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A Novel Resource Scheduling Scheme for CoMP Systems

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Abstract

Coordinated multiple points transmission and reception (CoMP) technology is used to mitigate the inter-cell interference, and increase cell average user normalized throughput and cell edge user normalized throughput. There are two kinds of radio resource schedule strategies in LTE-A/5G CoMP system, and they are called centralized scheduling strategy and distributed scheduling strategy. The regional centralized scheduling cannot solve interference of inter-region, and the distributed scheduling leads to worse efficiency in the utilize of resources. In this paper, a novel distributed scheduling scheme named 9-Cell alternate authorization (9-CAA) is proposed. In our scheme, time-domain resources are divided orthogonally by coloring theory for inter-region cooperation in 9-Cell scenario [6]. Then, we provide a formula based on 0-1 integer programming to get chromatic number in 9-CAA. Moreover, a feasible optimal chromatic number search algorithm named CNS-9CAA is proposed. In addition, this scheme is expanded to 3-Cell scenario, and name it 3-Cell alternate authorization (3-CAA). At last, simulation results indicate that 9/3-CAA scheme exceed All CU CoMP, 9/3C CU CoMP and DLC resource scheduling scheme in cell average user normalized throughput. Especially, compared with the non-CoMP scheme as a benchmark, the 9-CAA and 3-CAA have improved the edge user normalized throughput by 17.2% and 13.0% respectively.

Keywords: LTE-A/5G CoMP, inter-region cooperation, alternate authorization, chromatic number, user normalized throughput

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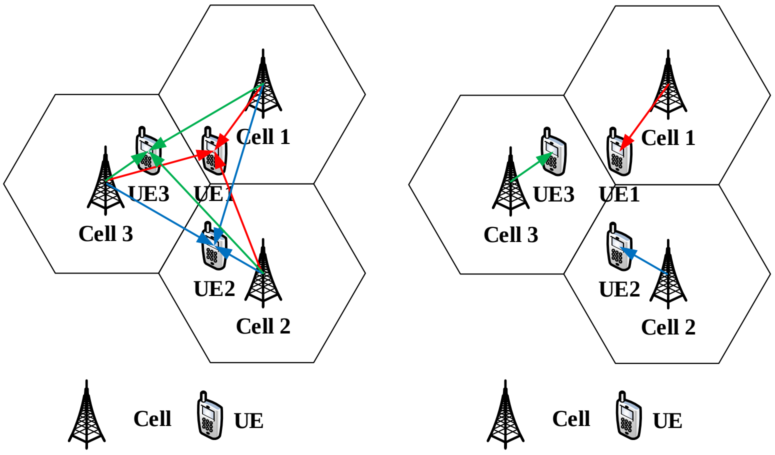
1. Introduction

With a growing demand to support larger throughput with higher spectral efficiency in mobile networks, Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) have been introduced in the Third Generation Partnership Project (3GPP) Long Term Evolution Advanced (LTE-A) transmission and reception system and have been studied widely in 5G [1]-[3]. As one of the key technology in LTE-A/5G, the Coordinated Multiple Points (CoMP) technology has been initiated as an effective way to mitigate the inter-cell interference as well as increase cell average and cell edge throughputs in 3GPP Release 11 [3-6].

