A Novel Simple User Scheduling Algorithm for MIMO Downlink System

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Abstract. In this paper, we propose a user scheduling algorithm based on the codebook for multiuser MIMO system. Users can feedback the CDI information based on the codebook in the multiuser MIMO system. Based on the CDI information, the base station can effectively schedule the users semi-orthogonally. Simulation results show that substantial system throughput gains are achievable by the proposed joint optimal algorithm with appropriate correlation threshold factor.

Keywords: multiuser MIMO, CDI, user scheduling.

1 Introduction

Since a multiuser multiple-input multiple-output(MIMO) system has higher achievable throughput than a single user MIMO system, next generation cellular systems such as Long Term Evolution(LTE) include the multiuser MIMO techniques to achieve the high data rate[1]. For multiuser MIMO system, it's known that dirty paper coding(DPC) can achieve the information theoretical capacity, but the implementation of DPC is difficult in practice[2]. Several sub-optimal algorithms such as channel inversion[3], vector perturbation[4], and multiuser eigenmode transmission[5] have been studied for practical systems. However, the precoding technique requires the perfect channel state information(CSI) at the base station, which means huge feedback overhead. So in the practical system, the precoding matrix is selected based on the codebook, and partial CSI is achieved.

In the multiuser MIMO system, the number of active users which is the number of simultaneously supported users, is restricted by the number of transmit antennas at the base station and the rank of the channels. Therefore, the base

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[⋆] This work is supported by the National High-Tech. R&D Program of China (863 Program) under Grant No. 2009AA01Z205, and by the National Science Key Special Project of China under Grants No. 2010ZX03003-001,2008ZX03003-004 and 2009ZX03003-007.

P. Ren et al. (Eds.): WICON 2011, LNICST 98, pp. 323–330, 2012.
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station must consider user scheduling to maximize the system capacity. The exhaust algorithm is the optimal user scheduling algorithm[6], but because of its complexity, the implementation is difficult. [7] proposed a greedy user scheduling algorithm with low complexity, where block diagonalization can maximize the system sum-capacity. The scheduling algorithm based on the channel norm had been proposed in[8], a scheduling algorithm based on the channel correlation was proposed in [9]. All the algorithms require the perfect CSI at the base station, but in the practical system, the base station just knows partial CSI considering the feedback overhead. Especially the LTE system is a limited feedback system based on the codebook, and the base station knows limited CSI[10]. A user scheduling algorithm base on the PMI(Precoding Matrix Index) was proposed in [11]. In the algorithm, the users first select the PMIs from the codebook based on the SINR(Signal Interference Noise Ratio) and feedback the PMIs to the base station, the base station selects the first user with the maximum SINR, then selects the users with maximum SINR in the users whose precoding matrix is orthogonal to the codewords of the pre-selected users. Since the codewords in the codebook are not pairwise orthogonal, the number of scheduled users is restricted.

In this paper, we focus on the user scheduling based on the codebook in the multiuser MIMO downlink system. We propose a semi-orthogonal user scheduling algorithm based on the CDI(Channel Direction Index) information, the base station schedules the users using the CDI information, and makes the zero-forcing precoding for the selected users. The simulation results show that the algorithm improves the system sum-capacity and guarantees the low complexity.

The rest of the paper is organized as follows: In Section 2,we briefly describe the multiuser MIMO system and summarize the feedback procedures for the user scheduling. In the Section 3, we presents the details of the proposed scheduling algorithm. Section 4 provides the simulation results. Finally, Section 5 concludes the paper.

