An Efficient Resource Allocation Algorithm for LTE Uplink VMIMO Systems

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Abstract. In this paper, we focus on the joint user grouping and the resource block (RB) allocation algorithm for LTE uplink virtual MIMO systems. Considering the user grouping and joint resource allocation, we construct a VMIMO transmission system model. Based on this system model, we formulate maximizes the sum of system's capacity with the system constrains, which is a complexity optimization problem. Further, to reduce the computational complexity, especially in the case of large number of users and resources, an efficient branch search algorithm using revised simplex method based on bi-direction 0-1 pivot (SM_BD0-1P) is proposed. We evaluate the proposed joint resource allocation algorithms in LTE uplink scenarios and the results show that it achieves good tradeoff between performance and complexity and has better system throughput than the existing algorithms for LTE uplink virtual MIMO systems.

Keywords: VMIMO · User grouping · System throughput · RB allocation · SC-FDMA

1 Introduction

Multiple-input multiple-output (MIMO) communication can obtain multiuser spatial diversity gain [1, 2, 20], which also has the high energy consumption. Thus, the VMIMO-SC-FDMA is proposed for LTE uplink system to achieve the high spectrum efficient performance [3–5, 14, 18, 19]. Further, some works have been performed about the efficient algorithm solving the joint resource allocation in [6–9, 11–13].

In the above articles, the main differences of the algorithms include: whether the number of resources allocated to the user group is flexible, and the calculation of the user group capacity is different. In [13], the number of the resource allocated to user group is fixed, and in [9, 12], the number of the resource allocated to user group is flexible. We also need pay attention on the metric matrix of user grouping for virtual

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MIMO systems. Most of these proposed metric matrixes are derived from the channel capacity [6, 9–11]. In [8], the receive SINR after MMSE equalization and Shannon capacity is used as the user schedule metric. In [9], similar method is adopted for uplink virtual MIMO system with ZF/MMSE/MMSE-SIC linear receiver. However, considering the actual communication systems, BER or SER under given system throughput is usually used as the performance metric at physical layer. In [12, 13], BER is used as a grouping optimization metric, where the BER is evaluated after MMSE linear multiuser equalization. The BER metric in [11] is presented when BPSK is used for modulation and maximal ratio combining is employed for diversity combination.

In comparison with the existing works, our main contributions are as follows: We construct a VMIMO-SC-FDMA transmission system model considering the user grouping and joint resource allocation. Then, we formulate the maximal throughput with BER constraint problem under different transmission constraints to an optimization problem. And then, we propose an efficient branch search algorithm for the optimization problem by using revised simplex method based on bi-direction 0-1 pivot (SM_BD0-1P). As the user and resource numbers increase, the search space becomes very large so that traditional branch-and-bound algorithm is too complex to work efficiently. So, we propose a rapid branch search algorithm using revised simplex method where the search direction is the steepest descent branch with 0-1 pivot. The simulation results have shown the proposed algorithm has better system throughput for LTE uplink virtual MIMO systems.

The rest of this paper is organized as follows. Section 2 gives a brief description of the uplink SC-FDMA multiuser-MIMO system model and presents the optimization object. In Sect. 3, we propose a rapid branch search algorithm for the optimization problem. Simulation results are presented in Sect. 4 and conclusions are drawn in Sect. 5.

2 System Model and Problem Formulation

2.1 System Model

Consider a virtual MIMO uplink system with one base station (BS) where the BS and users are equipped with N_r receive antennas and one transmit antenna, respectively, as shown in Fig. 1.

For an uplink SC-FDMA system with K active users, we write the set of the user groups as:

$$G = \left\{G_1, \cdots, G_i, \cdots, G_{|G|}\right\} \tag{1}$$

where $G_i = \{k_1, k_2, \cdots, k_m\}, 1 \leq k_1 < \cdots < k_m \leq K$ is i-th element in the set G.

