A Simplified Fair Scheduling Algorithm for Multiuser MIMO System

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Abstract. In this paper, an efficient user scheduling algorithm with fairness is proposed. In the multiuser MIMO system, how to ensure the MIMO multiplexing gain and fairness is a key point. Although the PF algorithm ensures the fairness of the system, the sum-capacity is restricted. We improves the PF algorithm, and achieve a tradeoff between the multiplexing gain and fairness. The simulation results show the proposed algorithm can get the multiplexing gain, ensuring the fairness.

Keywords: Multiuser MIMO, Fairness, Block digonalization, PF, user scheduling.

1 Introduction

In the downlink of multiuser multiple-input multiple-output(MIMO) system, the multiple antennas at the base station allow for spatial multiplexing of transmissions to multiple users in a given time slot and frequency band. When the channel state information(CSI) of all the users is known at the base station, complete multiuser interference precancellation can be performed. The optimal strategy is known as dirty paper coding(DPC)[1], but the implement of which is very difficult. Block diagonalization(BD) is a sub-optimal algorithm, which cancels the multiuser interference using channel inverse[2].

Meanwhile, in the multiuser MIMO system, the user scheduling is a challenging. The exhaust algorithm is the optimal user scheduling algorithm[3], but because of its complexity, the implementation is difficult. The literature[4] proposed a greedy user scheduling algorithm with low complexity, where block diagonalization can maximize the system sum-capacity. The scheduling algorithm

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based on the channel norm had been proposed in[5][6], a scheduling algorithm based on the channel correlation was proposed in [7]. However, the object of all the algorithms is to achieve the maximum sum-capacity, which tends to select the strong users, often causing unfairness. Proportionally fair(PF) scheduling is a user scheduling algorithm with fairness, but losing the multiplexing gain[8].

In this paper, an efficient user scheduling algorithm with fairness is proposed. Simulation results show that the proposed algorithm can get the multiplexing gain, ensuring the fairness.

The rest of this paper is organized as follows: Section 2 describes the system model. Proposed algorithm with fairness is discussed in Section 3. In the Section 4, simulation results are given, and Section 5 presents some concluding remarks.

In the paper, $(\bullet)^T$,$(\bullet)^H$,$|\bullet|$,$\|\bullet\|$ denote the transpose, conjugate and transpose operation(Hermitian), inner product and Frobenius norm. I means the identity matrix.

2 System Model

We consider the multiuser MIMO downlink system with M transmit antennas at the base station and N receive antennas at the kth user, and there are K users. $H_k \in \mathbb{C}^{N\times M}$ expresses the channel matrix of the kth user. We assume the channel is flat rayleigh fading and independent for different users. Let $S_k \in \mathbb{C}^{r_k\times 1}$ is the kth user's transmit data, $W_k \in \mathbb{C}^{M_T\times r_k}$ is the precoding matrix, when the base station sends data to L users simultaneously, the received signal of the kth user, is given:

$$y_k = H_k \sum_{j=1}^{L} W_j s_j + n_k \tag{1}$$

Where $n_k \in \mathbb{C}^{N\times 1}$ denotes the additive Gaussian noise of the kth user whose elements have zero mean and unit variance. When $K \gg M$, the station need to make user scheduling. Denote the service user set S, the number of the service users is $|S|$, the we get $\max\{|S|\} = M/N$.

3 The Proposed Scheduling Algorithm with Fairness

3.1 The Block Diagonalization (BD) Algorithm

Let us define a $\sum_{j=1,j\neq k}^{K} N\times M$ aggregate channel matrix as:

$$\hat{H}_k = (H_1^T,\ldots,H_{k-1}^T,H_{k+1}^T,\ldots,H_k^T)^T \tag{2}$$

Zero multiuser interference condition requires the precoding matrix W_k of the kth user lies in the null space of $\hat{H}_k$ to have a dimension which is greater than 0. Denote the singular value decomposition(SVD) of $\hat{H}_k$ as:

$$\hat{H}_k = \hat{U}_k(\hat{\sum}_k 0)(\hat{V}_k^1 \hat{V}_k^0)^H \tag{3}$$

$\hat{\sum}_k$ is a $r_k \times r_k$ diagonal matrix, containing r_k nonzero singular values of $\hat{H}_k$, $\hat{V}_k^0$ holds the $M - r_k$ right singular vectors and $r_k = rank(\hat{H}_k)$. BD is possible if $M > \max(r_1, r_2, \ldots, r_k)$[2]. With this, the multiuser channel is decoupled into several parallel single user MIMO channel, which is:

$$H_k' = H_k \hat{V}_k^0 \tag{4}$$

Denote the SVD of H_k' as:

$$H_k' = U_k \begin{bmatrix} \sum_k & 0 \\ 0 & 0 \end{bmatrix} [V_k^1 V_k^0]^H \tag{5}$$

So the precoding matrix of the kth user is $W_k = \hat{V}_k^0 V_k^1$, with sum power constraint P, the achievable throughput of the block diagonal system is:

$$C_{BD}(S) = \sum_{k \in S} \log \left| I + H_k W_k Q_k W_k^H H_k^H \right| \\ s.t\, Q_k \geq 0, \sum_{k \in S} Tr(Q_k) \leq P \tag{6}$$

Where Q_k is the power allocation matrix of the kth user.

3.2 The Proposed Scheduling Algorithm

In the Section 2, we assume that $K \gg M$, and user scheduling is required. Considering the fairness, we introduce the PF algorithm first.

The PF algorithm achieves the multiuser diversity and guarantees the fairness. Every slot only one user is scheduled, assume the k^*th user is scheduled at a slot, which satisfies the condition:

$$k^* = \arg\max_{k \in K} \{\frac{R_k(t)}{T_k(t)}\} \tag{7}$$

Where $R_k(t)$ and $T_k(t)$ express the instantaneous rate and average rate of the k^*th user at the tth slot. $T_k(t)$ is updated as following:

$$T_k(t+1) = \begin{cases} (1 - \frac{1}{t_c})^* T_k(t) + \frac{1}{t_c}^* R_k(t), k = k^* \\ (1 - \frac{1}{t_c})^* T_k(t), k \neq k^* \end{cases} \tag{8}$$

t_c is the forgetting factor, t_c is more larger, the update of the $T_k(t)$ is slower, and the fairness of the system is worse.

However, PF just schedules one user at a slot, which loses the multiplexing gain, and can not reflect the advantages of multiple degrees of freedom in the MIMO system. In order to take advantage of the multiplexing gain and guarantees the fairness, we propose a improved PF scheduling algorithm.

First, select a alternative user set $\tilde{S}$, which satisfies $S \leq |\tilde{S}| \leq K$. $\tilde{S}$ is selected as following criterion: sort $\frac{R_k(t)}{T_k(t)}$ in descending order, and choose the front $|\tilde{S}|$ users as the alternative users. $T_k(t)$ is updated as following:

$$T_k(t+1) = \begin{cases} (1 - \frac{1}{t_c})^* T_k(t) + \frac{1}{t_c}^* R_k(t), k \in S \\ (1 - \frac{1}{t_c})^* T_k(t), k \notin S \end{cases} \tag{9}$$

When the alternative set is determined, we need select $|S|$ users from the set $\tilde{S}$, in this paper, greedy scheduling is used, and the detail of the proposed algorithm is as following:

a) Determine the alternative set $\tilde{S}$;
b) Initialize the service user set $S = \emptyset$;
c) Initialize the power allocation matrix Ω:
$\Omega = \frac{P}{M} I_M$, $I_M$expresses the M-dimensional identity matrix;
d) Select the ith user μ_i from the set $\tilde{S}$:

$$u_i = \arg\max_{j \in \tilde{S}} \det(I + H_j \Omega H_j^H) \tag{10}$$

e) Update the related sets and matrixes:

$$\Omega = \Omega - \Omega H_i^H (I_{m_g} + H_i \Omega H_i^H)^{-1} H_i \Omega \tag{11}$$

$$\tilde{S} = \tilde{S} - \{u_i\}; S = S + \{u_i\} \tag{12}$$

f) Repeat the steps d), e), until M/N users are selected, or other restricted conditions are satisfied.

