Grouping Based Proportional Fair User Schedule Algorithm in MU-CoMP

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Abstract. Aiming at improving the system uplink transmitting and fairness performance, a novel grouping based proportional fair schedule algorithm is proposed. By dividing users into several groups, computation complexity in user selecting is reduced. Proportional fair mechanic provides more fairness among users, preventing users from starving of transmitting. Simulation results show that the proposed algorithm improves the uplink CoMP system's sum capacity while keep all users in a quite fair state.

Introduction

In the LTE-Advanced system, Cooperated Multi Point (CoMP) technology becomes very popular because of its capability on canceling inter cell interference. Recent researches on the CoMP can be classified into uplink CoMP (U-CoMP) and downlink CoMP (D-CoMP). In this paper, we mainly discuss a novel scheduling algorithm about U-CoMP.

In the modern mobile communication system, MIMO technology is playing an important part in increasing the system capacity due to its spatial multiplexing and diversity gain. However, the deployment of multi antennas on the mobile equipment is limited due to the costs and technical difficulties. Even the devices that have already been equipped with multi antennas have little performance increase due to the spatial correlation of antennas. In this situation, the multi user CoMP (MU-CoMP) was proposed. In a MU-CoMP system, two or more single antenna devices are united to form a virtual MIMO system with the base station. Been scheduled by the base station, all users in the system transmit their signals using the same time and frequency resource in an orderly manner.

Recent researches in the MU-CoMP mainly focus on the user pairing scheme. Scheduler of the base station, i.e. the E-Node B, dispatches user pairs during the scheduling period. Notel proposed two types of user pairing and scheduling method in [1], including the random user pairing scheduling and orthogonal user pairing scheduling, and the orthogonal user pairing scheduling can be implemented under the orthogonal formula and determinant formula criteria. A SNR based paring scheduling method is proposed in [2]. In these works only the system performance is considered, but the fairness is ignored. Chen, etc. presented a novel user pairing algorithm in [3], in which double proportional fair (PF) method is used, and the system performance was improved. Many newly user pairing algorithms were proposed based on Chen's work, but these works still aim at user pairing.

In the realistic environment, the amount of users in a single cell is usually very large, especially in some hot spots, the larger the amount of users is, the more the count of user pairs will be, then the payload of the scheduler in the E-NodeB would significantly increase. This may be one of the side effects of the user pairing scheme. On the other hand, by using user pairing scheme, only two users are dispatched in the same schedule slot, thus the system resources are not made full use. It has been proved in [4] that the multiplexing of the same time frequency resource block by multiple users will significantly increase the system performance, when the count of transmitting antennas is less than that of the receiving antennas.

In this paper, a user grouping based proportional fair (GPF) schedule algorithm is proposed. By dividing users into several groups, the computational complexity is reduced. Furthermore, a better tradeoff between the fairness and system performance is achieved.

System Model

In this paper, we consider a single cellular cell scenario as shown below.

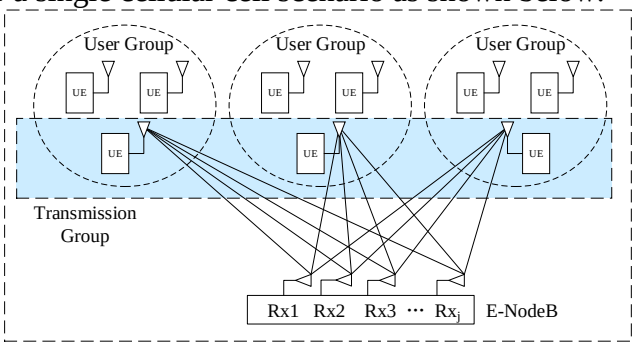

Figure1: MU-CoMP Scenario

In this scenario, N_t users are equipped with only one antenna each, and the E-NodeB is equipped with $N_r \geq N_t$ antennas, perfect channel state information (CSI) can be retrieved by the receiver. All the other conditions are set to be perfect. In this system, the received signal at the E-NodeB can be written as

