

# Joint User Grouping and Antenna Selection Based Massive MIMO Zero-Forcing Beamforming

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**Abstract.** In massive MIMO systems where the number of antennas at base station (BS) is larger than that of users, the existing beamforming schemes generally choose all users as receivers. However, due to the fact that the various channels may be significantly different, the existing schemes are not appropriate for the condition where the number of users becomes large, the system throughput is not optimal at that condition with transitional scheme. In addition, if a large number of antennas equipped at BS are selected to transmit data streams, the requirement of the hardware complexity will become higher, which results in the waste of RF links and transmit power. In this paper, a new zero-forcing beamforming algorithm is proposed based on joint user grouping and antenna selection for massive MIMO systems. When the number of antennas at BS and that of the users in the cell are large, we will deal with the antennas and the users. The simulation results show that the proposed algorithm provides a better trade-off between rate performance and hardware complexity in massive MIMO systems.

**Keywords:** Massive MIMO · User grouping · Antenna selection · Zero-forcing beamforming · Hardware complexity

## 1 Introduction

The basic characteristic of massive MIMO is that a base station (BS) equipped with multiple antennas serves a number of users. Compared with the number of antennas in 4G, which is utmost four for LTE and up to eight for LTE-A, the number of antennas of massive MIMO systems increases by one or two orders of magnitude [1, 2]. The users located in the coverage of BS use the degrees of freedom provided by large scale antennas to simultaneously communicate with BS in the same time-frequency resource, which not only significantly increases the throughput [3, 4], and improves the spectrum efficiency by orders of magnitude [5–7] to solve the problem of limited spectrum resources, but also reduces the interference and enhances the robustness of the system [8, 9]. Meanwhile,

diversity gain and array gain it provides enable us to reduce the transmitted power and improve power efficiency significantly [10, 11].

The BS is equipped with orders of magnitude more antennas, e.g., one hundred or more. On one hand, in order to support transmission through a large-scale antenna array, the massive MIMO system requires high hardware complexity in digital and RF/analog domains [12]. Thus, it consumes more energy than conventional small-scale MIMO technologies. So it is particularly necessary to look for an antenna selection technology with low-cost and low-complexity. In the system, some channels contribute little for throughput because of the difference of channel state information, that inevitably results in the waste of RF chains and transmit power without selecting effective channels for transmission. On the other hand, when the number of users is large, selecting all users as receivers may be unable to achieve the highest system throughput, due to the fact that the various channels may be significantly different. That means some processing schemes are necessary for the users, such as user grouping. By the reason of some users' channel conditions being superior to others, only sending the signal to the user group with better channel conditions at any moment can improve the efficiency of resource allocation and the system capacity or rate performance.

In this paper we propose a new zero-forcing beamforming algorithm based on joint user grouping and antenna selection for massive MIMO system. On one hand in the cell, we divided all users into two groups: one group contains the target users to receive signal, and the other for users is in idle mode, not to receive signal. With an aim to achieve a higher sum rate by selecting the users with a better channel condition. On the other hand at the BS, we process the transmit antennas by selecting an optimal antenna combination for each transmit data stream, in order that we can obtain the lower complexity of hardware with a little loss of performance, further lower RF circuit cost and save power consumption in massive MIMO systems.

**Notations:** Boldface lower and upper case symbols represent vectors and matrices, respectively. The transpose and Hermitian transpose operators are denoted by  $(\cdot)^T$  and  $(\cdot)^H$ , respectively. The Moore-Penrose pseudoinverse operator is denoted by  $(\cdot)^{-1}$ . The 0-norm and 2-norm of a vector is denoted by  $\|\cdot\|_0$  and  $\|\cdot\|_2$  or  $\|\cdot\|$ , respectively. The size of a set is denoted by  $|\cdot|$ .

## 2 System Model

Consider a single cell quasi-static flat-fading MIMO downlink channel with  $N$  transmit antennas at BS serving  $M$  single antenna users ( $N \geq M$ ). Let  $\mathbf{H} = [\mathbf{h}_1^H, \mathbf{h}_2^H, \dots, \mathbf{h}_M^H]^H \in \mathbb{C}^{M \times N}$  be the channel matrix of all users, where  $\mathbf{h}_k = [h_{k1}, h_{k1}, \dots, h_{kN}] \in \mathbb{C}^{1 \times N}$  is the channel vector of user  $k$ . Generally, the system operates in TDD mode to obtain the perfect downlink channel state information (CSI) from the uplink CSI, relying on reciprocity between the uplink and downlink channels.