Assuming the i-th user group G_i scheduled in c-th consecutive subcarriers, the received signal vector before MIMO detector can be written as:

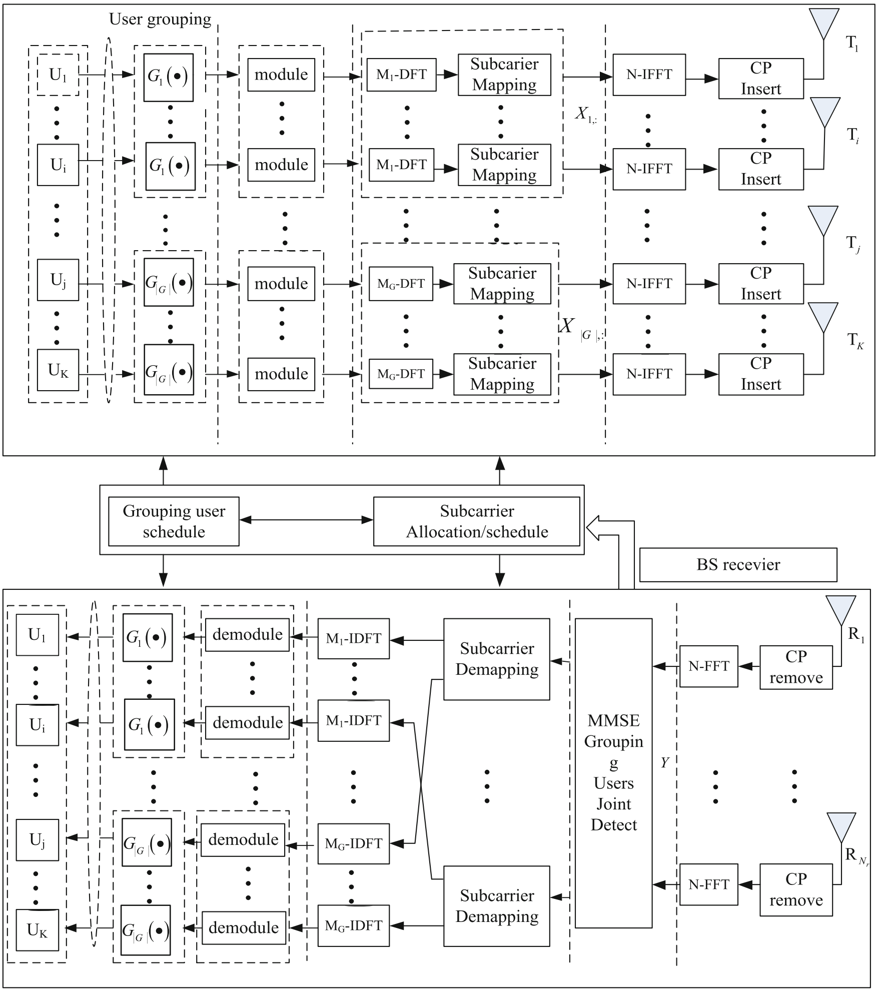

Fig. 1. Block diagram of virtual MIMO for LTE uplink system [12]

$$Y_{i,c} = H_{i,c}X_{i,c} + n_{i,c'} \tag{2}$$

where $H_{i,c}$ is the $N_r \times |U_{G_l}|$ virtual MIMO channel matrix, $X_{i,c}$ is the $|U_{G_l}| \times 1$ transmitting signal vector, $n_{i,c}$ is the $N_r \times 1$ zero-mean additive white Gaussian noise (AWGN) vector with covariance matrix $E\left\{n_{i,c}n_{i,c}^H\right\} = \sigma^2 I_{N_r}$.

At the BS, take the MMSE detector as an example, the detection result can be given as:

$$X_{i,c}^{\text{MMSE}} = (\sigma^2\mathbf{I}_{N_r} + \mathbf{H}_{i,c}^H\mathbf{H}_{i,c})^{-1}\mathbf{H}_{i,c}^H\mathbf{Y}_{i,c} \tag{3}$$

After the subcarrier de-mapping and user de-grouping, the receive data for different users is restored.