$$\mathbf{y} = \sqrt{E_s}\sqrt{\mathbf{P}}\mathbf{H}\mathbf{x} + \mathbf{n} \quad (1)$$

where $\mathbf{y}$ is an $N_r \times 1$ vector representing the received signal in frequency domain. $\mathbf{x}$ is an $N_t \times 1$ vector representing the transmitted signal from users. E_s is the average transmitting signal energy in one symbol time, and assume each user has identical value. $\mathbf{H} = [\mathbf{h_1}, \cdots, \mathbf{h_{N_t}}]$ is an $N_r \times N_t$ matrix, representing the channel between users and E-Node B. n is an $N_t \times 1$ vector, representing the zero-mean additive white Gaussian noise (AWGN), and $E(\mathbf{nn}^{\mathrm{H}}) = N_0 \mathbf{I}_{N_t}$. $P = diag(p_1, \cdots, p_{N_t})$ representing the path loss between the transmitting and receiving antennas. Thus the uplink capacity of this system can be calculated as

$$\begin{aligned} C &= \mathrm{lb}\ \det(\mathbf{I}_{N_t} + \frac{E_s \mathbf{P}}{N_0 n}\mathbf{H}^{\mathrm{H}}\mathbf{H}) \\ &= \sum_{i=1}^{N_t} \mathrm{lb}[1 + \frac{E_s p_i}{N_0 n}\lambda_i(\mathbf{H})] \end{aligned} \quad (2)$$

Where $\lambda_i(\mathbf{H})$ is the ith eigenvalue of $\mathbf{H}^{\mathrm{H}}\mathbf{H}$. *n* is the count of transmitting antennas of a single user, and here *n*=1.

In this system, resource blocks are shared by multi-users to improve the system performance at the transmitting side. At the receiving side, semi-definite relaxation (SDR) decoder[5]is adopted to ensure all data stream can be separated. The SDR decoder is an effective solution for multi user detection, the performance of which is very close to that of the maximum likelihood detection algorithm, but the cost of SDR is significantly decreased.

Grouping Based Proportional Fair Schedule (GPF) Algorithm

User grouping

In the realistic cell, the count of users may be very large. If we try selecting *n* transmitting users out of *N* users, the total combination would be C_N^n . When user grouping is adopted, the computation complexity will significantly decreased.

This algorithm groups users using instant SNR, position, velocity and direction as metrics. Taking the computation complexity into account, the k-means clustering algorithm[6] is used. K-means cluster is a light weight clustering algorithm, a very important initialization parameter, k, is needed, which is used to determine how many groups the users will be divided into. As stated former, we take the count of receiver antennas N_r as the initialization parameter, i.e. the users will be divided into N_r groups after grouping.

Proportional fair criteria

After grouping users, proportional fair criteria is used to select the transmitting users. In the following section proportional based user selection will be discussed.

We divide the user selection procedure into two sub tasks. One is group selection, in which transmitting groups are selected. Only users in transmitting groups have chance to send data in the coming schedule period. Another sub task is user selection, in which users within the transmitting groups is selected. Considering the complexity, we choose proportional fair mechanism in group selection, while round robin mechanism is chosen in user selection.

The schedule of user groups at time t can be formulated as the following problem:

$$g_n = \begin{cases} \arg\max_{i \in G} \left(\frac{C_i(t)}{\overline{C}_i(t)}\right), & \mathrm{n} = 1 \\ \arg\max_{g} \left(\frac{C_g(t) + \sum_{i=1}^{n-1} C_{g_i}(t)}{\overline{C}_g(t) + \sum_{i=1}^{n-1} \overline{C}_{g_i}(t)}\right), \mathrm{g} \in G \setminus S, & n \geq 2 \end{cases} \quad (3)$$

