JAREE-Journal on Advanced Research in Electrical Engineering
Volume 2, Number 2, October 2018

A Fair User Selection Algorithm for Multi-User Massive MIMO System

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***Abstract*—Massive Multiple-input Multiple-output (Massive MIMO) system is one of the most potential candidates for the fifth-generation wireless communication. Massive-MIMO system employs a very large number of antennas which could easily reach more than a thousand antennas in the future. Instead of using an omni directional antenna which is a very popular base station antenna nowadays, massive-MIMO uses its large number of antennas to create multiple smaller beams which are transmitted directly into the intended receivers. In this paper, we develop a user-scheduling technique for Multi-user Massive-MIMO system called Fair-CDUS which is developed from charcoal distance-based user selection (CDUS) technique. Fair-CDUS aims to give more fairness to users in term of selection frequency and at the same time could maintain the total throughput performance. Some experimental scenarios with a different number of beams and a different number of receiving antenna are presented in this paper. We believe this proposed method could be a potential method to be used in Multi-user Massive-MIMO system.**

Keyword*—*Massive-MIMO, Multi-user, 5G, User Scheduling, Fairness

I. INTRODUCTION

The era of 5G wireless communication is in sight. This era is expected to give higher data rate communication which has lower latency and has good performance in high mobility condition. 5G is also expected to serve a larger number of users than the previous generation more smoothly [1][2][3]. And importantly, 5G has to be ready for the Internet of Things (IoT) era and furthermore for the Internet of Everything (IoE) era. The realization of IoT and IoE era without a doubt will depend on the future wireless telecommunication technologies [4].

One of the most potential candidates for 5G wireless communication is Massive Multiple-input Multiple-output (Massive MIMO) system. Massive MIMO is a further development of MIMO system which employs a very larger number of antennas. The number of antennas could easily reach more than a thousand of antennas in the future, and with the recent development of small form antenna, this idea is not impossible to be developed [1][2][3]. The purpose of using a large number of antennas is to create a Massive Array Antenna System which can create smaller signal propagation and multiple beams in the same time. With a large number of antennas (array), the beams which are sent to the receivers in the Massive MIMO has smaller propagation than the previous wireless generations which usually employ omni directional antenna. In the same time, Massive MIMO can transmit multiple beams to the receiver where all of the beams have the same frequency band [2][3][5][6]. This technique will increase spectral efficiency, and at the same time, it produces less interference in the receiver [1][2][7][8][9]. Theoretically, the interference will be zero if every beam is received by the intended user. However, this is practically impossible to be achieved. To produce higher spectral efficiency and less interference in the receiver while at the same time maximizes the total throughput, the user selection algorithm becomes a very important subject to be researched [10].

Researches about Massive MIMO have become a hot topic in recent years, and the user selection algorithm has become one of the most important parts which has to be studied thoroughly. Most of the researches about Massive MIMO are focused on TDD system as has been proposed in [5][8][11][12] to optimize the Channel State Information, while some researchers choose to use FDD system [6][10][13] because this system is more popular in the previous generation (LTE). To minimize interference, some researchers use Zero-Forcing for precoding process [2][5-12][14][15], while the others propose user clustering or user grouping technique using chordal distance calculation to minimize the interference [1][8][11][16]. In the several papers, user scheduling algorithm is used to optimize the power consumption of Massive MIMO system [17][18]. Low complexity user scheduling also becomes an interesting topic; some papers propose low complexity user scheduling to anticipate the complexity problem because of massive user candidate in the future [1][21]. To maximize the contribution of user scheduling algorithm in the Massive MIMO system, some papers combine beam scheduling (beam selection algorithm) or antenna selection algorithm with user selection scheduling algorithm [9][13][19][20]. However, in this paper, we only focus on the user selection algorithm, and we show some experimental scenarios to ensure prove our proposed algorithm quality.

One of the user selection algorithms which is suitable for Multi-user Massive MIMO is the Chordal Distance-based User Selection (CDUS) which is proposed in [22]. This technique calculates the chordal distance between the first selected user and the other user candidates to decide the user which has to be selected a long side the first selected user. The first selected user is selected by calculating the channel energy of every user candidate and candidate which has the best channel energy will be selected. To obtain the channel energy of every user, the transmitter has to collect the Channel State Information (CSI) of every user. This means this algorithm will be implemented better if the system is Time Division Duplex (TDD) system. In Frequency Division Duplex (FDD) system which the downlink channel and uplink channel use different bands, further research has to be conducted if we want to user CSI in the transmitter.

