scheme is proposed for QSM-NOMA systems. It is assumed that $N$ users are divided into $\hat{T}$ initial sets $V_i$, and each initial set has $K$ users. It ensures that there are $N$ users with $T$ groups after grouping, where each group includes $K$ users after grouping. In this way, $\hat{T} = K, \hat{T} = T$. Moreover, we suppose that the user can not be selected from the same initial set, and each user is selected only once. The objective is to consider channel conditions, user locations, and channel correlations to reduce the impact of both intra-group interference and inter-group interference. For guaranteeing channel conditions as good as possible, all users have to be listed in descending order by the effective channel gain firstly, and then these users are divided into initial sets successively.
In addition, for guaranteeing user locations as close as possible, we can minimize the chordal distance between two users, which can be expressed as:

\[ d_{a,b} = \left\| H_{a,j_a} I_{a,j_a} - H_{b,j_b} I_{b,j_b} \right\| ^2 , \]  

(6)

where \( d_{a,b} \) is the chordal distance between the \( a^{th} \) user and the \( b^{th} \) user. \( H_{a,j_a} \) is the \( (j_a)^{th} \) column of the channel matrix of the \( i^{th} \) user, \( i = a, b \).

The lower the chordal distance \( d_{a,b} \), the closer the user locations between these two users. Therefore, if we select \( K \) users, including from the \( a^{th} \) user to \( a^{th} \) user, to a group, we can compute the ACD among all users coming from different initial sets, where \( a_i \in V_i \). The ACD for \( K \)-user grouping can be expressed as:

\[ \hat{d}_K = \frac{\sum_{a \in V_i, b \in V_i, i < j \leq K} d_{a,b}}{\binom{K}{2}} , \]  

(7)

where \( \hat{d}_K \) is the ACD among \( K \) users coming from different initial sets. \( \binom{K}{2} \) is the binomial coefficient. This step must ensure that all pairwise combinations of selected users can be considered.

Furthermore, users with higher channel correlations cannot be separated easily, which leads to poor performance. Therefore, in order to ensure that the system performance is high, we have to minimize channel correlations between users in the same group to reduce intra-group interference. The correlation coefficients between different two users can be defined as:

\[ \eta_{a,b} = \frac{\text{cov}(H_{a,j_a}, H_{b,j_b})}{\sqrt{\text{var}(H_{a,j_a}) \cdot \text{var}(H_{b,j_b})}} , \]  

(8)

where \( \eta_{a,b} \) is the correlation coefficient between the \( a^{th} \) user and the \( b^{th} \) user, but we consider only real parts of \( \eta_{a,b} \) for simplicity, \( \text{cov}(\cdot, \cdot) \) is the covariance matrix between different two matrices and \( \text{var}(\cdot) \) is variance.

Similarly, the stronger the correlation coefficient \( \eta_{a,b} \) indicates the stronger channel correlation between these two users. Therefore, if we select \( K \) users, including from the \( a^{th} \) user to \( a^{th} \) user, to a group, we can also compute the average correlation coefficient (ACC) among all users coming from different initial sets, where \( a_i \in V_i' \). The ACC for \( K \)-user grouping can be expressed as:

\[ \hat{\eta}_K = \frac{\sum_{a \in V_i', b \in V_{i'}, i < j \leq K} \eta_{a,b}}{\binom{K}{2}} , \]  

(9)

where \( \hat{\eta}_K \) denotes the ACC among \( K \) users coming from different initial sets.

Therefore, this procedure is listed in Algorithm 1 and will be used in this paper. It is important to note that the optimal user grouping involves \( \sum_{i=1}^{T} \binom{N-(i-1)K}{K} = \frac{(KT)!}{K!} \) possibilities as in [11], but Algorithm 1 is reduced to \( 2K \sum_{i=1}^{T} \binom{T-(i-1)}{1} \) possibilities by minimizing ACD and ACC. Therefore, Algorithm 1 is a low-complexity scheme.

**IV. POWER ALLOCATION SCHEME**

In this section, a power allocation scheme is proposed for QSM-NOMA systems based on various QoS requirements, i.e., the target rate requirement of each user. To determine the power allocation coefficients, a dynamic power allocation scheme based on the target rate of each user for a cooperative network can be extended to the QSM-NOMA system. However, we consider users’ requirements rather than relays’ requirements.