$$G = \{1, \cdots, k\}, S = \{g_1, \cdots g_{n-1}\}$$

$$\mathrm{s.t.}$$

$$\sum_{i=1}^{n} C_{g_i} \leq C$$

Where C is the total uplink capacity, G representing the set of user groups, S representing the set of selected groups, g_n representing the nth group in S. $C_x(t)$ is the uplink capacity of group x, which is determined by the users from group x. It is calculated as follow:

$$C_x(t) = \mathrm{lb}(1 + \tau_x(t)) \quad (4)$$

$\tau_x(t)$ is associated with the receiver type, it can either be $\mathrm{SNR}_{i,\mathrm{u}}(t)$ or $\mathrm{SINR}_{i,\mathrm{u}}(t)$. In this paper, as the SDR decoder is adopted, so $\tau_{i,u}(t)$ is $\mathrm{SNR}_{i,\mathrm{u}}(t)$.

$\overline{C}_x(t)$ is the average uplink capacity of group x. $\overline{C}_i$ can be formulated as follow[7,8]:

$$\begin{cases} \overline{C}_i(t) = (1 - \frac{1}{t_c})\overline{C}_i(t-1), & i \neq g_1 \\ \overline{C}_i(t) = (1 - \frac{1}{t_c})\overline{C}_i(t-1) + \frac{1}{t_c} c_i(t), & i = \mathrm{g}_1 \end{cases} \quad (5)$$

Where t_c is update interval, the average capacity will be updated every t_c ticks.

After the transmittinggroups are selected, uses in each group is selected by Round Robin mechanism. Users that have been selected for transmission will not be selected until the schedule round is complete.

The implementationsteps of the algorithm are as follow:

Step 1. Group users using k-means clustering algorithm with users' multi properties.

Step 2. Select user groups that satisfy Eq. (3)as transmitting groups.

Step 3. Select one user from each transmitting group using Round Robin mechanism, and put these users into set U_t.

Step 4. Calculate C_U, which is the capacity of U_t. If $C_U < C$, delete users in U_t from each group and go to Step 3, until no user can be selected.

Simulation and Results

In this section, the proposed algorithm is tested by Monte Carlo method. The simulation results are compared with existing algorithms.

Simulation settings

In this section, the algorithm is simulated in a single cell scenario. We assume that the resource block occupation of each user is set to no limit. Users are generated randomly in the E-NodeB coverage, when a user reaches the edge of the cell, he is reflected back to the cell. According to the Release 12 of 3GPP LTE-Advanced, the uplink transmission time interval (TTI) is 1ms, thus in 1000 TTI the user moves 16.67m at most. Thus we group users every 200 TTIs, and update the average capacity every 50 TTIs.

The detailed simulation settings are as follow:

Each Data transmission Period	≤1TTI
Terminal Antenna Count（n）	n=1
User Count（N_t）	N_t=100
E-NodeB Antenna Count（N_r）	N_r =8
SNR	-10~20 [dB]
Path Loss	128.1+37.61 lb(R)，R：[km]
N_0	-174 [dBm/Hz]
Cell Radius	250 [m]
Velocity	≤60 [km/h]
Direction	Any

Table 1: Simulation Settings

In order to compare the fairness of each algorithm, the fairness coefficient shown below is adopted:

$$\mathrm{F}_c(\Delta t) = \frac{(\sum_{u=1}^{U} c_u(\Delta t))^2}{U \cdot \sum_{u=1}^{U} c_u{}^2(\Delta t)} \quad (6)$$

Where U is the count of users, $c_u(\Delta t)$ representing the sum uplink capacity of the uth user in schedule period Δt. It's obviously that the absolute fairness is achieved when $\mathrm{F}_c(\Delta t) = 1$, i.e. all users have retrieved the same uplink capacity.

The Round Robin paring (RRP) scheme, Double Proportional Fair Pairing (DPFP) scheme, Greedy scheme are compared.

