Resource Allocation for Hyper-MIMO System with Block Diagonalization Precoding Technique

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***Abstract*—Hyper Multi-input Multi-output (hyper-MIMO) is considered as a promising technology for the fifth generation (5G) of wireless communication system. Base station (BS) is equipped with a large-scale transmit antenna array to serve the multiuser with single-received antennas for the active users in the system. To improve the system performance, BS must activate some selected users' receive antennas in the user side for data receiving and make the optimal power distribution. In this paper, we propose a reduced-complexity resource allocation method for Hyper-MIMO in the multiuser system. We consider the joint power distribution and user selection based on the signal to interference plus noise ratio (SINR) conditions of each user in the system. By using the block diagonalization precoding technique, SINR status of each user can be calculated and this value will be applied in the user selection process and resource allocation to increase the total sum-rate of multiuser hyper-MIMO system. We show that the proposed scheme offers enormous reduction in complexity while ensuring the acceptable performance compared with the optimal resource allocation scheme in the system.**

***Index Terms*—Hyper-MIMO, Resource Allocation, Complexity.**

I. INTRODUCTION

The 5th generation (5G) broadband wireless access network, which targets data rate over 10 Gbps, is expected to be ready for launch by 2020 [1]. Therefore, it is necessary to find a most promising technology to fulfill the requirements of 5G data rate in near future. On the other hand, hyper-MIMO systems have a great potential to improve the capacity without increasing the system bandwidth or the transmission power for the wireless communications [2].

A hyper-MIMO refers to a system where the base station is equipped with a large number of antennas (e.g. tens or hundreds) communicates with several single-antenna users in the same time-frequency domain [3]. The capacity can be improved and increased by using aggressive spatial multiplexing techniques in hyper-MIMO. The basic premise behind hyper-MIMO is to reap all the benefits of the conventional MIMO. But hyper-MIMO can handle very large number of antenna arrays which are not only on the transmitter side but also on receiver side [4]. It was shown that the large antenna array at BS can provide high degrees of freedom and increase the system capacity, link reliability, and radiated-energy efficiency.

Moreover, hyper-MIMO can simultaneously serve multiple users within a cell using the same time-frequency domain and thus, the spectral efficiency is dramatically improved. However, the user selection in the receiver side is also a critical important factor for optimizing the overall performance of hyper-MIMO systems. User selection in the conventional MIMO systems has been a key topic of research in the past years [5]. In [6], Gorokhov et al. introduced a complexity-efficient user selection algorithm that aims to maximize the spectral efficiency in the MIMO system. But, most of them considered for the conventional MIMO system only.

Recently, many selection schemes have been proposed for user selection schemes for multiuser hyper-MIMO systems in [7-9]. The two most well-known user scheduling methods are; round robin scheduling and random user selection (RUS) [7]. Liu et al. considered a pair of low-complexity user selection methods for TDD-based hyper-MIMO downlink scenarios [7]. By exploiting the instantaneous channel state information (CSI) of a candidate user's antenna, Lee and Sung proposed the semi orthogonal user selection method in [8], and Xu et al. developed a greedy user selection scheme in [9] to be applied in FDD-based hyper-MIMO downlink scenarios.

In the MIMO system, the precoding is important in order to avoid the co-channel interference across parallel channels at same time-frequency domain.

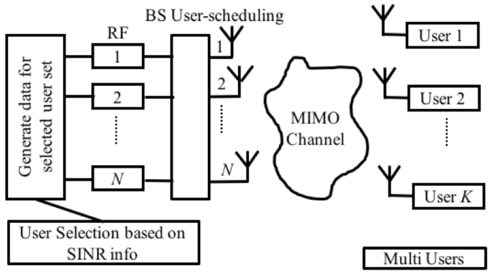

Fig. 1. System model

One of the most promising precoding techniques is block diagonalization (BD), which supports multiple stream transmissions. BD is known as one of the practical precoding techniques that can successfully eliminates co-channel interference in the downlink MU hyper-MIMO system. Moreover, the capacity of hyper-MIMO can still be improved by using optimal transmit power distribution in different users.

Therefore, the optimal method based on the exhaustive brute force search (BFS) finds the best user set over all possible combination of the receive antenna in the user side. By calculating the capacity for each combination of BS antennas and users set, the optimal scheme will select the combination, which gives the maximum capacity in the system. This method will use the optimal power allocation to each user based on their channel condition and SINR information. But, this BFS solution cannot be implemented in practice even in the small sized systems because of its very high computational complexity.