2.2 Problem Formulation

According to [12], we can get the user grouping metric matrix based on the above system model. Then, we get the spectral efficiency of user group after MMSE equalization and adaptive modulation (AM) as:

$$R_{G_l}^{\mathrm{MMSE}} = \sum_{k \in U_{G_l}} floor\left(\log_2\left(1 - \frac{1.5SNR_k}{\ln\left(5\mathrm{BER}^{\mathrm{target}}\right)}\right)\right) \tag{4}$$

where $\mathrm{BER}^{\mathrm{target}}$ is the upper bound of the BER for the AWGN channel.

Assume N_{rb} consecutive RBs in LTE uplink is available to allocate to users, similar to [12], we obtain the resource pattern matrix T as:

$$\begin{array}{c} pattern \quad 1 \quad 2 \quad \cdots \quad J \\ T_{N_{RB} \times J} = \begin{bmatrix} 0 & 1 & \cdots & 1 \\ 0 & 0 & \cdots & 1 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} \begin{array}{c} RB_1 \\ RB_2 \\ \cdots \\ RB_{N_{rb}} \end{array} \end{array} \tag{5}$$

In addition, we can obtain the metric matrix M,

$$\begin{array}{c} group\ index \quad 1 \quad 2 \quad \cdots \quad |G| \\ M_{N_{rb} \times |G|} = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & m_{1,|G|} \\ m_{2,1} & m_{2,2} & \cdots & m_{2,|G|} \\ \cdots & \cdots & \cdots & \cdots \\ m_{N_{rb},1} & m_{N_{rb},2} & \ldots & m_{N_{rb},|G|} \end{bmatrix} \begin{array}{c} RB_1 \\ RB_2 \\ \cdots \\ RB_{N_{rb}} \end{array} \end{array}, \tag{6}$$

where the elements $\{m_{i,j}\}$ are calculated according to Eq. (4).

Thus, the transmission rate for *i-th* user group at *j-th* resource pattern can be written as:

$$\eta_{i,j} = sum(M(:, i). \times\ T(:, j)) \tag{7}$$

Define the resource allocation vector $\mathbf{I}$ as: $\mathbf{I} = \left[I_{1,1}, \cdots, I_{|G|,1}, I_{1,2}, \cdots, I_{|G|,2}, \cdots, I_{i,j}, \cdots, I_{|G|,J}\right]^T$, where $I_{i,j} = \{0, 1\}, i = 1, \cdots |G|, j = 1, \cdots, J$, and let the transmission rate vector $\boldsymbol{\eta}$ as $\boldsymbol{\eta} = \left[\eta_{1,1}, \cdots, \eta_{|G|,1}, \eta_{1,2}, \cdots, \eta_{|G|,2}, \cdots, \eta_{i,j}, \cdots, \eta_{|G|,J}\right]^T$

Then, we write the optimization problem as

$$\arg\max_{\mathrm{I}} \left\{\boldsymbol{\eta}^T \mathbf{I}\right\} \tag{8}$$

subject to

$$\text{AC1:} \qquad C_1\mathbf{I} \le 1_{N_{RB}\times 1} \tag{8a}$$

$$\text{AC2:} \qquad C_2\text{I} \le 1_{K\times 1} \tag{8b}$$

$$\text{AC3:} \qquad I_{i,j} = \{0,1\}, i = 1,\cdots|G|, j = 1,\cdots,J \tag{8c}$$

where $C_1 = T \otimes 1_{1\times|G|}$, $C_2 = 1_{1\times J} \otimes B$.

The objectives in problem (8) is to maximize the total throughput. AC1 is to ensure that each RB can only be allocated to one user group, AC2 is to ensure that each user can occupy one resource pattern at most.