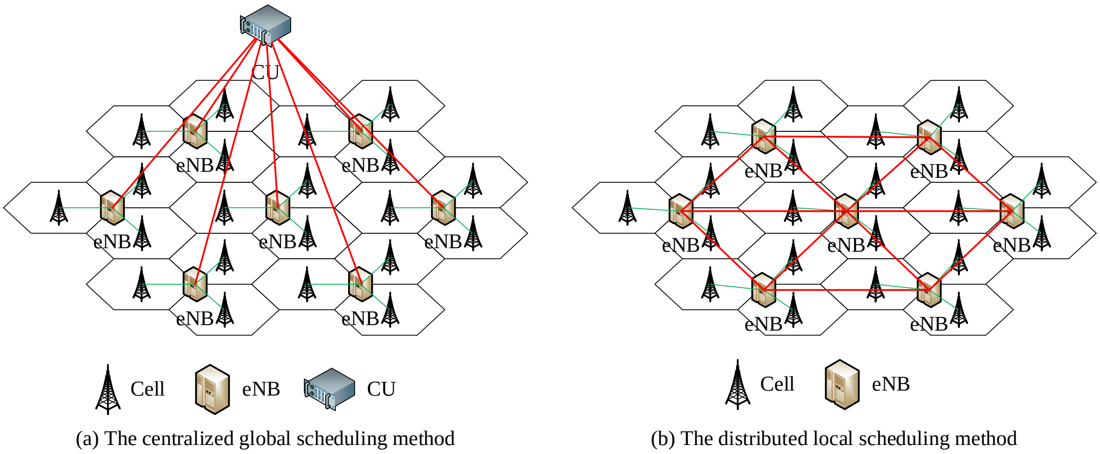
CoMP transmission techniques are divided into two categories: Joint Processing (JP) and Coordinated Scheduling/Beamforming (CS/CB), as shown in **Fig. 1**. Data are available at each cell in CoMP cooperating set in JP while data are only available at serving cell in CS/CB [2]. Information exchange between CoMP nodes will lead extra time delay inevitably, which reduces the cooperative gain. The key issues of CoMP technology contain three aspects: transmission and reception, power allocation, radio resource allocation and scheduling. So, the radio resource allocating and scheduling strategy is essential to improve system performance especially in CoMP-JP system [2].



(a) Joint Processing (b) Coordinated Scheduling/Beamforming

Fig. 1. CoMP transmission technology

In this paper, we only consider inter-region CoMP scenario. There are two kinds of radio resource scheduling strategies in it: (1) the centralized global scheduling; (2) the distributed local scheduling [7]. **Fig. 2** depicts the two types of strategies.



(a) The centralized global scheduling method (b) The distributed local scheduling method

Fig. 2. Radio resource scheduling strategies in downlink CoMP transmission

In the current works, centralized scheduling methods usually have one Central Unit (CU) and a corresponding cooperation set. The cooperation set is composed of a pre-fixed number of evolved NodeBs (eNBs), which is not only used for reduce the cost and processing capacity of CU, but also keep CU collects all users channel state information (CSI) and allocate resource blocks (RB) to evolved eNBs efficiently. When CU selects eNBs for transmitting the users' data cooperatively, and they connect all eNBs in the cooperation set with high-capacity and low-latency links. Thus, users can get the best cooperative resources. At the same time, the inter-cell interference (ICI) was mitigated within a cooperation set [6]. In order to make CU eliminates ICI more effectively, many novel methods have been studied [3][8]. In [8], Dario et al. innovatively utilized the advantage of cloud radio access network (C-RAN) architecture to mitigate the bandwidth-limiting ICI problem. This method is more dynamic and power-efficient than the traditional methods. During handover (HO) scenario, LTE-A/5G implement hard HO which requires a single connection for each user at any time. In [3], Maissa et al. proposed a HO algorithm based on CoMP joint transmission scheme in order to minimize the ICI problem and enhance the average throughput. Graph theory is also used for the reduction of interference in LTE-A network [9]-[11]. In [9], Chang et al. proposed a method to solve multi-cell OFDMA downlink channel assignment. The method consists of two phases. ICI reduction was mapped to the MAX k -CUT problem, and then solved it in the first phase. Channel assignment was conducted by taking into account instantaneous channel conditions in the second phase. In [10], interference graph (IG) is constructed by Tang et al. in which the vertexes represent Macro User (MUE) and femtocell. The purpose is to reduce the interference both MUE and femto user. Therefore, a dynamic spectrum assignment algorithm called hybrid clustering based on interference graph (HCIG) was proposed, in which the optimal clustering problem was constructed as a MAX k -CUT problem, and then a heuristic algorithm was given. Based on the results, a resource allocation scheme was given. In [11], the uplink resource allocation problem was modeled by Alexis et al. as the weighted fractional coloring problem (WFCP) in terms of graph theory, and a heuristic algorithm was proposed to obtain a solution in reasonable time. But, this paper does not consider distributed algorithm, user priority needs and traffic prediction. Fairness is another important factor. In [12], equal rate (ER) networks had been worked from G.J. Foschini et al. to guarantee users fairly. In [13], Han et al. proposed dynamic resource allocation (DRA) algorithm to get higher throughput than soft frequency reuse (SFR) and get fairness. In [14], Wang et al. proposed the scheme was called quantized time-domain compressed feedback (QTDCF). The scheme achieved higher performance improvement compared with existing feedback schemes. However, centralized methods cannot solve the ICI among many CSs. Therefore, the distributed method will come into being. Compared with centralized scheduling methods, distributed scheduling methods provide more flexibility, fairness, and higher network stability. The computational complexity and cost are also lower. The cooperative gain can be improved by better negotiations between eNBs before resource allocation.