Suppose \( \| H_{1}^1 \|^2 > \| H_{2}^2 \|^2 > \cdots > \| H_{K}^K \|^2 \), and then \( \beta_1^1 < \beta_2^2 < \cdots < \beta_K^K \). In addition, the ASR of the QSM-NOMA system should be defined as: \( R_{\text{sum}} = \sum_{i=1}^{T} \sum_{j=1}^{K} R_i^j \), where \( R_{\text{sum}} \) is the ASR of the QSM-NOMA system and \( R_i^j \) is the achievable rate of \( u_i^j \) as follows:

\[ R_i^j = \begin{cases} \log_2(1 + \frac{(\xi_i^j)^{-1} \beta_i^j P_i^j r_{i,j_k}}{\sigma^2}), & i = 1, \\ \log_2(1 + \frac{\sum_{k=1}^{K} (\xi_k^j)^{-1} \beta_k^j P_i^j r_{i,j_k} + \sigma^2)}, & \text{others,} \end{cases} \]  

(10)

where \( \beta_i^j \) and \( \beta_i^j \) denote the power allocation coefficients of \( u_i^j \) and \( u_i^j \), respectively. \( \xi_i^j \) and \( \xi_k^j \) represent the number of active TAs of \( u_i^j \) and \( u_i^j \), respectively.

Different from the conventional cooperative network, the proposed power allocation scheme ensures that the signal of each user can be correctly decoded at the corresponding receiver rather than at the relay. Therefore, we propose the target-rate constraints, \( R_i^j = \hat{R}_i^j \), which means that each user can correctly detect its TAs and symbols to satisfy its target-rate requirement, where \( \hat{R}_i^j \) is the target rate of \( u_i^j \).
Therefore, users’ target-rate requirements are as follows:

\[
\begin{align*}
R_i^t &= R_i^t, \\
\sum_{i=1}^{K} \beta_i^t &= 1.
\end{align*}
\]  

(11)

After some algebraic manipulations, (11) can be translated as follows:

\[
\begin{align*}
\beta_1^t &= \frac{(2^K_1 - 1)\alpha^2}{(\zeta_1^{l_1})^{-1}P_{\gamma_1}^{l_1},} \\
\beta_2^t &= \frac{(2^K_2 - 1)(\zeta_1^{l_2})^{-1}P_{\gamma_2}^{l_2}, + \sigma^2}{(\zeta_1^{l_2})^{-1}P_{\gamma_2}^{l_2},} \\
\beta_3^t &= \frac{(2^K_3 - 1)(\zeta_1^{l_3})^{-1}P_{\gamma_3}^{l_3}, + \sigma^2}{(\zeta_1^{l_3})^{-1}P_{\gamma_3}^{l_3},} \\
\vdots & \\
\beta_K^t &= \frac{(2^K_K - 1)(\zeta_1^{l_K})^{-1}P_{\gamma_K}^{l_K}, + \sigma^2}{(\zeta_1^{l_K})^{-1}P_{\gamma_K}^{l_K},}, \\
\sum_{i=1}^{K} \beta_i^t &= 1.
\end{align*}
\]  

(12)

When all users meet target-rate requirements, the intragroup interference can be suppressed by SIC, which leads to performance enhancement in terms of BER and ASR.

V. SIMULATION RESULTS

In this section, simulation results are provided to evaluate the effectiveness of the proposed schemes. In considerable systems, there are six groups with two users or there are four groups with three users for a fair comparison [6], [7]. The noise power of all users is \(\sigma^2\). The total power of each group is fixed to 1 for the BER performance [7] and to 5 for the ASR performance [6], [11], respectively. The coordinates of the BS and users of each group are given [7], [10]. In addition, the target rate of each user is assumed to 0.1 bits/s/Hz as in [18] unless otherwise specified. Moreover, all simulation results are averaged over 10,000 random realizations. For simplicity, during simulations, the eight schemes that will be investigated and compared are shown in Table 2. The proposed power allocation in [31] is named as ‘max sum-rate approach’. The fixed approach A denotes that power ratio is \(\beta_1 : \beta_2 = 1 : 9\), the fixed approach B is that power ratio is

\(\beta_1 : \beta_2 = 1 : 4\), and the fixed approach C represents that power ratio is \(\beta_1 : \beta_2 : \beta_3 = 2 : 3 : 45\).

