A Novel Opportunistic Scheduling Algorithm in Coordinated Multi-Point Transmission Scenario

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***Abstract*—In this paper, we propose a novel opportunistic scheduling algorithm, joint useful and interference channel based scheduling (JUICS), in coordinated multi-point (CoMP) transmission scenario. Our scheme jointly considers the useful channel condition of the scheduled user from its serving cell and the orthogonality between that and the corresponding interference channels to concurrently scheduled users in neighboring CoMP cells, thus to exploit multi-user diversity (MUD) and mitigate inter-cell interference (ICI) simultaneously. The performance of the proposed algorithm is evaluated through simulation in terms of the cumulative distribution performance of the received signal to interference plus noise ratio (SINR) and that of the scheduled times of all CoMP users. Results show that, with limited complexity and overhead, our scheme can significantly enhance the received SINR with relatively better fairness guarantee, thus to achieve the largest throughput and utility comparing to several well-known scheduling algorithms.**

***Index Terms*—coordinated multi-point (CoMP) transmission, inter-cell interference (ICI), multi-user diversity (MUD), opportunistic scheduling.**

I. Introduction

Coordinated multi-point (CoMP) transmission is considered for LTE-Advanced as a tool to improve the coverage of high data rates and the cell-edge throughput [1], which has received a lot of attention recently [2]–[5]. It contains two categories: 1) joint processing, in which user data is available at each base station (BS); 2) coordinated scheduling/beamforming (CS/CB), in which user data is only available at serving BS but user scheduling/beamforming decisions are made with coordination among cells. Since the first category needs user data shared among multiple BSs which brings a huge overhead to the network and is theoretically similar to the previous multi-user multi-input multi-output (MU-MIMO) system which has been exhaustively researched, we focus on the second one.

CS/CB explores a different type of coordination where user transmission strategies and resource allocation schemes, rather than user data, are coordinated across the BSs, which requires much less back-haul communication, and is much easier to implement in a practical deployment [6]. Lots of researches also have been done on CS/CB [7]–[13]. However, to the best of our knowledge, an effective scheduling algorithm with limited complexity and overhead for CoMP users in CS/CB is still devoid. For traditional scheduling schemes in single cell scenario, such as round robin scheduling, max rate scheduling and proportional fairness scheduling [14], users are scheduled only according to local channel feedbacks to exploit multi-user diversity (MUD). But none of them may be favorable in CoMP scenario, in which cell-edge CoMP users often suffer from severe inter-cell interference (ICI). Thus, in CoMP area, how to cooperatively select users to transmit by each cell to exploit MUD and mitigate ICI simultaneously with limited complexity and overhead becomes an important question. A good scheduling algorithm should jointly consider useful signal from a cell to its scheduling user and the corresponding interference signal from the same cell to concurrently scheduled users in neighboring CoMP cells, meanwhile it should be applicable to any reasonable beamforming strategy. Due to the above consideration, we propose a novel scheduling algorithm, joint useful and interference channel based scheduling (JUICS), which opportunistically selects user with a large value of the cumulative distribution function (CDF) of the norm of local useful channel to exploit MUD and a higher orthogonality between local channel and the corresponding interference channels to concurrently scheduled users in neighboring cells to mitigate ICI. The effectiveness of our scheme is verified by simulation. The results show that, comparing to several well-known scheduling algorithms, our proposed JUICS algorithm can significantly enhance the CDF of received signal to interference plus noise ratio (SINR) with relatively better fairness guarantee, thus to achieve the largest throughput and utility with limited complexity and overhead.

The remainder of this paper is organized as follows. In Section II, we introduce the system model. Then we shortly introduce RRS, MRS and PFS in single cell scenario, then reconsider them in CoMP scenario and propose a novel algorithm, JUICS, in Section III. Using eigenmode beamforming, we compare the performance of RRS, MRS, PFS and JUICS in Section IV. The whole paper is concluded in Section V.