Based on the eNBs whether are in a same CS or not, we notice that the existing works of distributed scheduling methods were divided into three types: static CS, semi-dynamic CS and dynamic CS. For static CS method, in [15], Sivarama Venkatesan defined a static coordination cluster as a subset of base stations, which had been proved to improve the spectral efficiency of cellular systems. The author highlighted the dependence of the user rate distribution on the number of rings of neighbors with which each base station is coordinated, as well as the underlying signal-to-noise ratio (SNR) distribution in the network. For semi-dynamic CS method, in [16], Zhou et al. proposed a distributed scheduling method, it was modified from Round Robin (RR) scheme for UE-specific CoMP. The conflict resource and the rest resource were reallocated by this method. However, the cooperative gain will decreased, and even worse than some centralized scheduling methods in some cases. In the studies of distributed scheduling schemes, the orthogonal division of resources in time-frequency domain was studied to avoid resources scheduling conflicts in order to reduce negotiation [7]. Compared with semi-dynamic CS and static CS, dynamic clustering approach outperforms static coordination schemes with much larger cluster sizes and enhances the fairness of the system. For dynamic CS method, in [17], Agisilaos Papadogiannis et al. described a novel dynamic greedy cooperating algorithm for the formation of the clusters of cooperating BSs is presented for a cellular network incorporating Multi-Cell Cooperative Processing (MCP). This algorithm is better than some static coordination schemes. But, in dynamic CS method, the negotiation would lead to more interaction time delay and signaling overhead [16]. Especially in [18], Zhou et al. evaluated the effect backhaul and interaction delay on the overall system performance.

The conclusion is that distributed scheduling methods will degrade with the rise of time delay and the negotiation becomes more complex. Thus, there are some studies to combine two kinds of methods. In [19], Yang et al. developed the method by deriving two kinds of IG which were called enhanced interference graph (EIG) and simplified interference graph (SIG). Then, they proposed both centralized algorithms and distributed algorithm to reduce the interference for the LTE-A uplink resource allocation. The throughput and fairness are better in centralized global scheduling, but the cost is higher. In [20], for the purpose of maximizing total downlink throughput of all edge users, Fu et al. according to each edge user of reference signal received power, they proposed two efficient transport scheme to select physical RB for edge user from the cooperative BS. One scheme was distributed, and the other one was centralized. After that, the authors also took the interference into consideration and proposed a non-cooperative game power allocation scheduling method.

Our main contributions are summarized as follows:

1) We propose a resource scheduling scheme which is called 9-Cell alternate authorization (9-CAA). Based on 9-CAA, we define region interference graph coloring (RIGC) method. And then, utilizing 0-1 integer programing method, we formulate an optimum formula to evaluate cooperative gain in the system under RIGC.

2) We give some theorems to simplify the optimum problem. In order to find a feasible optimal solution to solve RIGC under 9-CAA with lower computational complexity, we propose a chromatic number determination algorithm which is called CNS-9CAA.