In the proposed algorithm, the alternative set is determined with fairness, and the object of selecting users from the alternative set is to maximize the sum-capacity of the system. Thus we can get the multiplexing gain as well as the multiuser diversity.

Determining the size of the alternative set is a challenging. The more users in the alternative set, the larger is the sum-capacity, but the worse is the fairness. In the Section 4, we will discuss how to determine the best size of the alternative set.

4 Simulation Results

4.1 The Proposed Scheduling Algorithm Compared with BD and PF

The scheduling algorithms based on the capacity will always select the stronger users, often losing the fairness. Considering the block fading model, the channel matrix is constant every slot. Dividing a block into 1000 slots, every slot user scheduling is done. In the Fig.1 and 2, the probability of users being scheduled is shown.

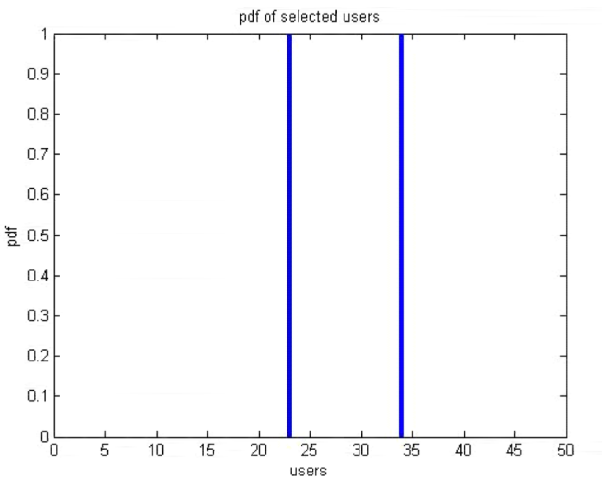

Fig. 1. The probability of users being selected in BD

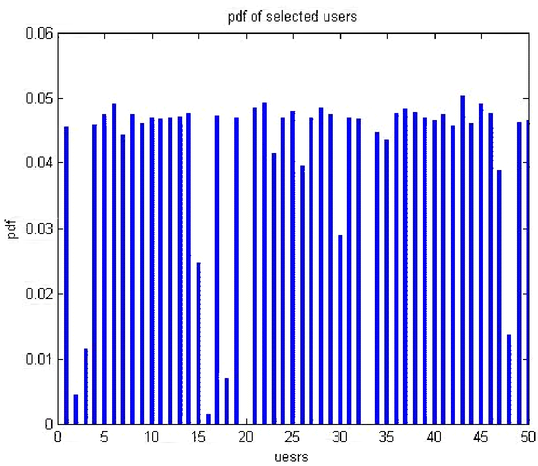

Fig. 2. The probability of users being selected in the proposed algorithm

In the Fig. 1, only user 23 and 34 are scheduled, no resource is allocated to other users. In the Fig. 2, in the proposed algorithm, we combine the PF and BD. When users are scheduled with equal probability, the scheduled probability is 0.04. Actually, the scheduled probability is 0.05, and the fairness is fine. In the Fig. 3, because the proposed algorithm has good fairness, the sum-capacity decreases.

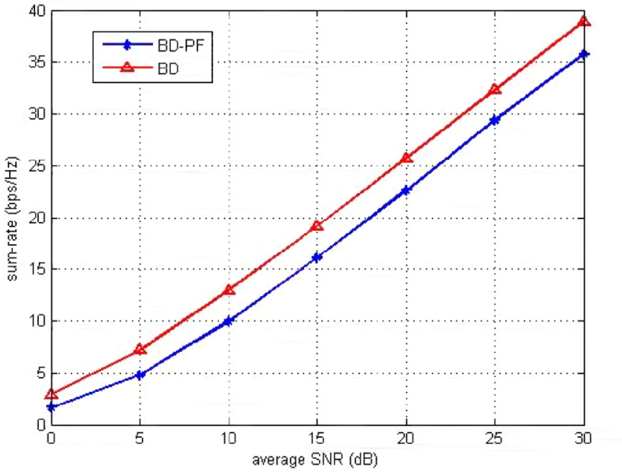

Fig. 3. The comparison of the proposed algorithm and BD

4.2 Determining the Size of the Alternative Set

In order to size of the set $\tilde{S}$, we define the fair factor F[9]:

$$F = \frac{(\sum_{k=1}^{K} x_k)^2}{K \sum_{k=1}^{K} x_k^2} \tag{13}$$

Here, x_k expresses the average throughput of the kth user. F varies from 0 to 1, when $F = 1$, the fairness is the best.