The problem of CDUS algorithm is in this algorithm, the fairness between users is not considered. Some user can be selected many times, but at the same time, there are users which are selected only a few times. To overcome this problem, we proposed a technique called Fair-CDUS which can improve the user selection frequency of the Multi-user Massive-MIMO system while at the same time maintain the total throughput performance. To measure the performance of the proposed algorithm, several experimental scenarios are analyzed in this paper.

This paper is arranged as the following: section 1 is Introduction, in section 2, we explain the system model, in section 3, CDUS Algorithm and the proposed Fair-CDUS Algorithm are introduced, in section 4, we show the results of our experimental, and section 5 is the conclusion.

II. SYSTEM MODEL

We consider our system is a downlink TDD Multi-user Massive-MIMO system which can transmit M number of beams in the same time. The number of transmitting antennas is not specified because we realize that in massive MIMO technology, multiple antennas can be used to send a single beam. Therefore, instead of using the number of antennas as a parameter, we use the number of beams. We consider $\widehat{K}$ as the number of users $(1, \dots, k)$ which can be served in the same time. The formula of the received signal can be written as the following:

$$Y_k = X_m H_k + N_k \tag{1}$$

Y_k is the received signal in the user k, X_m is the transmitted signal from beam m, H_k is the channel coefficient, and N_k is the noise in the receiver. In the case that a user has more than one antenna which every antenna works independently, then we can consider Y_k as the received signal from each transmitter.

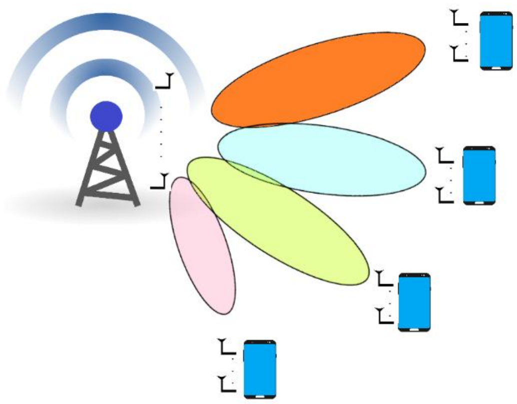

Fig. 1. Illustration of Multi-user MIMO Model

III. USER SELECTION ALGORITHM

3.1. CDUS

Ideally at the same time, the transmission system should choose users which orthogonal to each other so the interference will be exactly zero. However, that kind of condition in practical maybe does not exist. Therefore, instead of finding users which orthogonal to each other, Zhou, et al. in [22] proposed an algorithm called Chordal distance-based user selection. The idea of this technique is to choose the users who are served in the same time based on the chordal distance between their positions. CDUS is selected to be developed in this research because it has two advantages compared to the other technique. First, this technique has lower complexity compared to the other techniques such as Capacity-based algorithm and Frobenius norm-based Algorithm [23]. The complexity of CDUS as mentioned in the [22] is $O(KM^3)$, while Capacity-based Algorithm and Frobenius norm-based algorithm has similar complexity, $O(K\widehat{K}^2M^3)$. The second advantage, CDUS is one of the most suitable user selection algorithms for Massive MIMO technique. One of the reasons why massive MIMO has to be implemented in the future generation wireless communication is because it has potential to create zero interference communication system. However, because a perfect zero interference system is hard to be implemented, a good user selection algorithm which can help Massive-MIMO system to achieve this goal needs to be implemented.