As described above, computing burden of this problem increases heavily with the number of users, RBs and grouping users. Then, we design an algorithm reduce computational complexity.

3 Proposed Algorithm

The optimization problem (8) is typical binary integer programming problem. So it is suitable to be converted to Office Assignment Problem (OAP) [15] and use a linear programming (LP)-based branch-and-bound (BNB) algorithm to solve the problem. However, branch-and-bound algorithm is too complex and not practical when user and resource number become large.

3.1 Proposed Algorithm to the Optimization Problems

In order to reduce the algorithm complexity, we convert the optimization problem (8) to following normalized form

$$\min \quad \mathbf{C}^{\mathrm{T}}\mathbf{x} \tag{9}$$

subject to

$$\begin{array}{c} \mathbf{Ax} \le \mathbf{b} \\ x_i = \{0,1\},\ (\mathbf{b})_i = 1 \end{array} \tag{9a}$$

Where, **x** is the solution variable vector which represents the persons are assigned to the office or not, **C** is weight vector for assignment, **A** is equality or inequality constraint matrix, and **b** is equality or inequality limit vector.

For optimization problem (9), we propose a revised simplex method based on bi-direction 0-1 pivot (SM_BD0-1P) for efficient branch search of the solution. The flow chat providing the detailed description of the proposed algorithm is shown in Fig. 2.

The search space of the revised simplex method based on 0-1 pivot is shown in Fig. 2, where $\{X_B, X_N\}$ is the basic feasible variable set and $\{X_B, X_N\}_{(i,j)}$ represents the j-th node in level i of the branch-tree. The number of nodes in layer i is $\frac{n!}{(n-i)!}$. In each node, X_N is the non-basic variable set, X_B is the basic variable set, and {+m} represents x_m enter the basic variable set. As leaving variable is one and only, they are not marked in the tree nodes.