II. System Model

A. Network Model

We consider a typical three-cell CoMP scenario within a practical multi-cell wireless network, where each BS has N_t antennas and each user has a single antenna. As shown in

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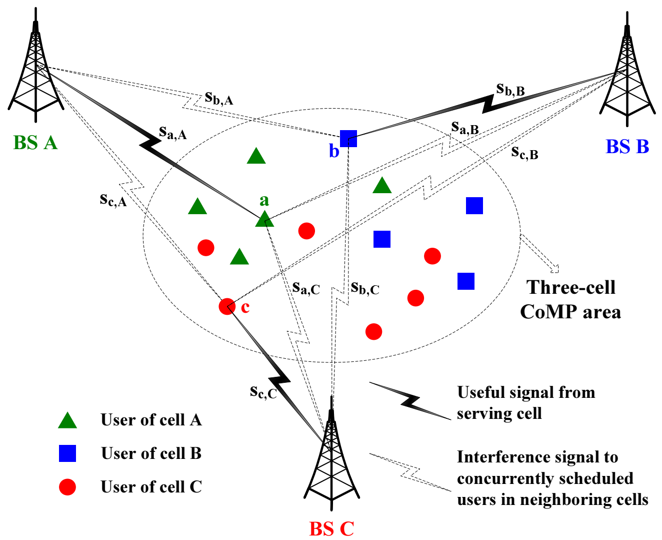

Fig. 1. A typical three-cell CoMP scenario.

Figure 1, each cell is controlled by a BS and the data for a user is only stored in its serving BS. For convenience, cell and BS are used interchangeably throughout this paper. For ease of presentation, inner region of the ellipse represents the CoMP area. In reality, its shape would be irregular due to the network topology, BS configuration, shadow fading and the criterion of choosing CoMP users.

We use $\mathbb{C}$, $\mathbb{U}$ and $\mathbb{U}_J$ to represent the set of CoMP cells, CoMP users and CoMP users belonging to cell J, respectively. It is obvious that $\mathbb{C} = \{A,\ B,\ C\}$ and $\mathbb{U} = \mathbb{U}_A \cup \mathbb{U}_B \cup \mathbb{U}_C$. We assume that each user feeds back the instantaneous channel status to its serving BS on each scheduling unit, and all the three CoMP BSs could exchange the channel information errorfree with no delay. Then, on a certain scheduling unit, when users a, b and c are scheduled by cells A, B and C, respectively, we give the received signal of user a in equation (1) while omitting that of users b and c due to similarity.

$$\begin{aligned} y_a &= s_{a,A} + s_{a,B} + s_{a,C} + s_{IN_a} \\ &= \sqrt{P_{a,A}} h^*_{a,A} w^A_{a,bc} x_a + \sqrt{P_{a,B}} h^*_{a,B} w^B_{b,ac} x_b \\ &\quad + \sqrt{P_{a,C}} h^*_{a,C} w^C_{c,ab} x_c + s_{IN_a} \end{aligned} \tag{1}$$

where h^* is the conjugate transpose of a vector h and

- $s_{i,J}$ is the received signal of user $i \in \mathbb{U}$ from cell $J \in \mathbb{C}$.
- s_{IN_i} is the combination of the interference signal from two-tier non-CoMP cells of user i's serving cell I and the noise signal.
- $P_{i,J}$ is the average received power at user i from cell J, which is determined by the transmit power, path loss and shadow fading.
- $h_{i,J}$ is the $N_t \times 1$ channel vector of user i from cell J. We assume each component of $h_{i,J}$ is independent and identically distributed (i.i.d.) circular symmetric complex Gaussian variable with zero mean and unit variance.
- $w^I_{i,mn}$ is the beamforming vector for cell I when users $i \in \mathbb{U}_I$, $m \in \mathbb{U}_M$ and $n \in \mathbb{U}_N$ are chosen by their respective cells. It is normalized, i.e. $\left\|w^I_{i,mn}\right\|^2 = 1$, and its design will be discussed later in this section.
- x_i is the transmit signal for user i, with the power constraint $E[|x_i|^2] = 1$.
- s_{IN_a} is the combination of interference and noise signal.

Then the received SINR of user a is

$$SINR_a = \frac{P_{a,A}|h^*_{a,A} w^A_{a,bc}|^2}{P_{a,B}|h^*_{a,B} w^B_{b,ac}|^2 + P_{a,C}|h^*_{a,C} w^C_{c,ab}|^2 + P_{IN_a}} \tag{2}$$

where P_{IN_a} is the power of s_{IN_a}, which contains two part: 1) received interference signal power from neighboring two-tier non-CoMP cells, which is a location-dependent variable and could be treated as background noise; 2) thermal noise power, which equals the thermal noise power spectral density multiple the bandwidth of a scheduling unit.