Therefore, we do the research work to find the suboptimal scheme for user selection in the MU hyper-MIMO system to reduce the complexity as well as to improve the sum-rate in this system. The proposed user selection scheme is done based on the SINR information with singular value decomposition (SVD) for the BD precoding techniques and user grouping to select the best user set in the system. The simulation results show that the proposed scheme can give the acceptable capacity with less complexity in calculation compared with the conventional optimal scheme and random selection scheme. Throughout the paper, lower-case bold letters are used for vectors and upper-case bold letters for matrices; $\| . \|_F^2$ denotes the Frobenius norm of a vector; $| . |$denotes the cardinality of a set or the absolute value of a scalar; and $(.)^H$ represents the Hermitian matrix.

II. SYSTEM MODEL

We consider a single cell MU hyper-MIMO downlink channel in TDD system consisting of BS, which has antenna set $\mathcal{N}$ and user set $\mathcal{K}$ with the single receive antenna for each user in the network as illustrated in Fig. 1. Moreover, BS can know the perfect CSI because of the channel reciprocity in the TDD system. The main channel between all of the transmitting antennas and receiving users can be represented by a channel matrix $\mathbf{H}_{(\mathcal{N},\mathcal{K})} = [h_{ij}]_{i\in\mathcal{N}, j\in\mathcal{K}}$,where $h_{ij} \in \mathbb{C}^{K\times N}$ represents a channel coefficient between a user i and transmit antenna j and it is assumed to be a quasi-static to block fading as well as independent and identically distributed (i.i.d) with zero mean circularly symmetric Gaussian (ZMCSG) Rayleigh fading channel.

To reduce the cost and the complexity in the MU hyper-MIMO system, BS performs the scheduling that selects $|\mathcal{U}|$ ($|\mathcal{U}|=N$) users among the $|\mathcal{K}|$ users within the cell to be served simultaneously. To maximize the sum-rate in the data transmission, BS creates one user set $\mathcal{U}$, to be scheduled in the system.

For the given $\mathcal{U}$, the channel between the transmit antennas (j) and selected schedule users (i) can be represented by a channel matrix $\mathbf{H}_{(\mathcal{U},\mathcal{N})} = [h_{ij}]$. For the user selection in our system, we try to improve not only for the reduction of the complexity but also for increasing of the capacity throughput (sum-rate) with lower user interferences in the system. To achieve the higher capacity throughput with good SINR value, we consider the block diagonalization (BD) precoding technique to be used in this system. In this case, the transmitted signal vector $(\mathbf{d}_{\mathcal{U}}^i)$ for i^{th} user in the set $\mathcal{U}$ is formed by the product of desired scalar signal $(\mathrm{x}_{\mathcal{U}}^i)$ and the associated precoding vector $(\mathbf{w}_{\mathcal{U}}^i)$ for user i in the set $\mathcal{U}$ and can be expressed as follows:

$$\mathbf{d}_{\mathcal{U}}^i = \mathrm{x}_{\mathcal{U}}^i \mathbf{w}_{\mathcal{U}}^i \quad (1)$$

where, $\mathbf{w}_{\mathcal{U}}^i \in \mathbb{C}^{S\times 1}$ is the precoding vector for i^{th} user in the set $\mathcal{U}$ and it satisfies $\|\mathbf{w}_{\mathcal{U}}^i\|^2 = 1$. Moreover, $\mathrm{x}_{\mathcal{U}}^i$ must be satisfied $\|\mathrm{x}_{\mathcal{U}}^i\|^2 = p_{\mathcal{U}}^i$ and $\sum_{i\in\mathcal{U}} p_{\mathcal{U}}^i \leq P$. $p_{\mathcal{U}}^i$ and P represent the transmit power assigned to the i^{th} user in the set $\mathcal{U}$ and the total transmit power for the set $\mathcal{U}$, respectively.