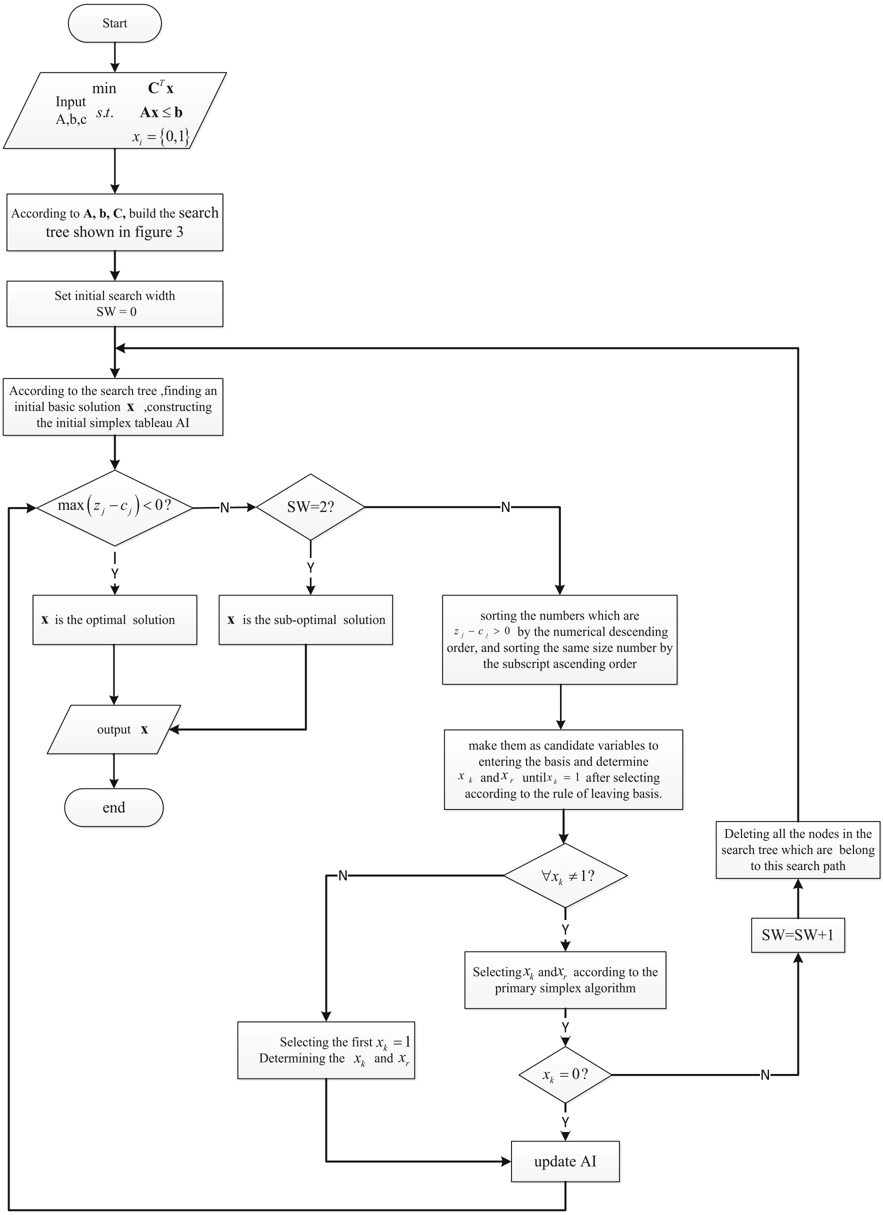

Fig. 2. Flow chart of the SM_BD0-1P algorithm (search width SW = 2)

The algorithm is put forward on the basis of the simplex algorithm [16]. The initial basis variable is artificial variable set. The branch search determination makes use of $\Delta f = f - f_0 = -(z_k - c_k)x_k$. Only the non-basic variable with $z_k - c_k > 0$ is selected as entering variable during each pivot. For $x_k \in \{0, 1\}$, two directions are searched in algorithm. The top priority one is the steepest descent direction with $x_k = 1$, and the second one is the translation direction with $x_k = 0$. So, it is a rapid local search along 0-1 steepest descent branch until the deepest node. The next branch searching process is implemented after the previous searching branch is deleted. The number of search branches depends on the preset search width, and the optimum solution is obtained after all branches in the search tree are traversed (Fig. 3).

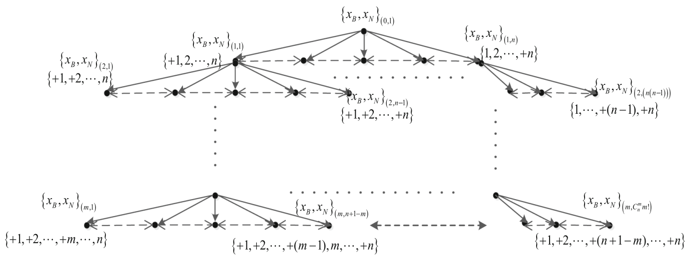

Fig. 3. illustration of search tree for the revised simplex method based on 0-1 pivot

3.2 The Complexity Analysis and the Performance of the Proposed Algorithm

To compare the performance of proposed algorithm with BNB's, we take problem (8) as an example. The search width (SW) of SM_BD0-1P algorithm is set to 1 and 2. From Fig. 4, we can see that the curves of SM_BD0-1P algorithm is very close to the BNB's. The reason is that the non-basic variable number is much larger than basic variable number so that very wide scopes of combinations are considered in each pivot process, and then the optimal solution can often be obtained. In the problem (9), the non-basic variable number is $\{|G|J - (K + N_{RB})\} = \left\{ \left(\sum_{m=1}^{N_r} C_K^m \right) \left[\frac{N_{RB}(N_{RB}+1)}{2} + 1 \right] - (K + N_{RB}) \right\}$ which is much larger than basic variable number of $\{K + N_{RB}\}$ when user and RB number is big. So, the proposed SM_BD0-1P algorithm is suitable to solve the dynamic user grouping and joint resource allocation optimization problems which may involve large number of users and RBs. In the following simulations, we use SM_BD0-1P algorithm to solve the joint resource allocation problems and set search width to 1.