Give $SINR_a$, the achievable rate of user a is

$$r_a = B_W \cdot log_2(1 + SINR_a) \tag{3}$$

where B_W is the bandwidth of a scheduling unit. For convenience, we use the Shannon capacity as the communication rate in equation (3) for theoretical analysis.

B. Beamforming Strategy

In typical three-cell CoMP scenario, the choice of the optimal beamforming strategy is still an open question [15], which is also out of the scope of this paper. Meanwhile, our proposed JUICS should be applicable to any reasonable beamforming strategy. Thus in the following, we take the well-known eigenmode beamforming (EMBF) as an example, in which the beamforming vector is the channel direction, i.e., for user $a \in \mathbb{U}_A$, its beamforming vector is

$$w^A_{a,bc} = \frac{h_{a,A}}{\|h_{a,A}\|} \tag{4}$$

III. A Novel Opportunistic Scheduling Algorithm

In this section, we first introduce three well-known scheduling schemes in single cell scenario, then reconsider them in CoMP scenario. After that, we propose our novel scheduling algorithm, JUICS.

A. Three Well-Known Scheduling Schemes in CoMP Scenario

There are a large number of scheduling algorithms proposed in single cell scenario, in which round robin scheduling (RRS), maximum rate scheduling (MRS) and proportional fairness scheduling (PFS) are widely researched. Resources are allocated to users in a round robin way in RRS, and to that with the maximum instantaneous rate in MRS. In PFS, the user with the highest ratio of instantaneous rate to average throughput is selected to be served. It can make a good tradeoff between spectrum efficiency and fairness [14].

In CoMP scenario, RRS remains the same as that in single cell scenario, in which each cell schedules user one by one independently. However, MRS and PFS are difficult to apply since the instantaneous rate of the selected user in each cell is hard to obtain. We can see it clearly from equations (2)-(4), where the instantaneous rate of a user is jointly decided by the concurrently scheduled uses in the other two CoMP cells and their respective beamforming vectors. Thus user scheduling, beamforming vectors design and the instantaneous rates of scheduled users are coupled with each other.

In the following, we try to use the feedback only from local cell to simplify the coupled problem, which is also similar to the method used in [11], [16]. First we revise the $SINR_a$ in equation (2) when only considering local feedback,

$$SINR'_a = \frac{P_{a,A}\|h_{a,A}\|}{P_{a,B}\|h_{a,B}\| + P_{a,C}\|h_{a,C}\| + P_{IN_a}} \tag{5}$$

Since all of the components in equation (5) could be obtained by each user independently through pilot detection, cell A could get all $SINR'_i, i \in \mathbb{U}_A$. Then together with equation (3), cell A could get all estimated rate r'_i which is indispensable in MRS or PFS procedure.

Then MRS and PFS in each CoMP cell $I \in \mathbb{C}$ become

$$\text{MRS}: \quad i = \arg\max_{i \in \mathbb{U}_I} \; r'_i \tag{6}$$

and

$$\text{PFS}: \quad i = \arg\max_{i \in \mathbb{U}_I} \frac{r'_i}{\widetilde{R_i}} \tag{7}$$

where $\widetilde{R_i}$ is the long-term average throughput of user i over past t_c scheduling units, which is updated as

$$\widetilde{R_i}^{+} = \begin{cases} (1 - \frac{1}{t_c})\widetilde{R_i} + \frac{1}{t_c} r_i, & \text{if scheduled,} \\ (1 - \frac{1}{t_c})\widetilde{R_i}, & \text{else.} \end{cases} \tag{8}$$

where $\widetilde{R_i}^{+}$ is the long-term average throughput after one scheduling, which is updated by practical instantaneous rate r_i from equations (2)-(4) rather than the estimated rate r'_i.

B. JUICS Algorithm

In fact, RRS, MRS and PFS consider only the local feedback from serving BS while ignoring the corresponding interference signal to concurrently scheduled users in neighboring CoMP cells. All of them exploit only MUD while ignoring the ICI completely. Then in the following, we propose a novel scheduling algorithm, which jointly considers MUD exploitation and ICI mitigation as follows

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Joint useful and interference channel based scheduling (JUICS) Algorithm.