Assume  $\mathbb{U}_{\text{all}} = \{1, 2, \dots, M\}$  is the set of indexes of all users in the cell, and  $\mathbb{S} = \{\pi(1), \pi(2), \dots, \pi(|\mathbb{S}|)\}$  is the set of indexes of the optimal users selected to receive signals, for any  $\mathbb{S} \subset \mathbb{U}_{\text{all}}$ , where  $\pi(i)$  is the  $i$ -th element of the optimal user index set  $\mathbb{S}$ , and the  $\pi(i)$ -th element of  $\mathbb{U}_{\text{all}}$ , corresponding to the  $\pi(i)$ -th user in the cell. Denote  $|\mathbb{S}|$  as the size of set  $\mathbb{S}$ , that is the number of optimal users. The transmit signal vector  $\mathbf{x}$  is a linear combination of all selected users data streams  $\mathbf{s}$  with the zero-forcing beamforming (ZFBF) matrix  $\mathbf{W}_{\mathbb{S}}$ , constructed as

$$\mathbf{x} = \mathbf{W}_{\mathbb{S}} \mathbf{P}_{\mathbb{S}}^{\frac{1}{2}} \mathbf{s} = \sum_{i=1}^{|\mathbb{S}|} \mathbf{w}_{\pi(i)} \sqrt{p_i} s_i, \tag{1}$$

where  $\mathbf{W}_{\mathbb{S}} = [\mathbf{w}_{\pi(1)}, \mathbf{w}_{\pi(2)}, \dots, \mathbf{w}_{\pi(|\mathbb{S}|)}] \in \mathbb{C}^{N \times |\mathbb{S}|}$  is the ZFBF weight matrix for the optimal users, with  $\mathbf{w}_{\pi(i)} = [w_{\pi(i)1}, w_{\pi(i)2}, \dots, w_{\pi(i)N}]^T \in \mathbb{C}^{N \times 1}$ .  $p_i$  is the transmit power scaling factor for  $\mathbf{P} = \text{diag}(p_1, p_2, \dots, p_{|\mathbb{S}|})$  and  $\mathbf{s}$  is the symbol vector at the transmitter. So the received vector for the optimal user set is

$$\mathbf{y} = \mathbf{H}_{\mathbb{S}} \mathbf{x} + \mathbf{n} = \mathbf{H}_{\mathbb{S}} \mathbf{W}_{\mathbb{S}} \mathbf{P}_{\mathbb{S}}^{\frac{1}{2}} \mathbf{s} + \mathbf{n}, \tag{2}$$

where  $\mathbf{H}_{\mathbb{S}} = [\mathbf{h}_{\pi(1)}^H, \mathbf{h}_{\pi(2)}^H, \dots, \mathbf{h}_{\pi(|\mathbb{S}|)}^H]^H \in \mathbb{C}^{|\mathbb{S}| \times N}$  is the channel matrix of the optimal users, and  $\mathbf{h}_{\pi(i)} = [h_{\pi(i)1}, h_{\pi(i)2}, \dots, h_{\pi(i)N}] \in \mathbb{C}^{1 \times N}$ .  $\mathbf{n} = [n_1, n_2, \dots, n_{|\mathbb{S}|}]^H \in \mathbb{C}^{|\mathbb{S}| \times 1}$  is white Gaussian noise with zero mean and unit variance, that is  $\mathbf{n} \sim CN(0, 1)$ . Specifically, the received signal at user  $i$  is given by

$$y_i = \mathbf{h}_{\pi(i)} \mathbf{w}_{\pi(i)} \sqrt{p_i} s_i + \sum_{l=1, l \neq i}^{|\mathbb{S}|} \mathbf{h}_{\pi(i)} \mathbf{w}_{\pi(l)} \sqrt{p_l} s_l + n_i. \tag{3}$$