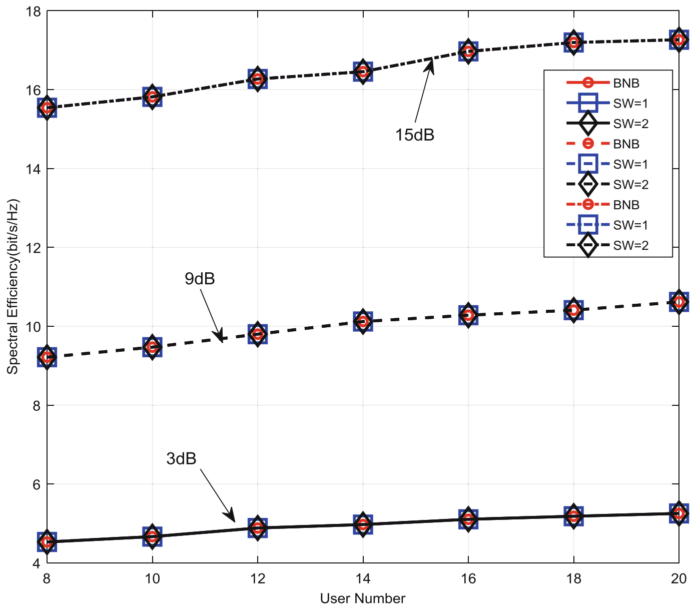

Fig. 4. Performance comparison between BNB and SM_BD0-1P with different user numbers

4 Simulation Results

4.1 Overall Simulation Design

To evaluate the performance of the proposed algorithm, we conduct the simulations based on LTE uplink and list the simulation parameters in Table 1. In addition, we adopt the pedestrian test environment channel A as suggested by ITU-R M.1225 [17].

Table 1. Simulation parameters

Channel parameters	Channel model: ITU Ped-A	Carrier frequency: 2 GHz
	Sampling frequency: 1.92 MHz	Maximum doppler shift: 10 Hz
Simulation parameters	FFT size: 128	Modulation: 16-QAM
	N_{RB}: 6	N_{sc}^{RB}: 12
	OFDM symbols per frame: 14	RB configure: 12 × 7
	Number of users: 20	MIMO detector: MMSE
	UE transmit antenna number: 1	BS receive antenna number: 4
	TTI duration: 1 ms	Simulation frames: 1000

4.2 Simulation Results of the Throughput Performance

For comparison purpose, three joint resource allocation algorithms with user grouping are implemented in this section. First one is the algorithm proposed in [9], denoted as