The first step of using the CDUS Algorithm is to select the first user by calculating the maximum channel energy, $\|H_k\|_F^2$. This step is identical with the first step of Frobenius norm-based algorithm. The calculation process to calculate which user has the best channel energy is shown in the equation (2).

$$s_i = \arg\max_k \|H_k\|_F^2 \tag{2}$$

The next step of CDUS Algorithm is to select the other users based on the chordal distance between each candidate and the first selected user. This step is aimed to calculate the orthogonality degree between every candidate with the first selected user. The higher the orthogonality, the lower the interference received by each receiver. The candidate which has the biggest chordal distance will be selected as the next selected user. The chordal distance between two users can be calculated using equation (3)

$$\begin{aligned} d_{cd}(H_1, H_2) &= \sqrt{\sum_{j=1}^{N} \sin^2 \theta_j} \\ &= \sqrt{N - tr(\widetilde{H}_1 \widetilde{H}_2^H \widetilde{H}_2 \widetilde{H}_1^H)} \end{aligned} \tag{3}$$

Here, θ_j is the angle between the column spaces of the matrices H_1 and H_2. $\widetilde{H}_1$ and $\widetilde{H}_2$ are the Gram Schmidt orthogonalizations (GSO) applied to H_1 and H_2, respectively, and N is the number of receiving antennas of each user. In this research, we assume all users has the same number of antennas. To get the channel matrix between the transmitter and every user candidate, CSI is needed in the transmitter. This is the reason why we consider our system as TDD, in TDD the transmitter and receiver use exactly the same frequency band, therefore the CSI which is received by the transmitter is more accurate than using FDD.

3.2. Fair-CDUS

CDUS Algorithm is proposed to minimize the interference between the selected users. However, this technique doesn't consider the fairness between users. This condition makes the user selection frequency unbalanced as shown in our experimental in Fig. 2.

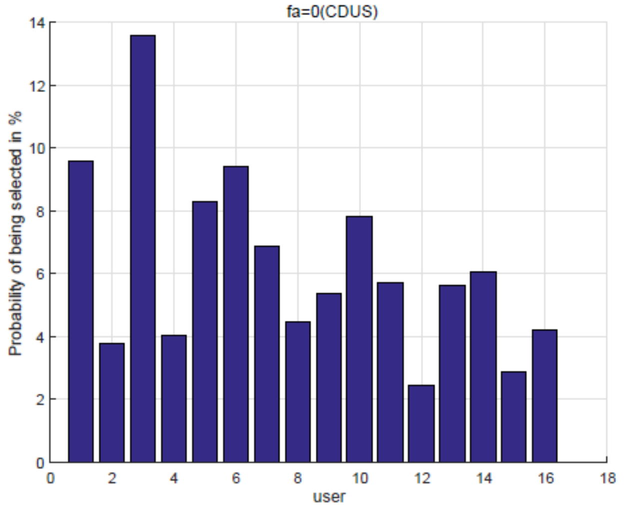

Fig. 2. User Selection Frequency of CDUS

To solve this user selection frequency problem, a method called Fair-CDUS is proposed in this paper. In our proposed method we introduce a parameter called fa which represent the degree of freedom to select the users for the next transmission. The variable fa determines the number of unselected user (Ω_l) which has to be selected for the next transmission. $fa = 1$ means that at least one of the users which has selected in the previous transmission (at $t-1$) cannot be selected for the next transmission (at t). In the next transmission, the first step, the Fair-CDUS Algorithm must choose one user candidate which has not been served in the previous transmission by calculating the channel energy of all users which have not been served in the previous transmission. Second step is similar with CDUS, the algorithm selects the other users based on the chordal distance between each candidate and the first selected user. The illustration of how our proposed model works can be seen in Fig. 3.