By using BD precoding vector $\mathbf{w}_{\mathcal{U}}^i$, i^{th} user in the set $\mathcal{U}$ can avoid the interference from other users at the set $\mathcal{U}$ in the same frequency and the time domain as shown below:

$$\mathbf{h}_{\mathcal{U}}^{i}\mathbf{w}_{\mathcal{U}}^{k} = 0 \text{ for all } i \neq k \text{ and } i \in \mathcal{U},\ k \in \mathcal{U} \quad (2)$$

where, $\mathbf{h}_{\mathcal{U}}^{i}$ denotes the i^{th} row of $\mathbf{H}_{(\mathcal{U},\mathcal{N})}$. Therefore, the received signal $\mathbf{y}_{\mathcal{U}}^{i}$ at the i^{th} user in the set $\mathcal{U}$ can be written as:

$$\mathbf{y}_{\mathcal{U}}^{i} = \mathbf{h}_{\mathcal{U}}^{i}\mathbf{w}_{\mathcal{U}}^{i}\mathrm{x}_{\mathcal{U}}^{i} + \mathbf{h}_{\mathcal{U}}^{i}\sum_{k\in\mathcal{U},k\neq i}\mathbf{w}_{\mathcal{U}}^{k}\mathrm{x}_{\mathcal{U}}^{k} + n_i\ . \quad (3)$$

n_i is the additive white Gaussian (AWGN) noise with zero mean and the variance N_0 at the receiver of i^{th} user in the set $\mathcal{U}$.

The signal to interference plus noise ratio ($\gamma_{\mathcal{U}}^{i}$) at i^{th} user in the set $\mathcal{U}$ can be described as:

$$\gamma_{\mathcal{U}}^{i} = \frac{p_{\mathcal{U}}^{i}\left|\mathbf{h}_{\mathcal{U}}^{i}\mathbf{w}_{\mathcal{U}}^{i}\right|^2}{N_0+\sum_{k\in\mathcal{U},k\neq i}p_{\mathcal{U}}^{k}\left|\mathbf{h}_{\mathcal{U}}^{i}\mathbf{w}_{\mathcal{U}}^{k}\right|^2} = \frac{SNR_{\mathcal{U}}^{i}\left|\mathbf{h}_{\mathcal{U}}^{i}\mathbf{w}_{\mathcal{U}}^{i}\right|^2}{1+\sum_{k\in\mathcal{U},k\neq i}SNR_{\mathcal{U}}^{k}\left|\mathbf{h}_{\mathcal{U}}^{i}\mathbf{w}_{\mathcal{U}}^{k}\right|^2} \quad (4)$$

where, $SNR_{\mathcal{U}}^{i}$ defined by $\frac{p_{\mathcal{U}}^{i}}{N_0}$ denotes the SNR for i^{th} user in the set $\mathcal{U}$. Finally, the broadcasting sum-rate for the given set $\mathcal{N}$ and $\mathcal{U}$ can be calculated as:

$$R_{sum}(\mathcal{U},\mathcal{N}) = \sum_{i\in\mathcal{U}} log_2\left(1+\gamma_{\mathcal{U}}^{i}\right). \quad (5)$$

III. Problem Formulation

The antenna selection can be formulated as an optimization problem and can be expressed as follows:

$$\max_{\mathcal{U},\mathcal{N}} R_{sum}(\mathcal{U},\mathcal{N}) = \max_{\mathcal{U},\mathcal{N}} \sum_{i\in\mathcal{U}} log_2\left(1+\gamma_{\mathcal{U}}^{i}\right) \quad (6)$$

subject to

$$|\mathcal{U}| \leq N \quad (7)$$

$$\sum_{i\in\mathcal{U}} p_{\mathcal{U}}^{i} \leq P. \quad (8)$$

In the proposed method, the BD precoding technique will be used and it requires for calculating the beamforming vector of a user i, $(1 \leq i \leq K)$, BS first calculates the null space of the remaining ($K-1$) users except the user i. The null space of a matrix can be obtained by using singular value decomposition (SVD) method [10].

The constraint in (7) ensures that the number of selected users $|\mathcal{U}|$ does note exceed the number of available antennas N in BS. The constraint in (8) ensures that the summation of transmit power of all users' data signal must be within the allowed total transmit power P in BS. And optimal water filling power distribution will be applied in selected user set in the system.

The formulated problem is a combinatorial problem, which involves finding the optimal sets of users represented by binary integer variables. The only known technique that can find the optimal solutions to this problem is the exhaustive search [7] and the corresponding computation complexity grows exponentially as $|\mathcal{K}|$ increases. Therefore, the suboptimal scheme is presented in next section to be used in real implementation for the joint antenna and user selection for the MU hyper-MIMO system.

IV. Proposed Scheme

In this section, we explain about a reduced complexity user-scheduling scheme that can be implemented in practical MU hyper-MIMO downlink systems. The proposed scheme aims to approach the maximum achievable sum-rate by exploiting the spatial selectivity gain offered by the user scheduling.