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_T transmit antennas at the base station and N_k receive antennas at the kth user as shown in Fig.1. $H_k \in \mathbb{C}^{N_k \times M_T}$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, the received signal of the kth user, y_k is given by:

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

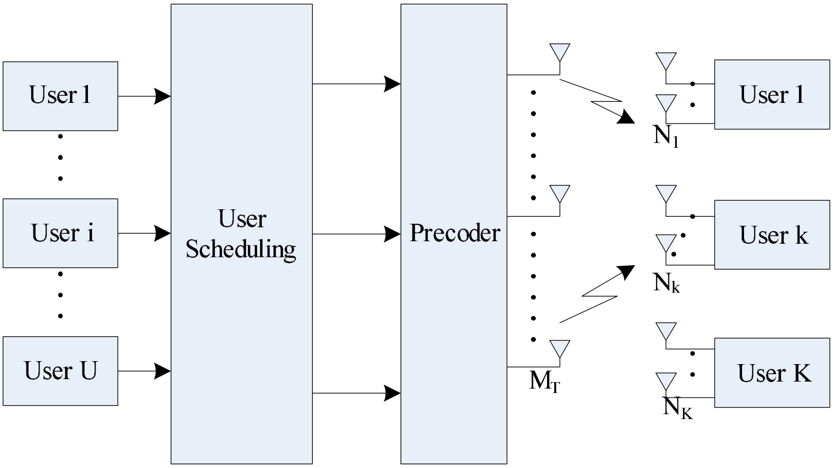

Fig. 1. MU-MIMO Downlink System Modem

Where $n_k \in \mathbb{C}^{N_k \times 1}$ denotes the additive Gaussian noise of the kth user whose elements have zero mean and unit variance. After the linear processing, the formula(1) can be expressed as:

$$\hat{y}_k = R_k^H (H_k \sum_{j=1}^{K} W_j s_j + n_k) \tag{2}$$

In order to eliminate the interference, the precoding matrix W_k of the kth user should be orthogonal with the channels of other users, that is:

$$H_k W_j = 0, k \neq j, 1 \leq k, j \leq k \tag{3}$$

The users will feedback the CDI information, first the users estimate their channel matrixes, then calculate their principal right singular vectors, which are their CDI information, finally, the users choose appropriate codeword and feedback the index to the base station. Assume F denotes the system codebook, in this paper, the LTE rel.8 codebook is used. The kth user chooses its codeword ν_k following the criterion as:

$$\nu_k = \arg \min_{\nu \in F} d(\nu, \bar{H}_k) = \arg \min_{\nu \in F} e_k \tag{4}$$

$\bar{H}_k = H_k / \|H_k\|$ is the kth user's normalized channel, $e_k = d(\nu, \bar{H}_k)$ presents the quantization error:

$$d(\nu, \bar{H}_k) = 1 - |\nu^H \bar{H}_k| \tag{5}$$

3 Proposed Scheduling Algorithm

In this section, we present the details of the proposed algorithm in subsection 3.1. Then discuss the sum-capacity region and the power allocation in subsection 3.2.

3.1 The Detail of the Proposed Scheduling Algorithm

Assume the base station will choose K users from the total U users based on the CDI information, the proposed algorithm can be summarized as following:

1. Select the first user: Denote the alternative user set U, service user set U_s, calculate the kth alternative users' $SINR$[12]:

   $$SINR_k = \frac{p\|H_k\|^2(1-e_k)}{1+p\|H_k\|^2 e_k} \tag{6}$$

   p is the transmit power, we assume the equal power allocation here, when the appropriate users are chosen , the power will be allocated by the water-filling. Then choose the first user μ_1 as following:

   $$\mu_1 = \arg\max_{k \in U} SINR_k \tag{7}$$

   Then update the sets: $U_1 = U_s / \{u_1\}, U_s = U_s \cup \{u_1\}$.
2. Select the ith user: if $|U_s| \leq K$, then

   $$U_i = \left\{k \in U_{i-1}, k \notin U_s \middle| |\nu_k^H \nu_j| \leq \alpha, j \in U_s\right\} \tag{8}$$

   α expresses the correlation threshold, which is constant number, in Section 4, we will discuss the value of α. If $|U_i|$, stop choosing users, else, choose the ith user:

   $$\mu_i = \arg\max_{k \in U_i} SINR_k \tag{9}$$
3. Repeat step 2, until enough users are chosen.