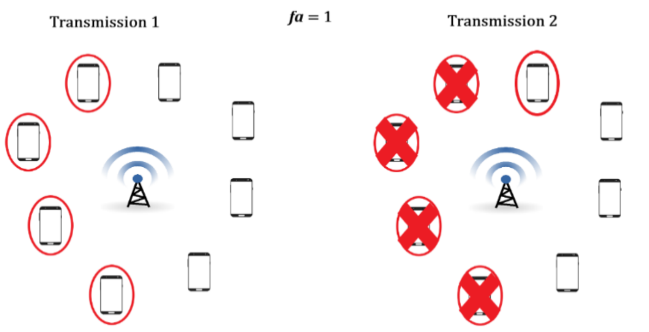

Fig. 3. Illustration of the proposed user selection concept

Algorithm 1: Proposed User Selection Algorithm

Inputs: $\Omega = \{1, 2, \dots, K\}, 0 \le fa \le \hat{K}$
$\Omega_l = \Omega, \Psi_1 = \emptyset$
for $j = 1$ to number of communications do
    $\Omega_j = \Omega_l, i = 1, \Psi_j = \emptyset$
    for $k \in \Omega_j$ do
        Obtain $\widetilde{H}_k$ after Gram-Schmidt orthogonalization for row-based H_k
    end for
    $s_1 = \arg\max_{k \in \Omega_l} \|H_k\|_F^2$ and $\widetilde{U}_1 = \widetilde{H}_{s_i}$
    $\Omega_j = \Omega_j - \{s_1\}, \Psi_j = \Psi_j + \{s_1\}$
    Calculate the system total throughput when serving user subset Ψ_j, i.e., $R(\Psi_j)$
    if $fa = 1$ then
        $\Omega_j = \Omega - s_1$
    end if
    for $i = 2$ to $\hat{K}$ do
        $s_i = \arg\max_{k \in \Omega_j} d_{cd}^2 (\widetilde{U}_{i-1}, \widetilde{H}_k)$
        Calculate the total throughput when serving s_i and users in Ψ_j, i.e., $R(\Psi_j \cup \{s_i\})$
        if $R(\Psi_j) > R(\Psi_j \cup \{s_i\})$ then
            break algorithm
        else
            $R(\Psi_j) > R(\Psi_j \cup \{s_i\})$
        end if
        $U_i = \left[\widetilde{U}_{i-1}^H \widetilde{H}_{s_i}^H\right]^H, \Omega_j = \Omega_j - \{s_1\},$
        $\Psi_j = \Psi_j + \{s_1\}$
        if $i = fa$ then
            $\Omega_j = \Omega \setminus \Psi_j$
        end if
    end for
    if $fa = 0$ then
        $\Omega_l = \Omega$
    else if $|\Omega_l \setminus \Psi_j| \ge fa$ then
        $\Omega_l = \Omega_l \setminus \Psi_j$
    else
        $\Omega_l = \Omega$
    end if
end for

In Fig. 3, we can see more clearly how Fair-CDUS with $fa = 1$ works. In the first transmission, they are 4 users which are served in the same time. In the second transmission, first, the system will choose one user that has not been selected in the previous transmission (Ω_1) by calculating the channel energy of Ω_1. The user which has been selected (Ψ_1) 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. If $fa = 2$, then the algorithm has to choose two candidates which have not been selected from the previous transmission. 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 $fa = \widehat{K} - 1$. For $fa = \widehat{K}$, that means all users that have been selected will be not selected again until all users selected, except when the algorithm breaks because the total throughput drops. The Algorithm is written in the Algorithm 1.

Compared to CDUS Algorithm, Fair-CDUS Algorithm seems more complicated. However, in term of system complexity, the complexity of Fair-CDUS algorithm is actually less than CDUS Algorithm. It can be happened because CDUS Algorithm has to calculate the channel energy and the d_{cd} of every user candidate in every turn, while in Fair-CDUS Algorithm, we only have to calculate the one that has not been served only. Therefore, the Fair-CDUS Algorithm is not increasing the complexity of CDUS Algorithm.

IV. EXPERIMENTAL RESULT

There are three parameters which are measured in the experimental process: the total throughput of the system, the user selection frequency and also the standard deviation of the user selection frequency. Two experimental scenarios are used so we can get a better analysis.

4.1. Scenario 1

For the first experiment, the transmitter submits 16 beams, the total user candidate is 16 and every user has 4 antennas, where every antenna receives a signal from a different beam in the same time. This condition can be applied only if a good interference cancelation is applied or every receiver works in the different frequency band. Under this scenario, the number of users which can be served in the same time is 4 users ($\widehat{K} = M/N$). The fa value varies from 0 until the number of users which can be served in the same time ($0 \le fa \le \widehat{K}$). As a note, $fa = 0$ means the original CDUS. The total throughput of the system is shown in Fig. 4, while the selection frequency of every user for each fa is shown in the Fig. 5 and the standard deviation of selection frequency for every fa is shown in Table I.