3) We implement our scheme on a LTE system level simulation platform and compare it with some other schemes. The simulation result shows that the performance of our scheme is better than some other schemes with larger cooperative area, more fairness and less negotiation.

The rest of this paper is organized as follows: Section 2 provides a system model. Then, we give a general description and propose a resource scheduling scheme named 9-CAA based on RIGC in Section 3. In Section 4, we proof some theorems to simplify the optimum problem and find an optimal solution under 9-Cell scenario. Numerical results to compare this proposed scheme with the current schemes are given in Section 5 and followed by conclusion in Section 6.

2. System Model

2.1 9-Cell Scenario of LTE-A CoMP-JP SYSTEM

In this paper, we consider a CoMP-JP system model based on 9-Cell scenario which is considered as the baseline and recommended by 3GPP [6] as shown in **Fig. 3**. The CoMP under homogeneous network with 9 high Tx power remote radio heads (RRHs). The 3 eNBs are controlled by a CU. There are intra-site and inter-site CoMP within a 9-Cell region, and were considered by [6]. In this paper, we consider additional inter-region CoMP between different 9-Cell regions in the proposed scheme. Hence, the CU needs full CSI of its regional internal and between.

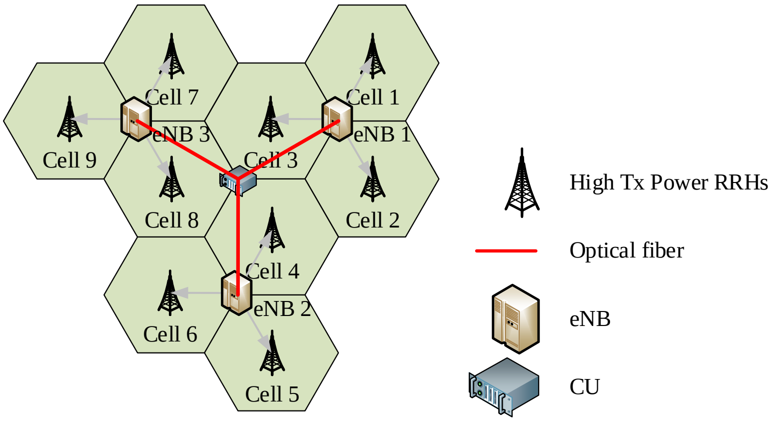


Fig. 3. 9-Cell scenario of LTE-A CoMP-JP system

2.2 SINR Comparison of Non-CoMP and COMP-JP

In non-CoMP scheme, it assumes UE is under eNB 1 (denoted as eNB_1) and receive signals from it, receive interference from eNB 2 and eNB 3 (denoted as eNB_2 and eNB_3). Assume H_i is the channel gain from eNB_i to UE, P_1 is the signal transmitted at eNB_1, P_2 and P_3 are the interference transmitted at eNB_2 and eNB_3, W_i is the precoding matrix at eNB_i, N is noise at the UE. So, the signal-to-noise-plus interference ratio (SINR) of UE in non-CoMP was expressed as (1) [22].

$$SINR = \frac{\left\| H_1 W_1 \right\|^2 P_1}{\left\| H_2 W_2 \right\|^2 P_2 + \left\| H_3 W_3 \right\|^2 P_3 + N} \tag{1}$$

But in CoMP-JP scheme, eNB_2 and eNB_3 compose a CoMP cooperating cluster, wherein UE are served by these 3 eNBs. So, the SINR of each UE in CoMP-JP was expressed as (2) [22].

$$SINR = \frac{\left\| H_1 W_1 \sqrt{P_1} + H_2 W_2 \sqrt{P_2} + H_3 W_3 \sqrt{P_3} \right\|^2}{N} \tag{2}$$

It can be seen that CoMP-JP scheme has a better SINR than the non-CoMP scheme obviously.

