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Fair-CDUS for Equalization of User Selection Frequency in Massive Multi-User MIMO System

Dhoni Putra Setiawan, Ryo Takahara and Hua-An Zhao
Graduate School of Science and Technology, Kumamoto University, Japan. Email: 166d9304@st.kumamoto-u.ac.jp; cho@cs.kumamoto-u.ac.jp

Abstract. Multi-user technique is a method which allows a transmitter serves multiple users in the same time. In the Massive-MIMO, Multi-user technique could be implemented with the help of beamforming technique which allows the system to create several beams in the same time, where every beam serves a different user. In this paper, we introduce a method called Fair-Chordal Distance User Selection (Fair-CDUS) to equalize the user selection in Massive-MIMO System. The fairness level which is measured in this research is the frequency of user selection. In this paper, we also explain how to adjust the degree of the fairness with our proposed method.

1. Introduction
Future generation of wireless telecommunication (5G) requires a high data rate communication. To improve the data rate in wireless communication, we need large bandwidth. However, we have to realize that the frequency band is limited and we have to find a way to utilize the frequency band effectively. One of the most popular way to improve the data rate is using Multiple-input Multiple-output (MIMO) antennas. The technique which is used to improve the data rate in MIMO system called Spatial Multiplexing (SM). With SM technique, the number of data rate directly proportional to the number of antennas. However, the there are still several problems in the MIMO system. First, the use of omni directional MIMO will cause interference in the receiver. This condition happens because the transmitter in the same time not only bring the data to one user but to many users. This unwanted signal which received in the same time with the desired signal is called as interference signal [1][2]. Besides that, the omni directional antenna will only profitable to the user which is close to the Base Station (BTS), the user which is far away from the BTS will suffer low quality signal. One of the solutions of this problem is by implementing the user interference cancellation as has been analyzed in [3][4]. However, user interference cancelation could not work well in the large number of users [1].

The solution of these problems is Massive-MIMO system which employs a large number of transmitter antenna. The key to solve these problems is the ability of Massive-MIMO to create signal beams which transmit the signal directly to the desired user, this technique is called beamforming technique. With beamforming technique, interference will be not a problem again because the signal sends directly only into the desired user. This technique also can effectively adapt the power of signal which is transmitted to the user whether the user close to the BTS or far away from the BTS. And the most important is, Massive-MIMO system can create more than one beams in the same time, where all the beams have the same frequency band. This condition boosts the data rate of Massive-MIMO system significantly [5].

Several papers have proposed the method to manage the multi-user in i.e., [5][6][7]. In this paper, we introduce a user selection method to manage the users of Massive-MIMO system. We consider the multi-user system is applied in Massive-MIMO system. This proposed method is called Fair-Chordal
Distance User Selection (Fair-CDUS). This method is basically an improvement from CDUS system which is proposed in [6]. In the CDUS, user selection is managed by measuring the chordal distance between every user. The set of users which approximately has higher orthogonality degree to each other will be selected. In our proposed method, we introduce a method to equalize the selection frequency of each user in order to give more fairness to every user.

This paper is arranged as the following: Section 2 shows the system models. In section 3, the user selection methods are introduced and we propose a fair scheduling algorithm. The experimental results are shown in section 4 and section 5 is the conclusion.

2. System Models
As discussed in the previous section, since MU-MIMO has limitations on the number of users that can support simultaneously, research on user selection methods is also being conducted. Since the number of users is expected to increase in the next generation wireless communication, the necessity of user selection is considered to increase.

The received signal at user $k$ in our proposed system is written in the following equation:

$$y_k = x H_k + N$$

Where, $x$ is the transmitted symbols, $H_k$ is the channel matrix between BTS and user $k$ $(k=1, ..., K)$, and $N$ represents the noise.

The proposed system is a downlink Massive Multi-user MIMO with one BTS and $K$ users. The BTS are equipped with $N_T$ transmitting antennas and each user has $N_R$ receiving antennas. The number of transmitting antennas ($N_T$) must be greater than or equal to the number of receiving antennas ($N_R$), we also consider the number of users which can be supported at the same time is $K\leq N_T$. The number of users which can be selected at a time is $K\leq N_T/N_R$.