![FIGURE 2. Comparison of the average BER of different systems with K = 2, T = 6, P = 1, a = 3, and R = 4 bits/symbol.](image)

Fig. 2 shows the average BER performance of different two-user systems versus the average transmitted SNR under different schemes. The coordinates of the BS, \(u_1^t\), and \(u_2^t\) are \((0, 0), (0.5 \cos((l - 1)\frac{\pi}{2}), 0.5 \sin((l - 1)\frac{\pi}{2}))\), and \((1.1 \cos((l - 1)\frac{\pi}{2}), 1.1 \sin((l - 1)\frac{\pi}{2}))\), respectively. For a fair comparison, the data rate of all systems is \(R = 4\) bits/symbol and \(M\)-QAM modulation technology will be utilized, where \(M\) is the modulation order. It can be seen that the SM-NOMA system with scheme 1 is superior to the SM-OMA system, but it is a little higher than the NOMA system with scheme 5, especially when the SNR is high. Furthermore, the QSM-NOMA system with scheme 1 outperforms other systems, which is decreased sharply from \(10^{-1}\) in 0 dB to about \(10^{-3}\) in 15 dB. It means that QSM-NOMA systems can improve the average BER performance by using two orthogonal symbols for transmission and the proposed scheme 1 is effective for the QSM-NOMA system.

![FIGURE 3. The average BER of different users of different systems versus the average transmitted SNR.](image)

Fig. 3 presents the average BER performance of each user versus the average transmitted SNR under different systems with different schemes. All considerable systems are the
same as Fig. 2 so simulation parameters are not changed. It is obvious that the average BER of the second user has better performance than that of the first user for the same system. Compared with other systems, the second user of the QSM-NOMA system with scheme 1 has the best performance in the BER. The reason is that the second user has a higher power allocation coefficient so that it can remove the intra-group interference during the SIC-based detection. The NOMA system with scheme 5 is a little higher than the SM-NOMA system with scheme 1 because the latter has the chosen only one TA which leads to deteriorating the BER performance.

Fig. 4 shows the average BER performance of QSM-NOMA systems versus the average transmitted SNR under different schemes. All simulation parameters are the same as Fig. 2 except for $\hat{R}_1 = 0.5, \hat{R}_2 = 0.1$. It is clear that the proposed scheme 1 has the best performance, and scheme 2 has the lowest one. It means the proposed power allocation is effective for QSM-NOMA systems so that it improves the BER performance by satisfying each user’s QoS requirement. Scheme 1 is also higher than scheme 3 and scheme 4, which means the proposed Algorithm 1 is better than the BNWF grouping and the BNBF grouping, respectively. It means that the channel gain, the user location, and the channel correlation can be considered effectively.

Fig. 5 presents the average BER performance of QSM-NOMA systems versus the average transmitted SNR under different antennas and different modulations. All simulation parameters are the same as Fig. 2 except for the modulation orders. It can be seen that the 4QAM modulation is better than 8QAM, which means the BER performance decreases with the increasing modulation order which enlarges the data rate. Another important observation is that $N_r = 8$ scheme is better than $N_r = 4$ scheme. The reason is that the BER performance increases with the increasing number of receive antennas due to an increase in diversity gain.

Fig. 6 shows the average BER performance of different three-user systems versus the average transmitted SNR under different schemes. The coordinates of the BS, $u_1^l, u_2^l$, and $u_3^l$ are $(0, 0), (0.2 \cos[(\ell-1)\frac{\pi}{2}], 0.2 \sin[(\ell-1)\frac{\pi}{2}]), (0.5 \cos[(\ell-1)\frac{\pi}{2}], 0.5 \sin[(\ell-1)\frac{\pi}{2}]),$ and $(1 \cos[(\ell-1)\frac{\pi}{2}], 1 \sin[(\ell-1)\frac{\pi}{2}])$, respectively. For a fair comparison, the data rate of all systems is $R = 4$ bits/symbol. It is obvious that the QSM-NOMA system with scheme 1 has the best performance compared with other systems, which means that the proposed dynamic schemes are more effective than random grouping and fixed power allocation for three-user QSM-NOMA/SM-NOMA systems.