3. 9-Cell Alternate Authorization Resource Scheduling Scheme and Problem Formulation

3.1 9-Cell Alternate Authorization Resource Scheduling Scheme

In Fig. 4, we give an example to show the main idea of 9-Cell alternate authorization (9-CAA) scheme. We define some conceptions in the scheme at first:

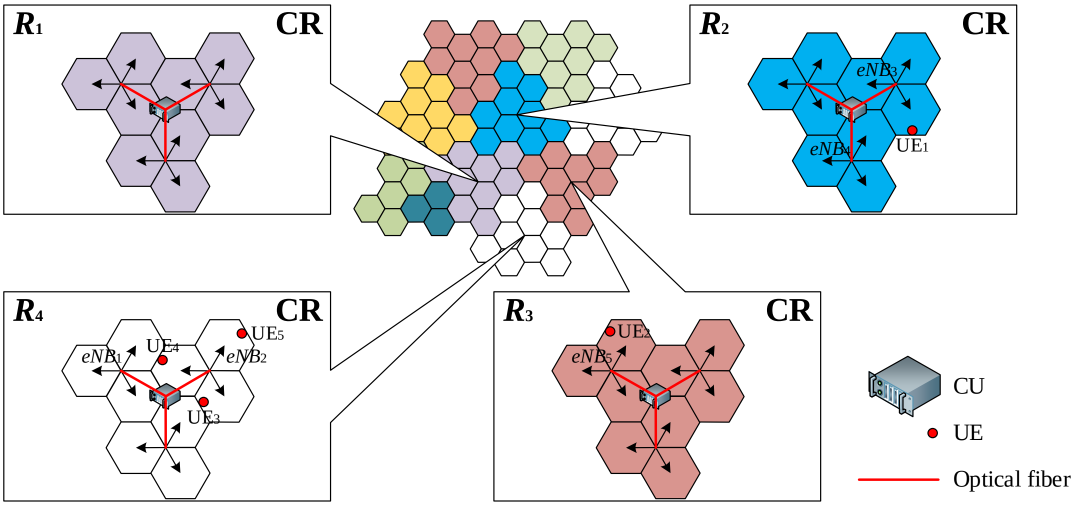


Fig. 4. An example of our resource scheduling scheme

Centralized Region (CR): A region is a CR that the CU uses the centralized scheduling method to allocate radio resources and conduct intra-CR CoMP.

Color: All CRs are assigned with a kind of color to distinguish orthogonal resources by different time slots.

Granted Region (GR): GR is a kind of CR that CU of itis granted to schedule resources of neighboring CRs.

Non-Granted Region (NGR): NGR is a kind of CR when resources of GR have been retake.

Blank Region (BR): BR is a kind of CR that cannot be granted at any time slot.

Cooperation: eNBs cooperation by three ways in our scheme: intra-CR, one-way inter-CR and two-way inter-CR.

Intra-CR Cooperation: eNBs cooperation in one CR as intra-CR cooperation.

Inter-CR Cooperation: eNBs cooperation between different CRs as inter-CR cooperation. It is divided two kinds: one-way and two-way inter-CR cooperation. In both of them, CU of GR is granted schedule resources of BRs. Especially, in two-way inter-CR cooperation, CU of GR is granted schedule resources of each other.

Based on the definitions above, the cooperation scheduling is described as follows:

Phase 1. The division of time slots.

We divide resources by orthogonal in time slots. After that, we assigned a kind of color to each CR to avoid resources scheduling conflicts. When the resources of some CRs are used in same time slots, these CRs are assigned with same colors. The number of color is equal to time slots.

Phase 2. The resource scheduling process in a time slot.