On each scheduling unit, each cell $I \in \mathbb{C}$ performs:

1: Sorts the CDF values of the norms of all the users' instantaneous channel feedback $F(\|h_{i,I}\|), i \in \mathbb{U}_I$ in descending order.

2: Chooses the largest M-percent feedbacks, asks the corresponding users to feed back the interference channel $h_{i,J}, i \in \mathbb{U}_{I_M}, J \in \mathbb{C}, J \neq I$ from neighboring CoMP cells, where $\mathbb{U}_{I_M}$ represents the set of users within the M-percent users.

3: For each user $i \in \mathbb{U}_{I_M}$, sends all of its channel information $h_{i,J}, J \in \mathbb{C}$ to all the other CoMP cells.

4: Having all the channel information, chooses the most orthogonal user pair as follows,

$$(a, b, c) = \arg \min_{a \in \mathbb{U}_{A_M},\, b \in \mathbb{U}_{B_M},\, c \in \mathbb{U}_{C_M}} \rho_A + \rho_B + \rho_C$$

where ρ_A, ρ_B and ρ_C are

$$\begin{aligned} \rho_A &= \left|h^n_{a,A} \cdot h^n_{b,A}\right| + \left|h^n_{a,A} \cdot h^n_{c,A}\right| \\ \rho_B &= \left|h^n_{b,B} \cdot h^n_{a,B}\right| + \left|h^n_{b,B} \cdot h^n_{c,B}\right| \\ \rho_C &= \left|h^n_{a,C} \cdot h^n_{a,C}\right| + \left|h^n_{c,C} \cdot h^n_{b,C}\right| \end{aligned}$$

and h^n represents the normalization of vector h.

5: End.

Remark 1: The above scheme is not limited to three-cell CoMP scenario. For any N-cell CoMP scenario, our algorithm still works with different complexity and overhead. Besides, it is not limited to any practical beamforming strategy.

Remark 2: The parameter M in Step 2 should be chosen carefully, which decides the weight we put on MUD exploration and ICI mitigation. On one hand, only choose the user with the largest feedback in Step 2 means that we pay all attention to exploiting the MUD. On the other hand, $M = 100\%$ represent that we choose the most orthogonal user pair to mitigate the ICI as much as possible while ignoring the MUD exploration completely.

IV. Simulation

A. Simulation Setup

In this section, we compare the performance of RRS, MRS, PFS and JUICS. One scheduling unit here is consistent with the definition of one physical resource block in 3GPP LTE, i.e., $180\ kHz\ *\ 1\ ms$ [17].

The ITU urban micro-cell scenario (Umi) [18] is adopted for modeling the multi-cell networks, which is strongly recommended by 3GPP LTE [1]. The corresponding parameters are shown in Table I.

First, we choose CoMP user i in each cell which satisfy the following condition

$$|P_{i,K} - P_{i,J}| \leq \Delta, \forall\ K, J \in \mathbb{C} \tag{9}$$

where Δ is the threshold of the maximal difference of average received power from different CoMP cells, we set it as 5 dB here. And we take $N_t = 3$ as an example.

B. Simulation Results

In the following, we compare the four scheduling algorithms through the metrics of the CDF of the received SINR and that of the scheduled times of all users, respectively. The two metrics represent the efficiency and fairness of a scheduling algorithm.

TABLE I
SIMULATION PARAMETERS

Parameter	Assumption
Cellular layout	Hexagonal grid, 19 sites, 3 sectors (cells) per site
Inter-Site Distance	200 m
Carrier Frequency	f_c = 2.5 GHz
Path-loss	$36.7log_{10}d[m] + 22.7 + 26log_{10}f_c$
BS TX power	41 dBm for 10 MHz, 24 dBm for one PRB
BS antenna height	10 m
UE antenna height	1∼ 2.5 m
BS antenna pattern	3D
UE antenna pattern	omni directional
User distribution	randomly and uniform distribution
t_c in equation (7)	1000 scheduling units
Thermal noise level	-174 dBm/Hz

In each simulation, we give 1000 scheduling units for each CoMP user. And we randomly perform the simulation 100 times to get the average performance of all of the four scheduling schemes. For our proposed JUICS, we select $M = 10\%$ in Step 2.