Fig. 7 presents the ASRs of different systems versus the average transmitted SNR under different schemes. It is clear that the QSM-NOMA system with scheme 1 is superior to other systems. The SM-OMA system with scheme 6 has the worst performance in the ASRs. The reason is that QSM-NOMA systems have an attractive tradeoff between complexity and spectral efficiency. Additionally, scheme 1 is more effective than scheme 6.

Fig. 8 shows the achievable rates of first users of different systems versus the average transmitted SNR. All simulation parameters are the same as Fig. 7. It can be seen that the first...
user of the QSM-NOMA system with scheme 1 still has the best performance in the achievable rates. The reason is that there are positive correlations between the achievable rates of first users and the ASRs. Furthermore, the proposed scheme 1 is effective for the proposed QSM-NOMA system.

Fig. 9 presents the achievable rates of second users of different systems versus the average transmitted SNR. All simulation parameters are the same as Fig. 7. Compared with Fig. 8, it is obvious that the achievable rates of second users are inferior to those of first users, which means the ASR performance has mainly benefited from the first user with the highest effective channel gain. The reason is also that the first user with a lower power allocation coefficient can remove the interference of other users by the SIC procedure. Another important observation is that the second user of the QSM-NOMA system has a better performance than the SM-NOMA system and the NOMA system. Additionally, in the SM-OMA system, the achievable rates of different users are the same.

Fig. 10 shows the ASRs of QSM-NOMA systems versus the average transmitted SNR under different schemes. All simulation parameters are the same as Fig. 7. Compared with scheme 2, the proposed scheme 1 has better performance in the ASRs. It means that the proposed power allocation is more effective than the max sum-rate power allocation in [31] for QSM-NOMA systems by considering users’ target-rate requirements. Additionally, the proposed user grouping is a better scheme than the BNWF grouping in [9] and the random grouping by comparing with scheme 3 and scheme 8, respectively. The reason is that, with scheme 1, users are grouped to different groups by considering channel gains, user locations, and channel correlations, which leads to performance enhancement.

Fig. 11 presents the achievable rates of different systems under different power ratios $\beta_1/\beta_2$. All simulation parameters are the same as Fig. 7 except for $\text{SNR}=30$ dB, and scheme 1 (i.e., the proposed Algorithm 1) is utilized. Because the path loss is not considered, it means that the first user maybe not be closer to the BS due to i.i.d. channel realizations. It is obvious that QSM-NOMA systems have the best performance in terms of the achievable rates of second users, which means the performance benefits mainly from the user with a lower power allocation coefficients so that intra-group interference

FIGURE 7. Comparison of the ASRs of different systems with $K = 2$, $T = 6$, $P = 5$, $\alpha = 0$.

FIGURE 8. The achievable rates of first users of different systems versus the average transmitted SNR.

FIGURE 9. The achievable rates of second users of different systems versus the average transmitted SNR.

FIGURE 10. Comparison of the ASRs of QSM-NOMA systems under different schemes.
can be removed by SIC. Furthermore, the achievable rates of second users decrease but the achievable rates of first users increase with the increasing power ratio.

Fig. 12 shows the fairness index versus the power allocation coefficient of the first user under different systems. All simulation parameters are the same as Fig. 11 except for SNR= 1 dB. The fairness can be expressed by the Jain’s fairness index \( J = \frac{1}{T} \sum_{i=1}^{T} \frac{(R_i^1+R_i^2)}{2(R_i^1)^2+2(R_i^2)^2} \) as in [32]. It can be seen that proposed QSM-NOMA systems can achieve the best (close to the best) fairness compared with other systems. By comparing Fig. 7, QSM-NOMA systems can achieve the optimal performance in term of the ASRs while maintaining effectively increased fairness.