GRs and NGRs are alternatly scheduled with time slots by RR scheme.

a. GRs

In GRs, the CU schedules the resources of their own for non-CoMP and intra-CR CoMP users, and schedules the resources of their neighbor NGRs and BRs for inter-CR CoMP users. When a CU works, it collects users' information under it and allocates resources by high-efficiency scheduling methods such as Score Based (SB) [23]. For example, in **Fig. 4**, if R_2 is granted, the CU in R_2 schedule resources of eNB_5 in R_3 for UE_2 to inter-CR CoMP.

b. NGRs and BRs

NGRs and BRs will wait until getting resource occupy and transmission information from their neighbor GRs. After that, the remain resources are scheduled for their own users. Especially, we allow cooperation from eNBs in NGRs or BRs to eNBs in GRs, and name this scheduling method as Agent-Scheduling (AS). In AS, the CSI of inter-CR CoMP users are transmitted to GRs. For example, in **Fig. 4**, the CU of R_4 schedules resources by intra-CR CoMP for UE_4 and by non-CoMP for UE_3 after getting scheduling information from R_1 and R_2. In addition, UE_1 in R_2 and UE_5 in R_4 use AS to schedule resources which in R_3.

After cooperative scheduling, the system will go into next time slot.

3.2 Problem Formulation

It can be seen that the SINR will increase because of the interference is mitigated by CoMP technology. We use the interference from eNB i to eNB j $(i, j = 1, 2, \cdots)$ to evaluate the cooperative utility, denoted it by $p_{i,j}$. Thus, the cooperative utility of eNB-to-eNB represented by $e_{i,j}$ is given by (3):

$$e_{i,j} = x_{i,j} p_{i,j} + \frac{1}{T} y_{i,j} \left(p_{i,j} + \alpha p_{j,i} \right) + \frac{1}{T} z_{i,j} \left(p_{i,j} + \beta p_{j,i} \right) \tag{3}$$

In equation (3), the value of $x_{i,j}, y_{i,j}$ and $z_{i,j}$ are respectively from $\{1,0\}$ denote the cooperation is existing or not. $x_{i,j}$ denotes the internal cooperation between eNB i and j. Also, $y_{i,j}$ is interpreted as the one-way inter-CR cooperation from eNB i and j. Similarly,

$z_{i,j}$ is interpreted as the two-way inter-CR cooperation of between eNB i and j in different time slot. Assume there are B $\left(B{=}1,2,\cdots\right)$ eNBs in one CR. Moreover, we assume the number of time slot is T $\left(T{=}1,2,\cdots\right)$, α and β are represent the impact factors of one-way and two-way inter-CR cooperation to the utility in the AS method respectively. Because in the AS method, interaction delay leads to cooperative going decrease, so $0<\alpha<1, 0<\beta<1$. Especially, as the cellis utilized in one-way, the edge user of it could be cooperated by AS. So, there have more affect in this case, therefore $\alpha<\beta$.

Our goal is to determine an optimization model to ensure the effectiveness of collaboration by equation (3). It can find the best way to divide the whole system into CRs and collaborative approach for Inter-CR. Especially, in order to simplify the optimization problem, we use eNB-to-eNB instead of CR-to-eNB. We use graph theory to define a conception in inter-CR CoMP as below.

Region Interference Graph (RIG): Define RIG as a directed graph $G=\langle V,A\rangle$ where vertexes represent entities (i.e., eNBs) which are assigned resources. Two vertexes $i,j\left(i,j\in V\right)$ represent region identity number are linked by an arc ij ($ij\in A$) if they have interference from i to j, and weight of ij represents the interference from j to i denoted by $p_{i,j}$.

And then, we have some properties between them:

1) $\forall i\in V, x_{i,i}=1, y_{i,i}=z_{i,i}=0$;

2) $\forall i,j\in V, x_{i,j}=x_{j,i}, z_{i,j}=z_{j,i}$;

3) $\forall i,j\in V, y_{i,j}=1$ implies $y_{j,i}=0$;

4) $\forall i,j\in V$ implies $x_{i,j}+y_{i,j}+z_{i,j}=\{0,1\}$;

5) $\forall i,j,k\in V, x_{i,j}=1, x_{j,k}=1$ implies $x_{i,k}=1$;

6) $\forall i,j,k\in V, x_{i,j}=1$ implies $y_{i,k}=y_{j,k}, z_{i,k}=z_{j,k}$;

7) $\forall i,j\in V$ implies $\sum_{j} x_{i,j}\le B$.