3.2 The Sum-Capacity of the System and the Precoding

Assume we have selected K(or less than K) users, making zero-forcing(ZF) precoding to the selected servicing users. Denote the accumulated channels of the service users as: $W = [w_1, \ldots, w_i, \ldots, w_k]$, the accumulated precoding matrixes of the service users are $\hat{H} = \left[\nu_1^T, \ldots, \nu_i^T, \ldots, \nu_K^T\right]^T$, wi expresses the precoding matrix of the ith user. Calculate the pseudoinverse of $\hat{H}$:

$$W = \hat{H}^+ = \hat{H}^H(\hat{H}\hat{H}^H)^{-1} \tag{10}$$

According to formula (1), we can get the system sum-capacity:

$$R = \max_{w_k} \sum_{k=1}^{K} \log \left\{ 1 + \frac{p_j |h_k w_k|^2}{1 + \sum\limits_{j=1, j \neq k}^{K} p_j |h_k w_j|^2} \right\}, \text{s.t} \sum_{k=1}^{K} p_k \|w_k\|^2 \leq P_T \tag{11}$$

p_j expresses the power efficient of jth user,P_T expresses the total transmit power.

After the ZF precoding, if the quantization error is small, we can assume the formula (3) is valid, then the sum-capacity of the system can be expressed as:

$$R^{ZF} \approx \max_{w_k} \sum_{k=1}^{K} \log\{1 + p_k\}, \text{s.t} \sum_{k=1}^{K} p_k \|w_k\|^2 \leq P_T \tag{12}$$

The optimal power allocation can be achieved by water-filling.

After normalization, the receiving signal for m relay nodes turns into:

$$\begin{aligned} \tilde{y}_{s,i} &= \frac{\sqrt{E_s} h_{s,i}}{\sqrt{E|y_{s,i}|^2}} s + \frac{n_{s,i}}{\sqrt{E|y_{s,i}|^2}} \\ &= \frac{\sqrt{E_s} h_{s,i}}{\sqrt{E_s |h_{s,i}|^2 + N_0}} s + \frac{n_{s,i}}{\sqrt{E_s |h_{s,i}|^2 + N_0}} \end{aligned} \tag{13}$$

4 Simulation Results

In the Section, we compare our proposed algorithm with the algorithm in [11](we denote it as PMI algorithm) from the sum-capacity of the system and discuss the value of the correlation threshold . The simulation parameter is listed in TABLE 1.

Table 1. The simulation parameter of Mu-MIMO downlik system

Channel	Flat fading Rayleigh channel
Data stream	2
The number of BS antenna	4
The number of MS antenna	1
The number of total users	10
The number of service users	2

In the Fig. 2-4, PMI capacity expresses the system sum-capacity using the PMI algorithm, ZF capacity expresses the optimal ZF capacity following the formula (12), Proposed Algorithm capacity expresses the real system sum-capacity using the proposed algorithm. When the quantization error is small, the curves of ZF capacity and Proposed Algorithm nearly coincide.