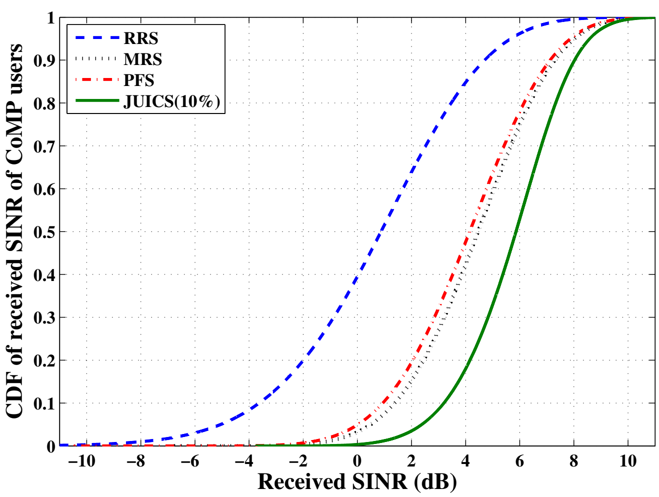

Fig. 2. CDF of received SINR of all users.

The CDF of received SINR of all users of all four scheduling algorithms are shown in Figure 2. We can find that the performance of RRS is the worst since it choose user one by one independently without any consideration on MUD exploration or ICI mitigation. Since MRS always choose user with the largest estimated rate to transmit, its performs is better than RRS. Similar to that in single cell scenario, PFS can make a tradeoff between efficiency and fairness so as to exploit MUD with fairness guarantee, the received CDF of it is slightly worse than MRS. For our proposed JUICS, it jointly consider MUD exploration and ICI mitigation when selecting users for transmission, the efficiency of it is the best. Its performance surpass that of MRS by about 2 dB.

The CDF of users' scheduled times of all four scheduling algorithms are shown in Figure 3. Once a user is scheduled, it gets a scheduling unit. This metric represents the fairness

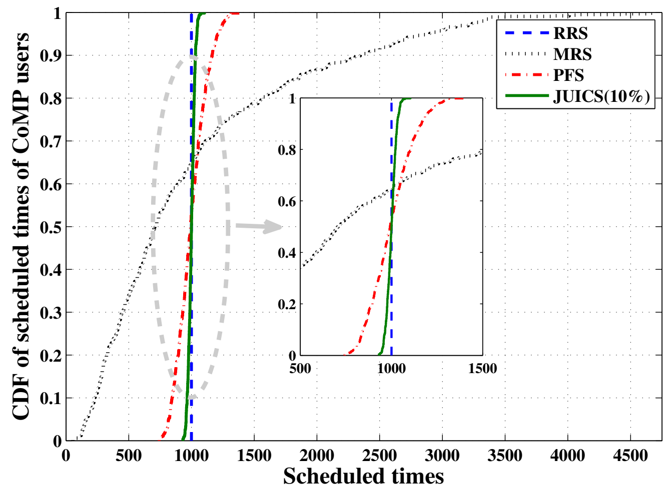

Fig. 3. CDF of scheduled times of all users.

of a scheduling algorithm. We can find that RRS is the most fair one in which each user gets equal scheduling units. While MRS is the most unfair one since it always select users with the largest estimated rate to transmit and give more scheduling opportunities to those users. In the enlarged figure of Figure 3, we can find that both PFS and JUICS maintain a relatively better fairness. While JUICS performs even better than PFS since both Step 2 and 4 in JUICS could guarantee the fairness to a significant extent.

In the following Table II, we give two more metrics of the four scheduling algorithms, i.e, total throughput and network utility. Total throughput is the sum of the long-term average throughput of each CoMP user $i \in \mathbb{U}$, i.e.,

$$\text{Total throughput} = \sum_{i \in \mathbb{U}} \widetilde{R_i} \tag{10}$$

Network utility is the sum of the widely used log utility of the long-term average throughput of each CoMP user $i \in \mathbb{U}$, i.e.,

$$\text{Network utility} = \sum_{i \in \mathbb{U}} log(\widetilde{R_i}) \tag{11}$$

where $\widetilde{R_i}$ is in kbps.