Region Interference Graph Coloring (RIGC): Let $\chi\left(G\right)$ colors (corresponding to time slots, i.e., $\chi\left(G\right){=}T$) are available, and they compose the color set L, each color is denoted by L_i. In addition, we assign L_0 is blank specially. We want to find a coloring scheme of RIG which in the period of configured GR grants, maximize the cooperative utility of CR-to-CR and model it by a new method that we call it RIGC. It is allowed to use up to $\chi\left(G\right)$ colors for the whole system, but each CR is assigned one color only. Assume there are $\left|V\right|$ eNBs in whole system. And then, we have $\frac{\left|V\right|}{B}$ CRs in the system (ignore some edge eNBs). Denoted C_i represents the color of CR i. Therefore, there are some properties:

8) $\forall i\in V$ implies $C_i\in\left\{L_0,L_1,\ldots,L_{m-1}\right\}=L, \left|L\right|=\chi\left(G\right)\le\frac{\left|V\right|}{B}$;

9) $\forall i, j \in V, x_{i,j} = 1$ implies $C_i = C_j$;

10) $\forall i, j, k \in V, C_i = C_j, x_{i,j} = 0$ implies $y_{i,k} y_{j,k} = z_{i,k} z_{j,k} = 0$;

11) $\forall i, j \in V, C_i = C_j$ implies $y_{i,j} = y_{j,i} = z_{i,j} = z_{j,i} = 0$;

12) $\forall i \in V, C_i = L_0$ implies $\sum y_{i,j} = \sum z_{i,j} = 0$.

And then, we define $f\left(\chi(G)\right)$ as the probability of inter-CR cooperate. Therefore, for a particular CR, the probability of a GR is given by $\frac{1}{\chi(G)}$, so letting $f\left(\chi(G)\right) = \frac{1}{\chi(G)}$ when $\chi(G) \geq 1$. We have cooperative utility of CR-to-CR in whole system is represented by $\sum_i \sum_j e_{i,j}$ and given by (4):

$$\sum_i \sum_j e_{i,j} = x_{i,j} p_{i,j} + f\left(\chi(G)\right) y_{i,j}\left(p_{i,j} + \alpha p_{j,i}\right) + f\left(\chi(G)\right) z_{i,j}\left(p_{i,j} + \beta p_{j,i}\right) \tag{4}$$

We proof RIGC method is better than non-coloring method by Theorem 1 below.

Theorem 1. The cooperative performance of any coloring scheme ($\chi(G) \geq 2$) is equal or better than non-coloring scheme (every CR is assigned blank, e.t., $\chi(G) = 1$).

Proof: In the non-coloring scheme, there have $\chi(G) = 1, y_{i,j} = z_{i,j} = 0$, and substitute them into equation (4), the resource utilize of whole system is expressed as:

$$\begin{aligned}\sum_i \sum_j e_{i,j} &= \sum_i \sum_j \left(x_{i,j} p_{i,j} + f\left(\chi(G)\right) y_{i,j}\left(p_{i,j} + \alpha p_{j,i}\right) + f\left(\chi(G)\right) z_{i,j}\left(p_{i,j} + \beta p_{j,i}\right)\right) \\ &= \sum_i \sum_j p_{i,j}.\end{aligned} \tag{5}$$

When there have $\chi(G) \geq 2,$ the resource utilizes of whole system based on equation (4) is expressed as:

$$\begin{aligned}\sum_i \sum_j e_{i,j} &= \sum_i \sum_j \left(x_{i,j} p_{i,j} + f\left(\chi(G)\right) y_{i,j}\left(p_{i,j} + \alpha p_{j,i}\right) + f\left(\chi(G)\right) z_{i,j}\left(p_{i,j} + \beta p_{j,i}\right)\right) \\ &\geq \sum_i \sum_j p_{i,j}.\end{aligned} \tag{6}$$

Then, iff $x_{i,j} = 1, y_{i,j} = z_{i,j} = 0$, the equal sign is established in equation (6), i.e., when $\chi(G) \geq 2$, the utility of coloring scheme is larger than non-coloring scheme.