3. User Selection in MU-MIMO
In this paper, we propose a fairness scheduling algorithm based on CDUS with chordal distance. For a large number of users, the optimal scheduling technique needs an exhaustive search, which is impractical. The key used in this paper is to use CDUS with the frequency of user selection.

3.1. Chordal Distance-based User Selection (CDUS)
We select CDUS rather than Capacity-based algorithm [7] and Frobenius norm-based Algorithm [7] for the user selection because CDUS has less complexity than both Capacity-based algorithm and Frobenius norm-based Algorithm schemes as has been stated in the paper [6]. This condition makes CDUS more applicable to be implemented than Capacity-based algorithm and Frobenius norm-based Algorithm especially when the number of transmitted antennas is very large.

In the CDUS, the first user is selected by calculating the maximum channel energy, i.e., $\|H_k\|_F^2$. This technique is similar with the one that implemented in Frobenius norm-based algorithm. The calculation is shown in the equation (1).

$$s_i = \arg \max_k \|H_k\|_F^2$$

where $s_i$ is the user which is served at that time.

For the other selected users, CDUS selects the user based on the chordal distance between the previous selected user and all the candidates. The candidate which has the biggest chordal distance with the previous selected user will be selected as the next selected user. The $d_{cd}$ expressed in the algorithm represents the angle between the two matrices, which can be thought of as the chord distance, so it can be expressed as Equation (2).
Here, $\theta_j$ is the angle between the column spaces of the matrices $H_1$ and $H_2$. $\bar{H}_1$ and $\bar{H}_2$ are the Gram Schmidt orthogonalizations (GSO) applied to $H_1$ and $H_2$, respectively.

\[ d_{cd}(H_1, H_2) = \sqrt{\sum_{j=1}^{N_R} \sin^2 \theta_j} \]
\[ = \sqrt{N_R - tr(\bar{H}_1 \bar{H}_2^H \bar{H}_2 \bar{H}_1^H)} \]  

(2)

3.2. Proposed User Selection Algorithm

CDUS as well as Capacity-based Algorithm and Frebenius norm-based Algorithm using greedy method (greedy algorithm) to select the next selected user. This condition makes the frequency of each user to be selected is biased. To fix this problem, we propose a user selection algorithm, called Fair-CDUS. In our proposed algorithm, the degree of freedom of CDUS is limited by the value of $fa$. The variable $fa$ determines the number of unselected user ($\Omega$) which has to be selected for the next transmission. In the original CDUS, the value of $fa$ is 0, which means it is possible that the same set of users will be selected for two or more consecutive transmissions. The illustration of this method is shown in the Figure 1.

In the Figure 1 we can see how Fair-CDUS with $fa = 1$ works. In the first transmission the system serves 4 users in the same time. For the second transmission, first, the system will choose one user that has not been selected in the previous transmission ($\Omega$) using equation (2). The user which has been selected ($\Psi$) in the first transmission still can be selected in the second transmission if the $d_{cd}$ value (3) between that user and the first user which is selected for the second transmission is higher than the $d_{cd}$ value of the other users. In the $fa = 2$, the user that can not be selected for the second transmission is not only the first user but also the second user. That means, the $d_{cd}$ calculation for choosing the second user excludes the calculation with the user that has been selected in the first transmission. The same concept is implemented from $fa = 1$ until $fa = K - 1$. For $fa = K$, that means that all user that has been selected will not get a chance until all users selected, except the algorithm breaks because of the total throughput drops.