The ZF beamforming matrix is

$$\mathbf{W}_{\mathbb{U}} = [\mathbf{w}_{\pi(1)}, \mathbf{w}_{\pi(2)}, \dots, \mathbf{w}_{\pi(|\mathbb{U}|)}] = \mathbf{H}_{\mathbb{U}}^H (\mathbf{H}_{\mathbb{U}} \mathbf{H}_{\mathbb{U}}^H)^{-1}, \tag{4}$$

where  $\mathbb{U} = [\pi(1), \pi(2), \dots, \pi(|\mathbb{U}|)]$  is the index set of users to be selected, with  $\mathbb{U} \subset \mathbb{U}_{\text{all}}$ . And the initial  $\mathbb{U}$  represents all users, that means  $\mathbb{U} = \mathbb{U}_{\text{all}}$ . Similarly, the channel matrix and beamforming matrix for  $\mathbb{U}$  are  $\mathbf{H}_{\mathbb{U}} = [\mathbf{h}_{\pi(1)}^H, \mathbf{h}_{\pi(2)}^H, \dots, \mathbf{h}_{\pi(|\mathbb{U}|)}^H]^H \in \mathbb{C}^{|\mathbb{U}| \times N}$  and  $\mathbf{W}_{\mathbb{S}} = [\mathbf{w}_{\pi(1)}, \mathbf{w}_{\pi(2)}, \dots, \mathbf{w}_{\pi(|\mathbb{U}|)}] \in \mathbb{C}^{N \times |\mathbb{U}|}$ . Assuming that  $\mathbb{U} \setminus \{n\}$  denotes the new set that deletes the element  $n$  from the set  $\mathbb{U}$ ,  $\mathbf{H}_{\mathbb{U} \setminus \{n\}}$  is the row-reduced channel matrix of all the selected users except user  $n$  and  $\mathbf{W}_{\mathbb{U} \setminus \{n\}}$  is the column-reduced beamforming matrix. The sum rate of the user set  $\mathbb{U}$  is:

$$\begin{aligned} R(\mathbb{U}) &= \log_2[\det(\mathbf{I}_{\mathbb{U}} + \mathbf{H}_{\mathbb{U}} \mathbf{W}_{\mathbb{U}} \mathbf{P}_{\mathbb{U}} \mathbf{W}_{\mathbb{U}}^H \mathbf{H}_{\mathbb{U}}^H)] \\ &= \sum_{\substack{\pi(i) \in \mathbb{U}, \\ p_i: \sum_{\pi(i) \in \mathbb{U}} \lambda_i^{-1} p_i \leq P}} \log_2(1 + p_i), \end{aligned} \tag{5}$$

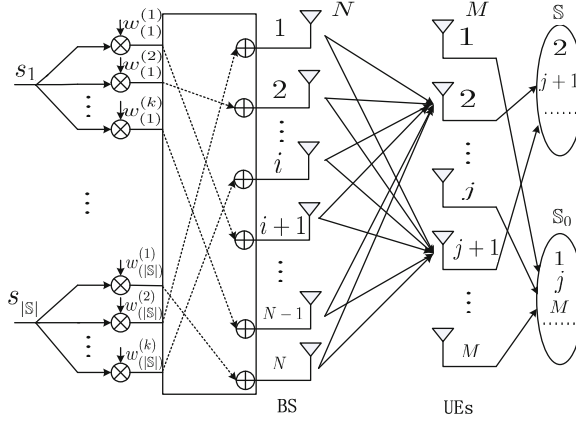
where

$$\lambda_i = \frac{1}{\|\mathbf{w}_i\|^2}, \tag{6}$$

is the effective channel gain of user  $\pi(i)$  [14], and  $\lambda_i^{-1}p_i$  is the transmit power allocated to user  $\pi(i)$ , the optimal power scaling factor  $p_i$  can be found by waterfilling and  $P$  represents the total transmit power.  $\mathbf{I}_{\mathbb{U}}$  is the  $|\mathbb{U}| \times |\mathbb{U}|$  identity matrix.

### 3 Joint Beamforming Algorithm

Joint user grouping and antenna selection beamforming algorithm is proposed in this paper for massive MIMO transmission systems, as shown in Fig. 1. In this scheme, we consider combining schemes of user grouping within a cell and antenna selection at BS, which means that at the side of the cell all users are divided into two groups: one group is selected to receive signal, namely the target user set  $\mathbb{S}$ , and the other group is not, as  $\mathbb{S}_0$ ; at the same time selecting antennas at BS for transmission significantly reduces the hardware complexity with a little loss of system performance.