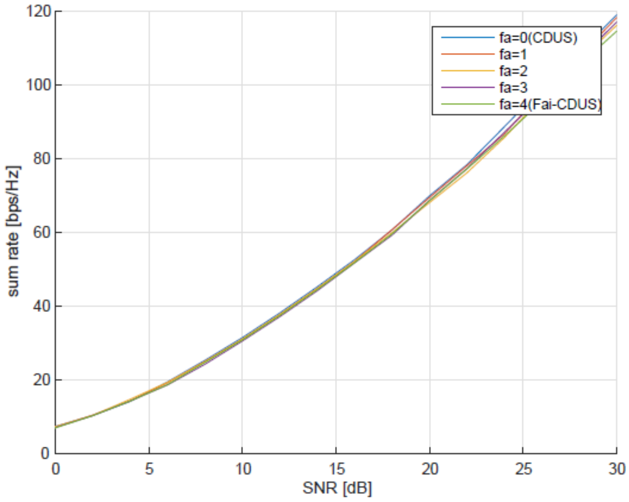

Fig. 4. Comparison of total throughput in Scenario 1

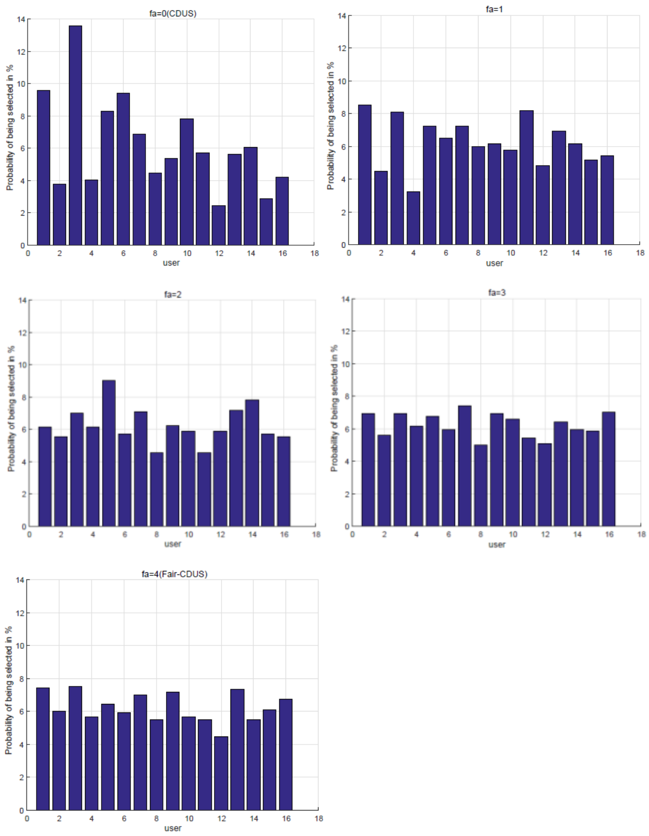

Fig. 5. User selection frequency with different fa in scenario 1

TABLE I. THE STANDARD DEVIATION OF EACH fa (SCENARIO 1)

fa	Standard deviation
0	34.82
1	17.21
2	13.62
3	8.82
4	10.47

From Fig. 5 and Table I we can see that $fa = 0$ or CDUS has the worse fairness level. The best fairness level is not achieved when $fa = 4$ but when $fa = 3$. This condition occurs because when $fa = 4$ is used in our system, the Fair-CDUS algorithm breaks many times due to the drop of the total throughput. The total throughput of this scenario is shown in Fig. 4.

We can see in Fig. 4 that our proposed Fair-CDUS Algorithm almost match the total throughput of the original CDUS. At SNR of 30 dB, the total throughput of CDUS is 118.82 bps/Hz and $fa = 3$ is 116.88 bps/Hz. We also can see that the increasing of fa makes the total throughput decreases. For the first scenario we can conclude that in our experiment, $fa = 3$ is the most ideal number of fa because it can give a good fairness to the users and at the same time maintain the total throughput.

4.2. Scenario 2

In the second scenario, the number of user candidate is 32, the number of beams which is transmitted in the same time is 64 beams and we set the number of receiving antennas of every user to 8 antennas, so that the number of users that can be served in the same time is 8 users, and the fa value varies from 0 until 8. In this scenario we show the total throughput in Fig. 6, the user selection frequency of each fa in Fig. 7 and the standard deviation of each fa is presented in Table II.