The proposed scheme will use the SINR information from BD precoding techniques to select the best suitable users in the selection and the complexity of selection will be limited by eliminating the lower SINR users in the selection of users. Then, we get the final set of user in the system for optimal transmit power distribution among users in the system. At last, the optimal water-filling power distribution technique will be applied on the final selected user set to achieve higher capacity throughput in the system. The proposed selection algorithm is described in Table I. The details operation of algorithm is explained in follows:

At first, the proposed scheme initializes the

TABLE I. Pseudo Code for the Proposed Scheme

1	Input: CSI information for all users and antennas in the BS side.
2	Initialization: the user set for user-scheduling $\mathcal{U}^{init}$ = $\{1,\ldots,K\}$.
3	Calculate the SINR ($\gamma_{\mathcal{U}}^{k}$) of each user by using SVD and BD precoding techniques.
4	Create the set $\mathcal{U}^{sort}$ with sorted user's SINR according to $\|\gamma_{\mathcal{U}}^{k}\|$ ($1\leq k\leq\|\mathcal{U}^{init}\|$) in descending order.
5	Select the users at the higher part of the sorted user set which is equal to the number of available antennas N in the system.
6	Well-known optimal water-filling transmit power distribution technique will be applied on the selected channel matrix $\mathbf{H}_{(\mathcal{U}^{sel},\mathcal{A})}^{sel}$ in the 5[th] step to improve the sum-rate and SINR value for each user in the MU hyper-MIMO downlink scenario.

sets $\mathcal{A}$ = {1,…,N} and $\mathcal{U}^{init}$ = {1,…, K}, and obtains the corresponding $\mathbf{H}^{init}_{(\mathcal{U}^{init},\mathcal{A})}$. Users K in the receiver side are necessary to be sorted in descending order based on the SINR information.

Therefore, we need to find the SINR for each user in the receiver side by using the SVD method. All users included in $\mathcal{U}^{init}$ are sorted according to $\left\|\mathbf{h}^{k}_{\mathcal{U}^{init}}\right\|^2$ $(1\leq k\leq|\mathcal{U}^{init}|)$ in descending order, where $\mathbf{h}^{k}_{\mathcal{U}^{init}}$ is the k^{th} row of $\mathbf{H}^{init}_{(\mathcal{U}^{init},\mathcal{A})}$ and denotes the channel coefficients between user k in the set $\mathcal{U}^{init}$ and all antennas in the set $\mathcal{A}$. The set of sorted users is newly denoted by $\mathcal{U}^{sort}$ and thus it satisfies the following condition (9):

$$\|\mathbf{h}^{1}_{\mathcal{U}^{sort}}\|^2 \geq \|\mathbf{h}^{2}_{\mathcal{U}^{sort}}\|^2 \geq \ldots \|\mathbf{h}^{K}_{\mathcal{U}^{sort}}\|^2 . \quad (9)$$

Then, the user set $\mathcal{U}^{sel}$ will be created by selecting the user starting from the first user to the N user in the sorted user set $\mathcal{U}^{sort}$. At last, the well-known water-filling transmit power distribution technique will be applied on the selected channel matrix $\mathbf{H}^{sel}_{(\mathcal{U}^{sel},\mathcal{A})}$ based on the $\mathcal{U}^{sel}$.

V. Simulation Results

The simulation parameters are shown in Table II. We compare the performances of scheme in terms of the CPU usage time and the sum-rate for the hyper-MIMO system. To show the various scenarios for the MU hyper-MIMO system, we consider the cases with different user numbers in the given system. CPU usage time for the calculation complexity results are normalized by using the smallest value in each complexity performance figures to clarify the ratio of complexity for each scheme.

As shown in Fig. 2, sum-rate performance of the proposed scheme is higher than the random selection method. When the total number of users is not much greater than the number of antennas in the system, the proposed scheme and random selection scheme have not many options to choose the good user set to avoid the user correlation in the system.