**Fig. 1.** Illustration of joint user grouping and antenna selection ZF beamforming algorithm

The design problem is formulated as follows.

$$\text{maximize } R(\mathbb{U}) \quad (7)$$

$$\text{subject to } \mathbb{U} \subset \mathbb{U}_{\text{all}} \quad (8)$$

$$\|\mathbf{w}_{\pi(i)}\|_0 = k, \quad i = 1, 2, \dots, |\mathbb{S}| \quad (9)$$

$$\sum_{i=1}^{|\mathbb{S}|} \|\mathbf{w}_{\pi(i)}\|_2^2 p_i \leq P, \quad i = 1, 2, \dots, |\mathbb{S}| \quad (10)$$

where (8) is the constraint of user grouping, and (9) and (10) are respectively the constraints of antenna selection. The 0-norm in (9) represents that in the

set each column of the beamforming matrix has  $k$  nonzero elements and all the rest elements are zero, that means the number of transmit antennas selected at BS. Equation (10) stands for the power constraints.

### 3.1 User Grouping at the Receiver Side

The proposed scheme at the receiver side uses a decremental user grouping scheme, which means deleting the user with the minimum effective channel gain of the beamforming matrix per iteration. The algorithm works as follows: it starts by selecting all users as the target users to receive signal, then deletes the user with the minimum effective channel gain  $\lambda_n$  per iteration until the sum rate increment  $\Delta R = R(\mathbb{U} \setminus \{n\}) - R(\mathbb{U}) < 0$ , and subsequently calculates the set  $\mathbb{S}$  of indexes of optimal users and the ZF beamforming matrix  $\mathbf{W}_{\mathbb{S}}$ . The power allocation matrix  $\mathbf{P}_{\mathbb{S}}$  is given by waterfilling in previous section.

Without the constraints (9) and (10) in user grouping, we only need consider:

$$\begin{aligned} & \text{maximize} \quad R(\mathbb{U}) \\ & \text{subject to} \quad \mathbb{U} \subset \mathbb{U}_{\text{all}} \end{aligned}$$

The set of users indexes to be selected will change because of deleting the user with the minimum effective channel gain. Denote the updated set of indexes of the users  $\mathbb{U}$  as  $\tilde{\mathbb{U}}$ , and  $\tilde{\mathbb{U}} = \mathbb{U} \setminus \{n\}$ . The beamforming vector  $\mathbf{w}_i$  can be obtained through the effective channel vector (ECV)  $\mathbf{v}_i$  defined by [13]

$$\mathbf{v}_i = \mathbf{h}_i \mathbf{P}_i^\perp, \tag{11}$$

$$\mathbf{w}_i = \frac{\mathbf{v}_i^H}{\|\mathbf{v}_i\|^2}, \tag{12}$$

where  $\mathbf{P}_i^\perp = \mathbf{I}_N - \mathbf{H}_{\mathbb{U} \setminus \{i\}}^H (\mathbf{H}_{\mathbb{U} \setminus \{i\}} \mathbf{H}_{\mathbb{U} \setminus \{i\}}^H)^{-1} \mathbf{H}_{\mathbb{U} \setminus \{i\}}$  is the orthogonal projector matrix on the subspace  $\mathbf{V}_n = \text{span}\{\mathbf{h}_j | j \in \mathbb{U}, j \neq n\}$ . The effective channel gain of user  $i$  is  $\lambda_i = \|\mathbf{v}_i\|^2$ . The updated effective channel vector is given by

$$\begin{aligned} \tilde{\mathbf{v}}_i &= \mathbf{h}_i (\mathbf{I}_N - \mathbf{H}_{\mathbb{U} \setminus \{i\}}^H (\mathbf{H}_{\mathbb{U} \setminus \{i\}} \mathbf{H}_{\mathbb{U} \setminus \{i\}}^H)^{-1} \mathbf{H}_{\mathbb{U} \setminus \{i\}}) \\ &= \mathbf{h}_i \begin{bmatrix} \mathbf{v}_i^H & \mathbf{v}_n^H \end{bmatrix} \begin{bmatrix} \mathbf{v}_i \mathbf{v}_i^H & \mathbf{v}_i \mathbf{v}_n^H \\ \mathbf{v}_n \mathbf{v}_i^H & \mathbf{v}_n \mathbf{v}_n^H \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{v}_i \\ \mathbf{v}_n \end{bmatrix} \\ &= \begin{bmatrix} \mathbf{h}_i \mathbf{v}_i^H & 0 \end{bmatrix} \frac{1}{\|\mathbf{v}_i\|^2 \|\mathbf{v}_n\|^2 - \|\mathbf{v}_i \mathbf{v}_n^H\|^2} \\ &\quad \cdot \begin{bmatrix} \mathbf{v}_n \mathbf{v}_n^H & -\mathbf{v}_i \mathbf{v}_n^H \\ -\mathbf{v}_n \mathbf{v}_i^H & \mathbf{v}_i \mathbf{v}_i^H \end{bmatrix} \begin{bmatrix} \mathbf{v}_i \\ \mathbf{v}_n \end{bmatrix} \\ &= \frac{\|\mathbf{v}_i\|^2 \|\mathbf{v}_n\|^2}{\|\mathbf{v}_i\|^2 \|\mathbf{v}_n\|^2 - \|\mathbf{v}_i \mathbf{v}_n^H\|^2} (\mathbf{v}_i - \frac{\mathbf{v}_i \mathbf{v}_n^H}{\|\mathbf{v}_n\|^2} \mathbf{v}_n), \end{aligned} \tag{13}$$