**VI. CONCLUSION**

In this paper, we have proposed the QSM-NOMA system, where spatial constellation can be expanded to two orthogonal real (in-phase) and imaginary (quadrature) components. In this way, real and imaginary TAs can send real and imaginary symbols in QSM-NOMA systems, which means that spectral efficiency can be further improved. Moreover, efficient user grouping and power allocation have proposed for QSM-NOMA systems. Therefore, users are firstly grouped into different groups by a low-complexity algorithm and then the suboptimal power allocation scheme is performed in each group. The proposed user grouping is superior to the BNWF grouping and the BNBF grouping because we consider channel conditions, user locations, and channel correlations. The proposed power allocation is more effective than the max sum-rate power allocation for proposed QSM-NOMA systems because all users can meet their target-rate requirements. For a fair comparison, we first consider the two-user QSM-NOMA case in the simulation and also present the results for the three-user case. Simulation results show that the performance of the proposed schemes outperforms that of these existing ones in terms of BER, ASR, and fairness. In the future, the impact of the inter-group interference will be further considered for the proposed system under imperfect CSI, and a power allocation scheme will be designed for QSM-NOMA systems by heuristic algorithms.

**REFERENCES**

[1] M. Renzo, H. Haas, and P. Grant, “Spatial modulation for multi-antenna wireless systems: A survey,” *IEEE Commun. Mag.*, vol. 49, no. 12, pp. 182–191, Dec. 2011.

[2] R. Mesleh, S. S. Ikkii, and H. M. Aggoun, “Quadrature spatial modulation,” *IEEE Trans. Veh. Technol.*, vol. 64, no. 6, pp. 2738–2742, Jun. 2015.

[3] A. Younis, N. Abuzgaia, R. Mesleh, and H. Haas, “Quadrature spatial modulation for 5G outdoor millimeter-wave communications: Capacity analysis,” *IEEE Trans. Wireless Commun.*, vol. 16, no. 5, pp. 2882–2890, May 2017.

[4] I. Al-Nahhal, O. A. Dobre, and S. S. Ikkii, “Quadrature spatial modulation decoding complexity: Study and reduction,” *IEEE Wireless Commun. Lett.*, vol. 6, no. 3, pp. 378–381, Jun. 2017.

[5] L. Dai, B. Wang, Y. Yuan, S. Han, C.-L. I, and Z. Wang, “Non-orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends,” *IEEE Commun. Mag.*, vol. 53, no. 9, pp. 74–81, Sep. 2015.

[6] X. Wang, J. Wang, L. He, Z. Tang, and J. Song, “On the achievable spectral efficiency of spatial modulation aided downlink non-orthogonal multiple access,” *IEEE Commun. Lett.*, vol. 21, no. 9, pp. 1937–1940, Sep. 2017.

[7] X. Zhu, Z. Wang, and J. Cao, “NOMA-based spatial modulation,” *IEEE Access*, vol. 5, pp. 3790–3800, 2017.

[8] X. Wang, J. Wang, L. He, and J. Song, “Spectral efficiency analysis for downlink NOMA aided spatial modulation with finite alphabet inputs,” *IEEE Trans. Veh. Technol.*, vol. 66, no. 11, pp. 10562–10566, Nov. 2017.

[9] M. S. Ali, H. Tabassum, and E. Hossain, “Dynamic user clustering and power allocation for uplink and downlink non-orthogonal multiple access (NOMA) systems,” *IEEE Access*, vol. 4, no. 99, pp. 6325–6343, Aug. 2016.

[10] N. T. T. Do, D. B. Da Costa, T. Q. Duong, and B. An, “A BNWF user selection scheme for NOMA-based cooperative relaying systems with SWIPT,” *IEEE Commun. Lett.*, vol. 21, no. 3, pp. 664–667, Mar. 2017.

[11] J.-M. Kang and I.-M. Kim, “Optimal user grouping for downlink NOMA,” *IEEE Wireless Commun. Lett.*, vol. 7, no. 5, pp. 724–727, Oct. 2018.

[12] J. Nam, A. Adhikary, J.-Y. Ahn, and G. Caire, “Joint spatial division and multiplexing: Opportunistic beamforming, user grouping and simplified downlink scheduling,” *IEEE J. Sel. Topics Signal Process.*, vol. 8, no. 5, pp. 876–890, Oct. 2014.

[13] Z. Lian, L. Jiang, C. He, and D. He, “User grouping and beamforming for HAP massive MIMO systems based on statistical-eigenmode,” *IEEE Wireless Commun. Lett.*, vol. 8, no. 3, pp. 961–964, Jun. 2019.