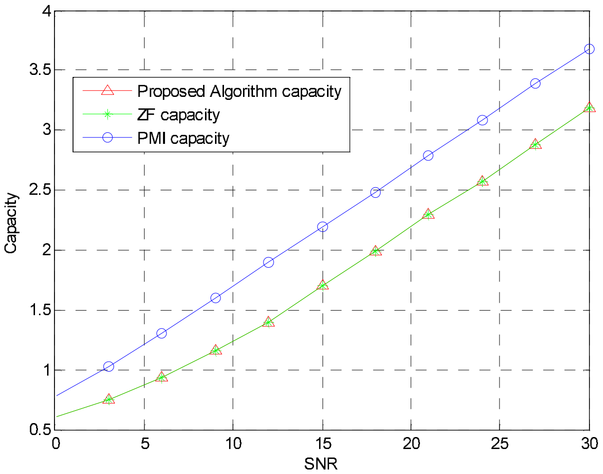

Fig. 2. $\alpha = 0.1$, Comparison of sum-capacity of different algorithms

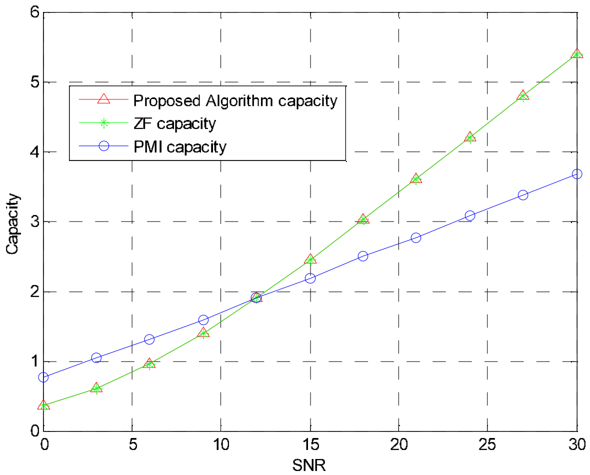

Fig. 3. $\alpha = 0.5$, Comparison of sum-capacity of different algorithms

In the Fig. 2, because the value of the correction threshold is small, the number of the scheduled users is restricted. The base station can not select enough service users, so the sum-capacity of the system loses.

In the Fig.3, the value of the correction threshold is moderate, then the base station can select enough service users. In the low SNR region, the performance of the proposed algorithm is slightly worse than PMI algorithm, because all the users' channel state are bad, the proposed algorithm based on the $SINR$ can not select users with good performance. As the SNR increasing, the performance of the proposed algorithm outperforms the PMI algorithm, because when the

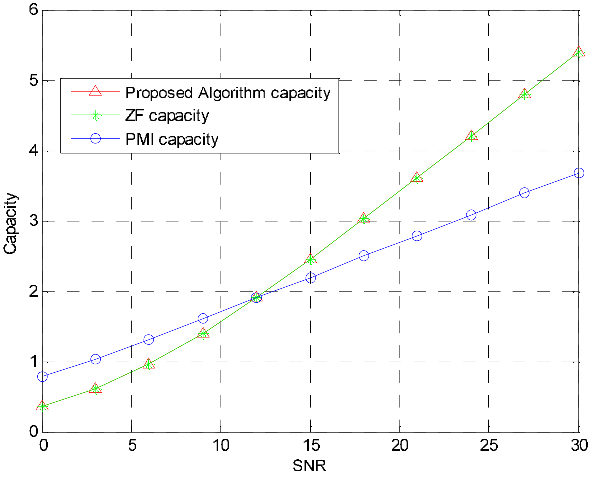

Fig. 4. $\alpha = 0.9$,Comparison of sum-capacity of different algorithms

channel state is good, the proposed algorithm can select good users and the paired users are semi-orthogonal, the interference of the service users is small.

In the Fig.4, the value of the correction threshold is large, the base station can schedule more users, but the orthogonality of the paired users is worse, meanwhile, the scheduling complexity increases. Comparing the Fig.3 and the Fig.4, increasing the value of the correction threshold contributes little to the system performance and increases the scheduling complexity. So correlation factor of about 0.5 is the best.

5 Conclusion

In this paper, we propose a semi-orthogonal user scheduling algorithm based on the CDI(Channel Direction Index) information in the multiuser MIMO system. By setting a reasonable correlation factor in ensuring the low complexity, the proposed algorithm can schedule semi-orthogonal users with good channel quality, thus ensuring little interference between service users. Simulation conclusions show that the proposed algorithm has improved the sum-capacity of the system significantly in high SNR region.

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