So the updated effective channel gain and effective channel vector are respectively:

$$\begin{aligned}\tilde{\lambda}_i = \|\tilde{\mathbf{v}}_i\|^2 &= \lambda_i \frac{\|\mathbf{v}_i\|^2 \|\mathbf{v}_n\|^2}{\|\mathbf{v}_i\|^2 \|\mathbf{v}_n\|^2 - \|\mathbf{v}_i \mathbf{v}_n^H\|^2}, \\ &= \frac{\lambda_i^2 \lambda_n}{\lambda_i \lambda_n - \|\mathbf{v}_i \mathbf{v}_n^H\|^2},\end{aligned}\quad (14)$$

$$\tilde{\mathbf{v}}_i = \frac{\lambda_i \lambda_n}{\lambda_i \lambda_n - \|\mathbf{v}_i \mathbf{v}_n^H\|^2} \left( \mathbf{v}_i - \frac{\mathbf{v}_i \mathbf{v}_n^H}{\lambda_n} \mathbf{v}_n \right). \quad (15)$$

By plugging  $\mathbf{w}_i = \frac{\mathbf{v}_i^H}{\|\mathbf{v}_i\|^2}$  and  $\lambda_i = \|\mathbf{v}_i\|^2$  into (14) and (15), we can get the updated  $\tilde{\lambda}_i$  based on the beamforming vector  $\mathbf{w}_i$  as

$$\tilde{\lambda}_i = \frac{\lambda_i}{1 - \lambda_n \lambda_i |\mathbf{w}_n^H \mathbf{w}_i|^2}, \quad (16)$$

$$\tilde{\mathbf{w}}_i = \mathbf{w}_i - \lambda_n \mathbf{w}_n^H \mathbf{w}_i \mathbf{w}_n. \quad (17)$$

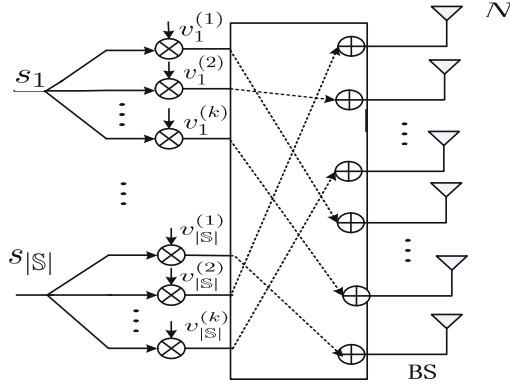
### 3.2 Antenna Selection at BS

Based on the proposed user grouping algorithm, the strategy of antenna selection is considered in this subsection for designing the joint scheme. A major critical factor in increasing the number of antennas in massive MIMO system is the cost of the RF chain consisting of low noise amplifiers, mixers and analog to digital converters (ADCs) and the hardware complexity we want to reduce mainly lies in the number of ADCs in this paper. In the proposed beamforming scheme, each of the data streams for MIMO transmission is multiplied by  $k$  complex gains and assigned to  $k$  out of the available transmit  $N$  antennas, and signals assigned to the same transmit antenna are added and transmitted through the assigned antenna as shown in Fig. 2. That means each of the channel beamforming column vectors has  $k$  nonzero elements and all the rest elements are zero. The main difficulty in this beamformer design lies in finding  $k$  best antennas for each data stream.