[14] M. Alkhaled, E. Alsuwa, and W. Pramudito, “Adaptive user grouping algorithm for the downlink massive MIMO systems,” in Proc. *IEEE Wireless Commun. Netw. Conf.*, Doha, Qatar, Apr. 2016, pp. 1–5.
[15] J. Wu, Y. Chang, and M. Hu, “Correlation based user grouping and resource allocation in uplink massive MIMO systems,” in Proc. 15th Int. Symp. Wireless Commun. Syst. (ISWCS), Lisbon, Portugal, Aug. 2018, pp. 1–5.

[16] F. Fang, H. Zhang, J. Cheng, and V. C. M. Leung, “Energy-efficient resource allocation for downlink non-orthogonal multiple access network,” IEEE Trans. Commun., vol. 64, no. 9, pp. 3722–3732, Sep. 2016.

[17] Z. Yang, Z. Ding, P. Fan, and N. Al-Dhahir, “The impact of power allocation on cooperative non-orthogonal multiple access networks with SWIPT,” IEEE Trans. Wireless Commun., vol. 16, no. 7, pp. 4332–4343, Jul. 2017.

[18] T. N. Do, D. B. da Costa, T. Q. Duong, and B. An, “Improving the performance of cell-edge users in MISO-NOMA systems using TAS and SWIPT-based cooperative transmissions,” IEEE Trans. Green Commun. Netw., vol. 2, no. 1, pp. 49–62, Mar. 2018.

[19] X. Li, J. Li, Y. Liu, Z. Ding, and A. Nallanathan, “Residual transceiver hardware impairments on cooperative NOMA networks,” IEEE Trans. Wireless Commun., vol. 19, no. 1, pp. 680–695, Jan. 2020, doi: 10.1109/TWC.2019.2947670.

[20] X. Li, J. Li, and L. Li, “Performance analysis of impaired SWIPT NOMA relaying networks over imperfect Weibull channels,” IEEE Syst. J., to be published, doi: 10.1109/JSYST.2019.2919654.

[21] T. Wang, S. Liu, F. Yang, J. Wang, J. Song, and Z. Han, “Generalized spatial modulation-based multi-user and signal detection scheme for terrestrial return channel with NOMA,” IEEE Trans. Broadcast., vol. 64, no. 2, pp. 211–216, Jun. 2018.

[22] Z. Hong, G. Li, J. Lin, Y. Xu, and X. Zhou, “Power allocation for downlink multiuser NOMA-based generalized spatial modulation,” in Proc. 11th Int. Conf. Wireless Commun. Signal Process. (WCSP), Xi’an, China, Oct. 2019, pp. 1–6.

[23] Y. Xu, G. Li, Y. Yang, M. Liu, and G. Gui, “Robust resource allocation and power splitting in SWIPT enabled heterogeneous networks: A robust min-max approach,” IEEE Internet Things J., vol. 6, no. 6, pp. 10799–10811, Dec. 2019.

[24] F. Kara and H. Kaya, “Performance analysis of SSK-NOMA, IEEE Trans. Veh. Technol., vol. 68, no. 7, pp. 6231–6242, Jul. 2019.

[25] J. W. Kim, S. Y. Shin, and V. C. M. Leung, “Performance enhancement of downlink NOMA by combination with GSSK,” IEEE Wireless Commun. Lett., vol. 7, no. 5, pp. 860–863, Oct. 2018.

[26] R. F. Siregar, N. Rajatheva, and M. Latva-Aho, “QSM based NOMA for multi-user wireless communication,” in Proc. 16th Int. Symp. Wireless Commun. Syst. (ISWCS), Oulu, Finland, Aug. 2019, pp. 1–6.

[27] M. S. Ali, E. Hossain, and D. I. Kim, “Non-orthogonal multiple access (NOMA) for downlink multiuser MIMO systems: User clustering, beamforming, and power allocation,” IEEE Access, vol. 5, pp. 565–577, Dec. 2017.

[28] F. Shu, X. Liu, G. Xia, T. Xu, J. Li, and J. Wang, “High-performance power allocation strategies for secure spatial modulation,” IEEE Trans. Veh. Technol., vol. 68, no. 5, pp. 5164–5168, May 2019.

[29] Z. Yang, Z. Ding, P. Fan, and N. Al-Dhahir, “A general power allocation scheme to guarantee quality of service in downlink and uplink NOMA systems,” IEEE Trans. Wireless Commun., vol. 15, no. 11, pp. 7244–7257, Nov. 2016.