From the result of the second experimental scenario, we can see that the total throughput of all value of fa is almost the same. At SNR of 30 dB, the difference between the best fa and CDUS is only 0.6% (CDUS is 438.67 bps/Hz and fa is 436.08 bps/Hz), means that the Fair-CDUS Algorithm could maintain the throughput performance, while the best fairness according to Table II is given when $fa = 6$. Once again it is shown in this experiment that the highest value of fa does not give the best fairness level. However, we still can conclude that a high number of fa give better fairness to the users than the low number of fa.

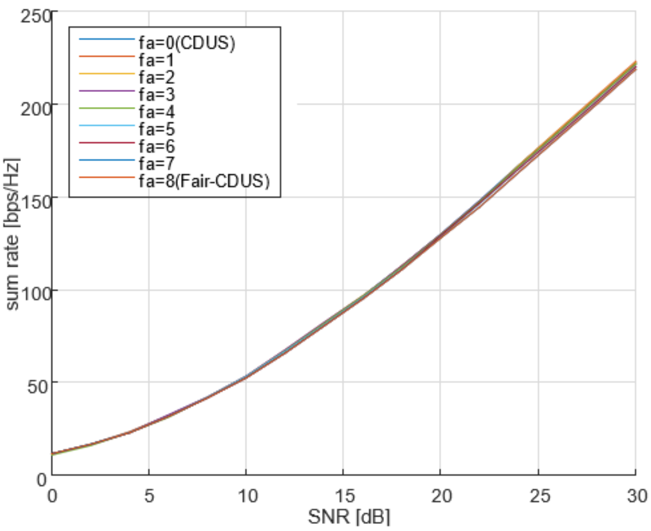

Fig. 6. Comparison of total throughput in Scenario 2

TABLE II. STANDARD DEVIATION OF EACH fa (SCENARIO 2)

Fa	Standard Deviation
0	26.92
1	17.4
2	13.44
3	14.84
4	10.21
5	10.74
6	8.37
7	8.95
8	8.76