In the Fig. 4, it is shown that the better is the fairness, the worse is the sum-capacity, especially when the fair factor is larger than 0.7. We define the function G:

$$G(\tilde{S}) = F(\tilde{S}) * C(\tilde{S}) \tag{14}$$

$F(\tilde{S})$ is the function of the fair factor varying with the size of $\tilde{S}$, and $C(\tilde{S})$ is the function of the sum-capacity varying with the size of $\tilde{S}$. When $G(\tilde{S})$ has the maximum value, the size of the alternative set $\tilde{S}$ is the best.

In the simulation, the number of the total users is 50, the number of scheduled users is $M/N = 2$, so the size of the alternative set satisfies $2 \leq |\tilde{S}| \leq 50$.

Fig. 4 shows that the function G is convex, and G has a maximum value, when $|\tilde{S}| = 11$, which is the best size of the alternative set. From the TABEL 1, we see that when the size of the alternative is optimal, the sum-capacity of the system has small decline , but the fairness of the system increases significantly.

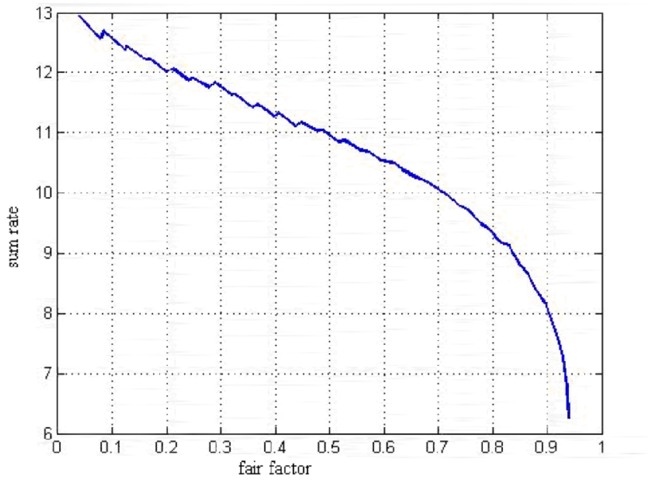

Fig. 4. The variation of the fair factor and sum rate

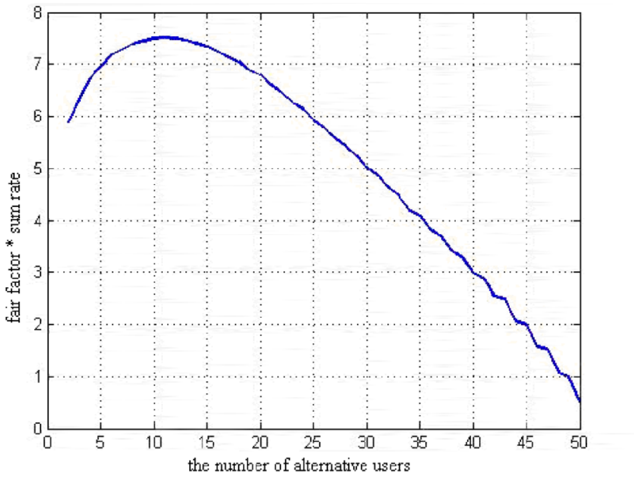

Fig. 5. G varies with the number of alternative users

Table 1. The performance of different sizes of the alternative set

The num of alternative set	2	11 (optional)	30	50
Fair facror	0.9418	0.8310	0.4309	0.0397
Sum-capacity	6.2759	9.1370	10.826	12.93

5 Conclusion

In this paper, an efficient user scheduling algorithm with fairness is proposed. Simulation results show that the proposed algorithm can get the multiplexing gain, ensuring the fairness, especially when the size of the alternative set is optimal.

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