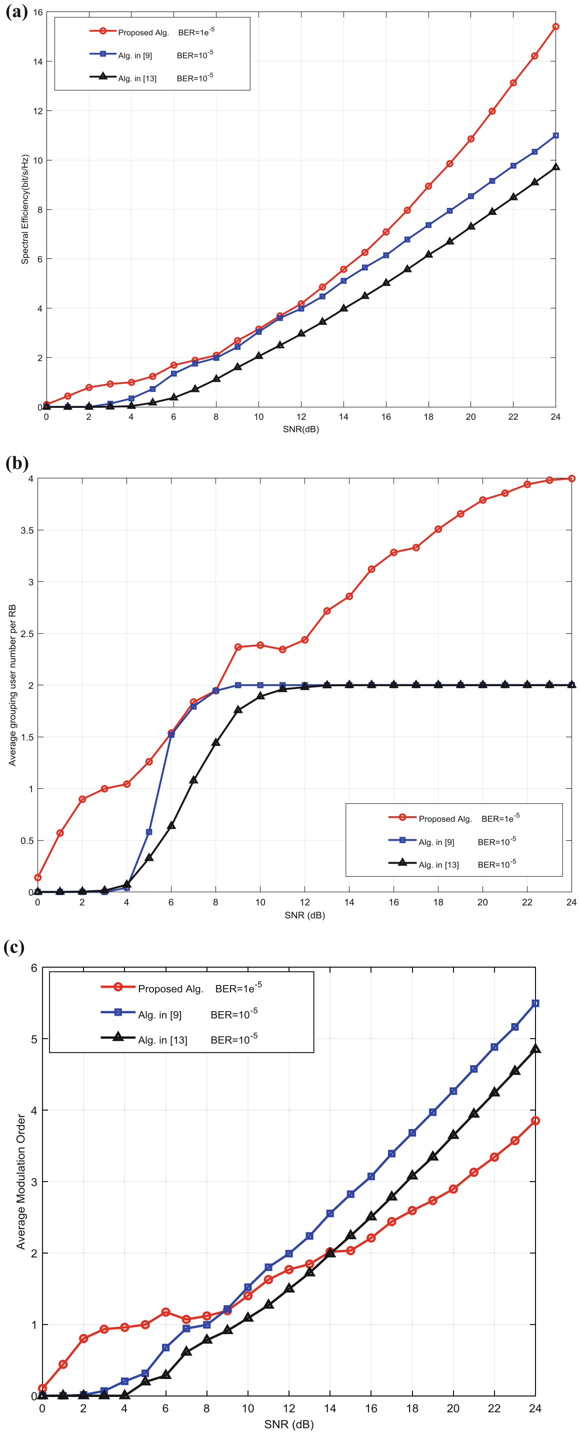

Fig. 5. (a) Spectral efficiency versus SNR for different algorithms using AM technique (b) Average grouping user number versus SNR for different algorithms using AM technique (c) Average modulation order versus SNR for different algorithms using AM technique

'Alg. in [9]'; second one is the algorithm proposed in [13], denoted as 'Alg. in [13]'; last one is the algorithm proposed in this paper, denoted as 'Proposed Alg.'.

To evaluate the proposed algorithm in actual systems, we simulate the algorithm using Eq. (4). For ease of comparison, we modify algorithms in [9, 13] by using AM technique. The results are shown in Fig. 5(a), (b) and (c). As expected, the proposed algorithm achieves the highest spectral efficiency due to the multiuser diversity gain and the joint resource allocation gain. The results of average user grouping number and modulation order per RB are shown in Fig. 5(b) and (c) respectively. Given a BER constraint, the spectral efficiency increases with the increasing of SNR, which dues to adaptive modulation and adaptive user grouping on each RB.

The average user grouping number can be considered as spatial multiplex gain in the system. In the low SNR region, mobile users cannot work normal in 'Alg. in [9]' and 'Alg. in [13]' due to the BER constraints while they can work under single-user mode in proposed algorithm. On the other hand, in the high SNR region, mobile users work under 2-user group mode in 'Alg. in [9]' and 'Alg. in [13]' while they can work under multi-user group mode which is up to 4. At the same time, the modulation order increases with the increasing increase of SNR. Though the modulation order growth rate of proposed algorithm is slower than that of the 'Alg. in [9]' and 'Alg. in [13]', the joint growth rate from spatial multiplex and modulation order of proposed algorithm is faster than other two algorithms, which is shown in Fig. 5(a).

5 Conclusions

In this paper, we investigate the dynamic user grouping and joint resource allocation in uplink SC-FDMA systems. Through the consideration of both system throughput and the receive signal detection performance, we derive the dynamic user grouping criteria and propose adaptive resource allocation algorithm for Shannon capacity and actual throughput with AM techniques. The simulation results demonstrate that the proposed algorithm attain better system throughput than conventional algorithm.

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