The best way of finding  $k$  would be the exhaustive search method, i.e., selecting a best one from all the possible antenna combinations to maximize the throughput. However, because the complexity order of this optimal method is  $O((C_N^k)^M)$ , which requires  $C_N^k$  operations per section, the larger the number of antennas, the higher the complexity, which results in that the actual system cannot realize the data real-time processing. In this paper the algorithm we proposed uses the maximum correlation method (MCM) based on vector modulus. Compared with the exhaustive search method, the algorithm reduces the computational complexity with the feasible realization of antenna selection.

The sum rate with antenna selection is:

$$R(\mathbb{S}) = \log_2[\det(\mathbf{I}_{|\mathbb{S}|} + \mathbf{H}_{\mathbb{S}} \mathbf{W}_{\mathbb{S}} \mathbf{P}_{\mathbb{S}} \mathbf{W}_{\mathbb{S}}^H \mathbf{H}_{\mathbb{S}}^H)], \quad (18)$$



**Fig. 2.** The antenna selection architecture at BS for massive MIMO

where,  $\mathbf{H}_{\mathbb{S}}$  is the channel matrix,  $\mathbf{W}_{\mathbb{S}}$  is the beamforming matrix for the set of the optimal users, and  $\mathbf{P}_{\mathbb{S}}$  is the transmit power scaling matrix for the optimal users.

The maximum correlation method is formulated as follows:

$$\text{maximize } |\langle \boldsymbol{\psi}_i, \mathbf{w}_{\pi(i)} \rangle| \tag{19}$$

$$\text{subject to } \|\mathbf{w}_{\pi(i)}\|_0 = k, i = 1, 2, \dots, |\mathbb{S}|, \tag{20}$$

$$\sum_{i=1}^{|\mathbb{S}|} \|\mathbf{w}_{\pi(i)}\|_2^2 p_i \leq P, i = 1, 2, \dots, |\mathbb{S}|, \tag{21}$$

where  $|\langle \cdot, \cdot \rangle|$  denotes the inner product operation and  $\boldsymbol{\psi}_i = [\psi_{i1}, \psi_{i2}, \dots, \psi_{iN}]^H$  is the first  $k$  beamforming vector.

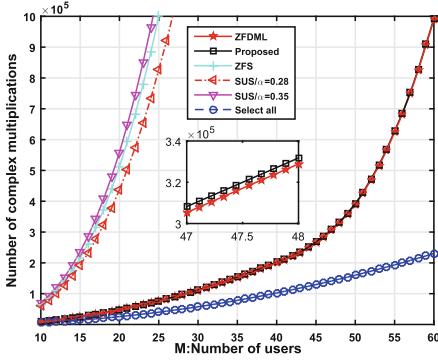
The solution to the MCM problem is to select the first  $k$  largest absolute values of elements of the beamforming vectors:

$$\boldsymbol{\psi}_{ij} = \begin{cases} \mathbf{w}_{\pi(i)j}, & i \in 1, 2, \dots, |\mathbb{S}|, \quad j \in \mathcal{K} \\ 0, & \text{otherwise} \end{cases}, \tag{22}$$

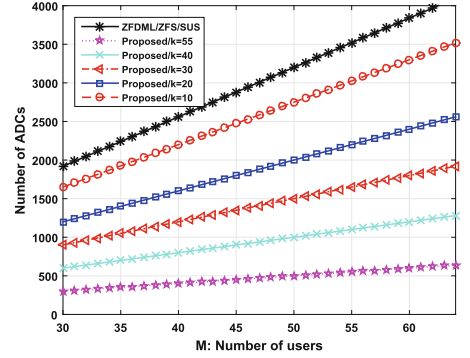
where  $\mathcal{K}$  is the set of indices of the elements of  $\mathbf{w}_{\pi(i)}$  with the first  $k$  largest absolute values.

### 3.3 Complexity Analysis

The complexity of joint user grouping and antenna selection beamforming algorithm lies mainly in the initialization step of the Moore-Penrose pseudo-inverse of  $\mathbf{W}$ , which involves a complexity of  $O(NM^2)$ . The corresponding  $\lambda_i$  initialization in Step (1) involves  $M$  2-norms of  $1 \times N$  vectors, which include complex multiplications. The updating of  $\mathbf{w}_i$  and  $\lambda_i$  in Step (2) involves  $|\mathbb{S}| - 1$  vector-vector multiplications and  $|\mathbb{S}| - 1$  2-norms, which include  $2N(|\mathbb{S}| - 1)$  complex