The detail Algorithm is written as the following:
Proposed User Selection Algorithm (Fair-CDUS)

1: Inputs: \( \Omega = \{1, 2, ..., K\}, 0 \leq f a \leq \tilde{R} \)

2: \( \Omega_t = \Omega, \Psi_t = \emptyset \)

3: for \( j = 1 \) to number of communications do

4: \( \Omega_j = \Omega_t, i = 1, \Psi_j = \emptyset \)

5: for \( k \in \Omega_j \) do

6: Obtain \( \tilde{H}_k \) after Gram-Schmidt orthogonalization for row-based \( H_k \)

7: end for

8: \( s_1 = \arg \max_k \|H_k\|_F^2 \) and \( \tilde{U}_1 = \tilde{H}_s_1 \)

9: \( \Omega_j = \Omega_j - \{s_1\}, \Psi_j = \Psi_j + \{s_1\} \)

10: Calculate the system total throughput when serving user subset \( \Psi_j \), i.e., \( R(\Psi_j) \)

11: if \( f a = 1 \) then

12: \( \Omega_j = \Omega - s_1 \)

13: end if

14: for \( i = 2 \) to \( \tilde{R} \) do

15: \( s_i = \arg \max_k d_{ed}^2 (\tilde{U}_{i-1}, \tilde{H}_k) \)

16: Calculate the total throughput when serving \( s_i \) and users in \( \Psi_j \), i.e., \( R(\Psi_j \cup \{s_i\}) \)

17: if \( R(\Psi_j) > R(\Psi_j \cup \{s_i\}) \) then

18: break algorithm

19: else

20: \( R(\Psi_j) > R(\Psi_j \cup \{s_i\}) \)

21: end if

22: \( U_i = [\tilde{U}_{i-1} \tilde{R}_s_i]^H, \Omega_j = \Omega_j - \{s_1\}, \Psi_j = \Psi_j + \{s_1\} \)

23: if \( i = f a \) then

24: \( \Omega_j = \Omega \setminus \Psi_j \)

25: end if

26: end for

27: if \( f a = 0 \) then

28: \( \Omega_t = \Omega \)

29: else if \( |\Omega_t \setminus \Psi_j| \geq f a \) then

30: \( \Omega_t = \Omega_t \setminus \Psi_j \)

31: else

32: \( \Omega_t = \Omega \)

33: end if

34: end for

4. Experimental Results

In the experiment we calculated the total throughput of the proposed system and also the user selection fairness. We also calculate the standard deviation. The parameters of this research are: \( N_T = 16, N_k = 4, K = 16, \) and \( \tilde{R} = 4 \). Although we use rather small number of antennas for Massive MIMO system, this proposed technique can be applied for larger number of antennas. The effect of the number of \( f_a \) is also analyzed in this paper.

In Figure 2 bellow, we can see that the proposed Fair-CDUS gives better fairness level compared to the original CDUS. The large number of \( f_a \) (i.e., \( f_a = 3, f_a = 4 \)) make the user selection frequency become fairer compared to the small number of \( f_a \). We also can see that \( f_a = 3 \) and \( f_a = 4 \) have similar fairness level. To make it sure which one is fairer, we calculate the standard deviation of every result. The result can be seen in Table I.
Figure 2. User selection fairness in the different $fa$

Table 1. Standard deviation for each $fa$

| $fa$ | Standard Deviation |
|------|--------------------|
| 0    | 34.82              |
| 1    | 17.21              |
| 2    | 13.62              |
| 3    | 8.82               |
| 4    | 10.47              |

Table 1 reaffirmed our conclusion that large number of $fa$ makes the user selection frequency become more equalize. In the table 1, we also can see that $fa = 3$ has better fairness than $fa = 4$. This result could occur because of the rules in algorithm which states if the total throughput drops the algorithm will break and starting from the beginning again. This condition makes the $fa = 4$ can not give better fairness level compared to $fa = 3$.

The comparison of the total throughput which is produced by our proposed and CDUS can be seen in figure 3. The result shows that our proposed Fair-CDUS can give very close performance compared with CDUS. The result also shows that a higher number of $fa$ makes the total throughput become lower.
5. Conclusion

In this paper we propose a user selection technique for Massive Multi-user MIMO. Our proposed method is called Fair-CDUS which is developed from CDUS which has low complexity compared to the other user selection techniques. Our proposed method successfully matches with the performance of CDUS while in the same time give better selection fairness between users. Although in this paper only 16 transmit antennas is used in the experimental process, this method can be used also for higher number of antennas. We believe our proposed technique could be developed any further to be used in Massive MIMO system.

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