Simulation result

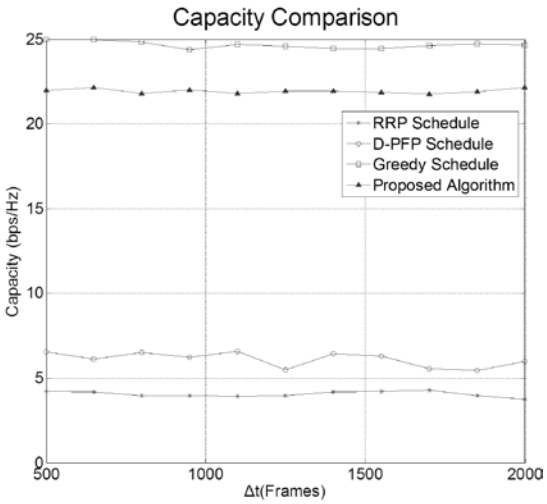

Figure2: Capacity Comparison

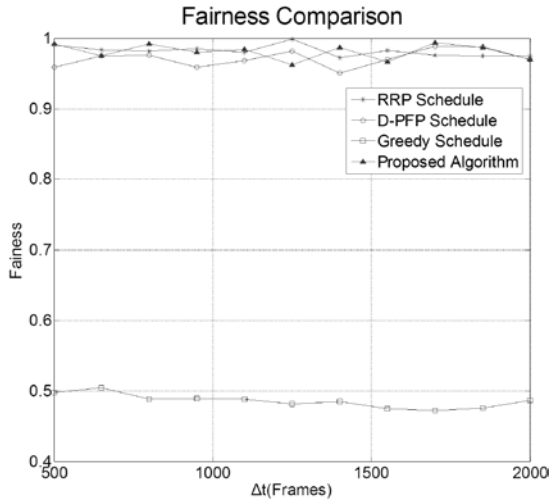

Figure3: Fairness Comparison

Figure2shows the capacity comparison among different algorithms. We can see that the RRP has the lowest capacity, because it considers the user fairness only. The D-PFP has a better performance, it takes both fairness and system performance into account. But it's obviously that the mentioned two user paring algorithms cannot make full use of the system resources, especially the spatial multiplexing benefits brought by MIMO technology. The Greedy schedule algorithm has the highest system performance, because it always selects user who has the highest uplink capacity as the transmitting user.

Figure3 shows the fairness comparison among different algorithms. All algorithms have similar fairness performance except the Greedy schedule algorithm.

From the two figures above, it is noted that the proposed algorithm achieves a good tradeoff between the uplink capacity and the fairness.

Furthermore, Figure4 presents the comparison of CDF of each algorithm. It can be observed that the CDF curve of the proposed algorithm is steeper than the others', which shows that the proposed algorithm can provide more benefits to the users.

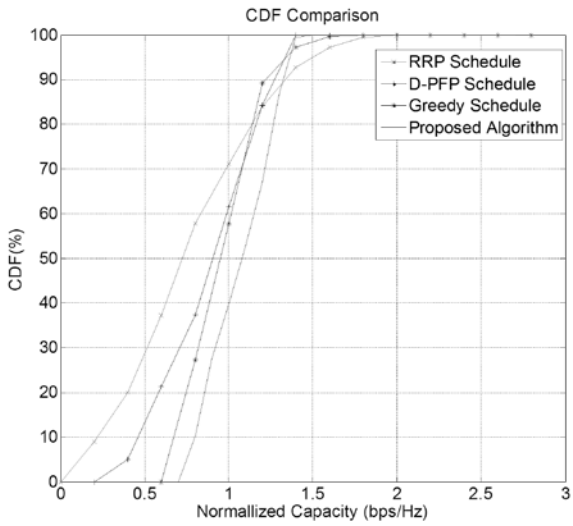

Figure4: CDF Comparison

Conclusion

In this paper, we discussed the issues on user scheduling of U-CoMP system, and have proposed a grouping based proportional fair schedule algorithm. The capacity and fairness performances of the proposed algorithm have been compared with those of existing algorithms. Simulation results indicate that the proposed algorithm archives a fairly good tradeoff between the system uplink capacity and user fairness.

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