**Fig. 3.** The computational complexity about number of complex multiplications.



**Fig. 4.** The hardware complexity about ADCs of RF chains.

multiplications. While the computational complexity of antenna selection lies in the finding of the first  $k$  nonzero elements with largest absolute values, it involves a complexity of  $O(N|\mathcal{S}|)$ . The total complexity of the proposed scheme is (Fig. 3)

$$O(NM^2 + MN + \sum_{n=|\mathcal{S}|}^K 2N(n-1) + N|\mathcal{S}|).$$

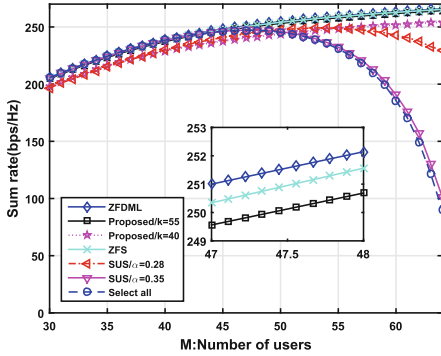
We have shown that the complexity of Select All is  $O(NM^2)$ , due to the Moore-Penrose pseudo-inverse of  $\mathbf{H}_{\mathcal{U}_{\text{all}}}$ , which is lower with poor performance. From Fig. 5, we can see the computational complexity of proposed scheme is basically the same as Select All. This is a significant improvement over previous user selection algorithms, such as ZFS and SUS, which all have the complexity of  $O(NM^3)$ .

## 4 Simulation Results

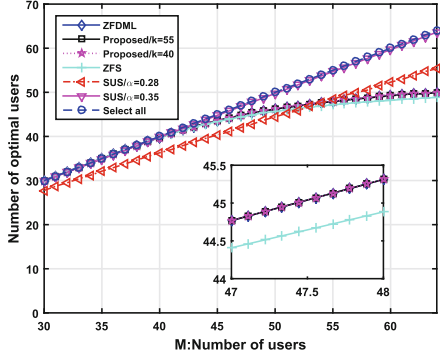
In this section, we compare the performance of DML, ZFS, SUS (with  $\alpha = 0.28$  and  $\alpha = 0.35$ ), ‘Select All’, and the proposed scheme (with  $k = 55$  and  $k = 40$ ) with ZFBF serving a fixed number of users. The BS is equipped with  $N = 64$  antennas. The transmit SNR is 20 dB, and the number of users  $M$  ranges from 30 to 64. All curves are obtained by averaging over  $10^3$  independent channel matrices with each entry being a zero-mean unit-variance circular symmetric complex Gaussian random variable.

From Fig. 6, we can see that when the number of users in the cell is small, that is  $M < 45$ , the user grouping phenomenon of other schemes are not obvious, except SUS related with the threshold  $\alpha$ . We also can see that the proposed algorithm have a certain extent in antenna selection with almost the same performance in this range. However, according to Fig. 4, when  $k = 55$ , selecting 55





**Fig. 5.** Sum rate performance comparison serving a fixed number of users.



**Fig. 6.** The comparison of the number of optimal user grouping serving a fixed number of users.

antennas from the massive antennas at BS for each transmit data stream, the proposed scheme greatly reduces the hardware complexity. When the number of users is larger, the schemes with superior performance are DML, ZF, and the proposed scheme with  $k = 55$  and  $k = 40$ , which have almost the same rate and computational complexity. The proposed algorithm provides a better trade-off between rate performance and hardware complexity in massive MIMO systems with the same set of users and rate performance as shown in Figs. 5 and 6. The simulation results also show that when  $k = 55$  and  $k = 40$ , the utilization of degrees of freedom are respectively 85.9% and 62.5%. As expected, for the antenna selection, still a large portion of antennas are not connected to signals for reasonably small  $k$  values. This aspect of the proposed scheme can be exploited to reduce the hardware complexity in addition to the reduction in the number of required multiplications or multipliers.

## 5 Conclusion

In this paper, we have considered a joint user grouping and antenna selection zero-forcing beamforming algorithm and analyzed it from throughput, computational complexity and hardware complexity. In this algorithm, we lower the hardware complexity with the number of ADCs by selecting a optimal antenna subset for each transmit data stream, subject to maximize system throughput with low computational complexity by user grouping when the number of users in the cell is large for massive MIMO system. The proposed scheme provides a better trade-off between rate performance and hardware complexity with a small  $k$ .

**Acknowledgments.** This work was supported by the National Science and Technology Major Project of the Ministry of Science and Technology of China (Grant No. 2015ZX03001033-002).

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