TABLE II. Simulation Parameters

Channel	Rayleigh Fading
SNR	5dB
Cell	Single
Number of packets in simulation	15000
Frames/Packet	5
Number of antennas N in BS	Varies (4 to 20) and (25 to 50)
Number of users K	4 and 10

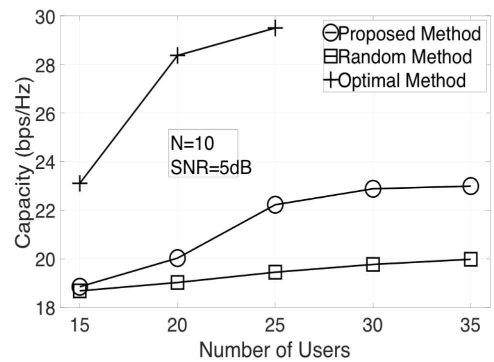

Fig. 2 Comparison of sum-rate for larger number of various K with N=10

Therefore, the performances of the optimal scheme is better at the lower number of user region in the simulation. Nevertheless, the proposed scheme can give better capacity result compared with the random selection scheme as shown in Fig. 2.

Fig.3 shows the complexity performance in real CPU usage time in the MATLAB simulation platform for the proposed scheme and other two conventional schemes. In this case, the fixed antenna number N=10 is using with the increasing user numbers from 10 to 50. As shown in this figure, the CPU usage of the proposed scheme is much lower than that of the optimal brute force search. On the other hand, the proposed scheme's CPU usage time is nearly same as that of the random selection scheme. This is because the proposed scheme is eliminating the lower SINR users from the selection process.

Fig.4 and 5 also show the performances of proposed scheme with smaller number of users, which are increasing, from 15 users to 35 users in the system. We achieve the similar results as larger number of various users case in Fig.4 and 5. In these

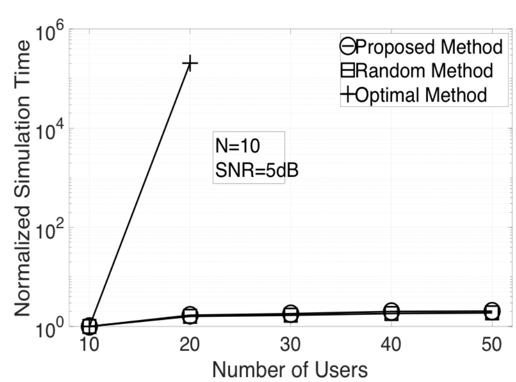

Fig. 3. Comparison of calculation complexity for larger number of various K with N=10

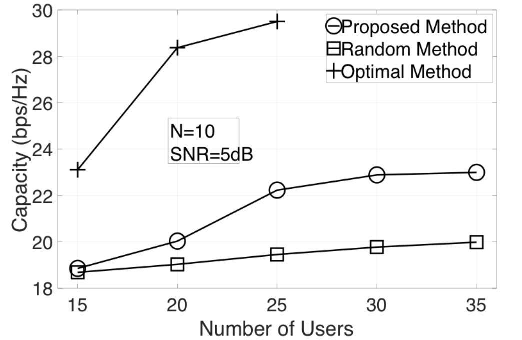

Fig. 4. Comparison of sum-rate for smaller number of various K with N=10

results, we can see that the total sum-rate of proposed method is higher than that of random selection method. As stated in Fig.5, the CPU usage time of the proposed method is much lower than the optimal selection method and nearly equal to the conventional random selection method. Therefore, it can be concluded that the proposed method can give reduced complexity in calculation time for the selection process while maintaining the acceptable total sum-rate for MU hyper-MIMO system.

VI. CONCLUSION

We have presented the low complexity antenna selection scheme for the downlink MU hyper-MIMO TDD system. To achieve the reduce complexity in the antenna selection while maintaining the acceptable capacity in the system, the proposed scheme relied on SINR calculation based on the BD precoding techniques and the SVD method. The optimal water-filling transmit power distribution for each user is applied in the selected user list to improve the data sum-rate in the proposed system. The proposed scheme can perform successfully to increase the capacity with lower complexity for various numbers of users in the system. It has been shown using simulations that the proposed scheme outperforms the conventional optimal scheme and random selection scheme in CPU usage time while maintaining the acceptable capacity in the MU hyper-MIMO communication .

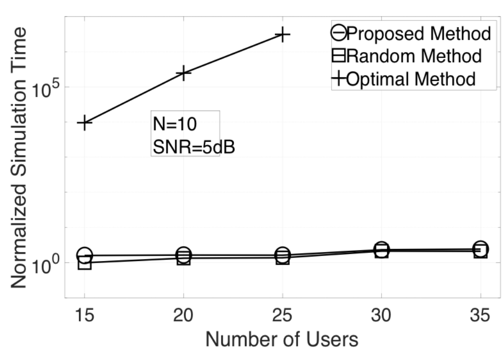

Fig. 5. Comparison of calculation complexity for smaller number of various K with N=10

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