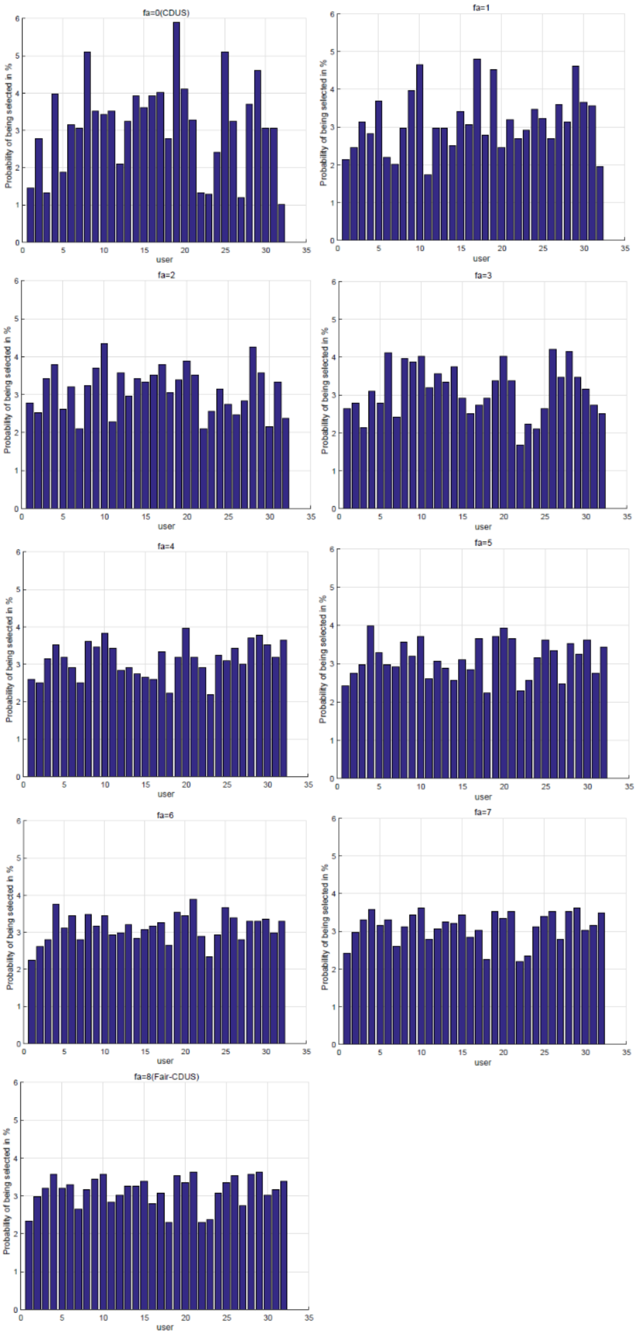

Fig. 7. User selection frequency with different fa in scenario 2

4.3. Comparison with Capacity-based Algorithm and Frobenius Norm-based Algorithm

In this subsection, we compare the performance of our proposed Fair-CDUS with CDUS, Capacity-based Algorithm, and Frobenius Norm-based Algorithm which is mentioned in [23]. We use the first scenario parameters to compare the performance of these algorithms. The result can be seen in Fig. 8 and Fig. 9.

From Fig. 8. We can conclude that the Fair-CDUS Algorithm has the worse total throughput compared to the other algorithms. The best total throughput (at SNR of 30 dB) is produced by Capacity based Algorithm with 124.66 bps/Hz, then Frobenius norm-based Algorithm with 120.72 bps/Hz. However, from Fig. 9 we can see that the proposed Fair-CDUS is the most fair algorithm among these four algorithms because in our proposed algorithm the selection frequency of every user is almost in a similar level. The other advantage is our proposed Fair-CDUS Algorithm has the lowest computational complexity, as it has been mentioned in Section 3.

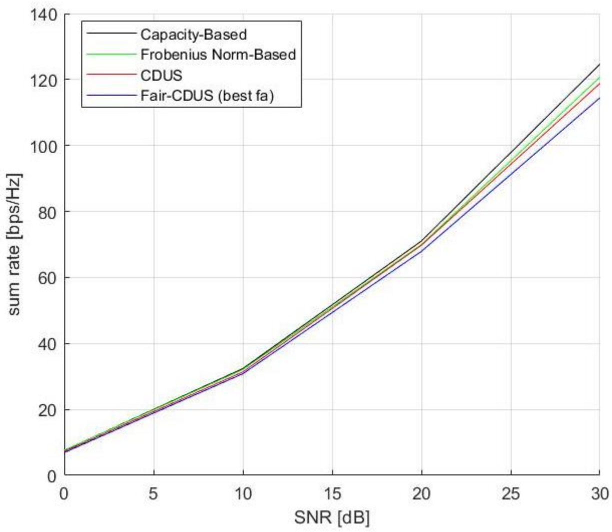

Fig. 8. Comparison of the total throughput of Fair-CDUS with the other algorithms.

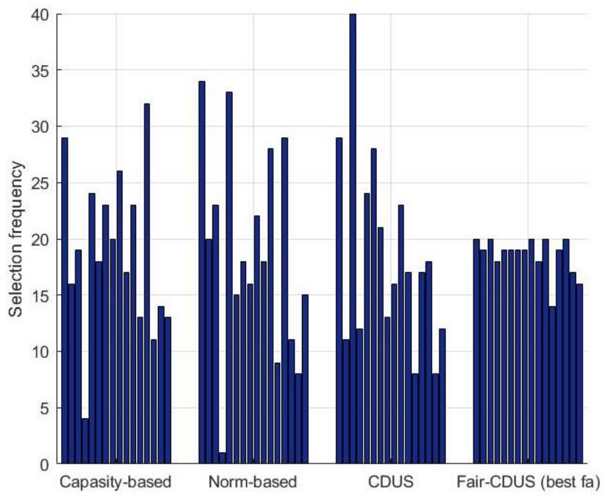

Fig. 9. Comparison of user selection frequency of Fair-CDUS with the other algorithms

V. CONCLUSION

In this paper, we introduce a user selection algorithm called Fair-CDUS which is suitable for Multi-user Massive MIMO system. This technique is developed to improve the user selection fairness of CDUS Algorithm while maintaining the complexity level and the total throughput. Because we need CSI in the transmitter for user selection process, this Algorithm is suitable for TDD Downlink system which employs the same frequency band for uplink and downlink. Our experiments show that our proposed algorithm gives better fairness level for every user compared to CDUS algorithm while at the same time we can maintain the total throughput. Therefore, we believe our proposed Fair-CDUS Algorithm could be an ideal user selection algorithm for Massive MIMO system.

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