TABLE II
TOTAL THROUGHPUT & NETWORK UTILITY

Scheduling schemes	Total throughput	Network utility
RRS	654.2 kbps	64.8945
MRS	1049.2 kbps	68.3257
PFS	1012.2 kbps	77.3081
JUICS (M=10%)	1222.8 kbps	82.7527

As shown in Table II, our proposed scheduling algorithm JUICS achieves the largest throughput and utility at the same time.

In the following, we evaluate the performance with different M in our proposed JUICS algorithm.

In Figure 4, we show the CDF of the received SINR of our proposed algorithm with different M in Step 2. For clarity,

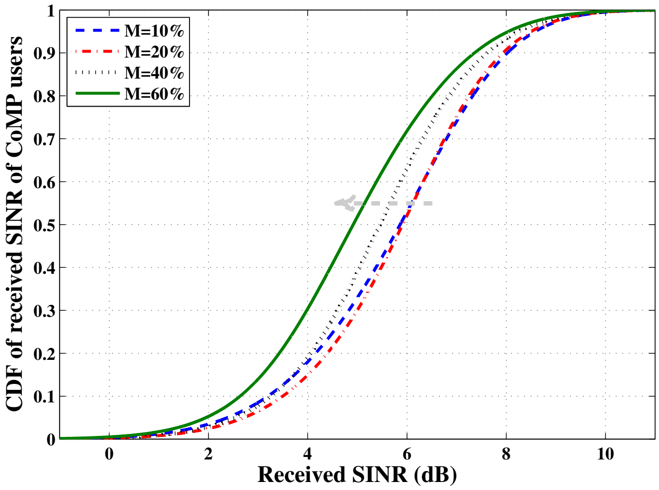

Fig. 4. CDF of received SINR with different M.

we only show parts of the performance of $M \in (0, 1]$. We can find that the curve of SINR is not better and better with the increasing M. That is because with increasing M in Step 2, more and more users are considered for ICI mitigation. Meanwhile, we put less and less attention on MUD exploitation, which could not be ignored in a typical three-cell CoMP scenario within a practical multi-cell networks. From this figure, $M = 10\%$ and 20% may be two good choices.

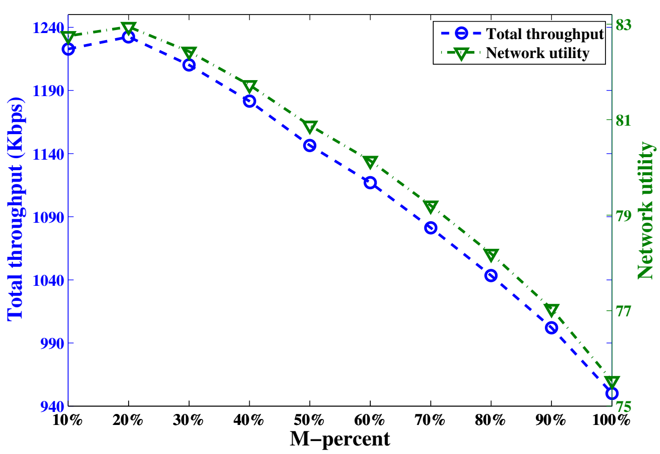

Fig. 5. Network utility & Total throughput with different M.

In Figure 5, we show the total throughput and network utility with various M. We can find that both of the two metrics achieve their maximum when $M = 20\%$. Since the complexity and overhead of JUICS increased exponentially with M and the two metrics deteriorate slightly with $M = 10\%$ comparing to their maximum, we choose $M = 10\%$ as the optimal operating parameter for our proposed algorithm, JUICS.

Besides, we also evaluate our algorithm with zaro-forcing beamforming, it achieves the similar superiority as that with EMBF.

V. Conclusions

In this paper, we propose a novel scheduling algorithm, JUICS, for users in CoMP area within a practical multi-cell networks. Compared to RRS, MRS and PFS, our algorithm maintains the best received SINR with relatively better fairness guarantee, thus to achieve the largest throughput and utility. Besides, we evaluate our algorithm with various parameter, simulation results show that 10% is a good choice with better performance and limited complexity and overhead.

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