Therefore, Theorem 1 is proved. □

Remark 1. In order to guarantee fairness in CRs scheduling resources, set equal opportunity for all CRs.

Based on the analysis above, the optimal color $\chi(G)^*$ assignment to highest resource utilize of whole system under RIGC is formalized as follows:

$$\chi(G)^* = \arg \max_{i,j=1,\ldots,|V|} \left(\sum_i \sum_j e_{i,j} \right) \tag{7}$$

subject to

$$x_{i,j}, y_{i,j}, z_{i,j} = \{0,1\}; \tag{8}$$

$$x_{i,i} = 1; \tag{9}$$

$$y_{i,i} = 0; \tag{10}$$

$$z_{i,i} = 0; \tag{11}$$

$$x_{i,j} - x_{j,i} = 0; \tag{12}$$

$$y_{i,j} + y_{j,i} = \{0,1\}; \tag{13}$$

$$z_{i,j} + z_{j,i} = \{0,2\}; \tag{14}$$

$$x_{i,j} + y_{i,j} + z_{i,j} = \{0,1\}; \tag{15}$$

$$\sum_j x_{i,j} \le B; \tag{16}$$

$$C_i \in L; \tag{17}$$

$$x_{i,j} = 1 \Rightarrow C_i = C_j; \tag{18}$$

$$C_i = 0 \Leftrightarrow \left(\left(\sum_j y_{i,j} = 0 \right) \wedge \left(\sum_j z_{i,j} = 0 \right) \right); \tag{19}$$

$$\left(C_i = C_j\right) \wedge \left(x_{i,j} = 0\right) \Rightarrow \left(y_{i,k} y_{j,k} = 0\right) \wedge \left(z_{i,k} z_{j,k} = 0\right); \tag{20}$$

$$\left(C_i = C_j\right) \Rightarrow \left(y_{i,j} = 0\right) \wedge \left(y_{j,i} = 0\right) \wedge \left(z_{i,j} = 0\right) \wedge \left(z_{j,i} = 0\right); \tag{21}$$

$$i, j, k = 1, 2, 3, \ldots, |V|; \tag{22}$$

$$\alpha < \beta < 1. \tag{23}$$

4. Problem Solution Under the Particular CoMP Scenario

4.1 Simplify the Objective Problem

In this section, we analyze the utility maximization problem and prove the following theorems to simplify the objective function.

The global optimum is obtained by a collection of sub-optimum under different values of $\chi(G)$. Each sub-optimum is resolved by 0-1 integer programming under different value of $\chi(G)$. However, the exhaustion method is too complex to get the optimum. So we elaborate three properties of the proposed scheme, and then we characterized them by the following theorems to obtain a simplify method to decrease computational complexity.

Theorem 2. For a coloring scheme, the cooperative utility $e_{i,j} + e_{j,i}$ gets maximum when CR i and j implement intra-CR cooperation.

Proof: If CR i and j implement intra-CR cooperation, based on the notion of RIG and properties, we have $x_{i,j} = x_{j,i} = 1, y_{i,j} = y_{j,i} = z_{i,j} = z_{j,i} = 0, \chi(G) = 1$. Then, substitute them into equation (3), we have

$$e_{i,j} + e_{j,i} = p_{i,j} + p_{j,i} . \tag{24}$$

Similarly, if eNBs implement one-way inter-CR cooperation from i to j, we have $y_{i,j} = 1, x_{i,j} = x_{j,i} = y_{j,i} = z_{i,j} = z_{j,i} = 0, \chi(G) \geq 2$, then

$$e_{i,j} + e_{j,i} = f\left(\chi(G)\right)\left(p_{i,j} + \alpha p_{j,i}\right) < p_{i,j} + p_{j,i} . \tag{25}$$

If eNBs implement one-way inter-CR cooperation from j to i, we have $y_{j,i} = 1, x_{i,j} = x_{j,i} = y_{i,j} = z_{i,j} = z_{j,i} = 0, \chi(G) \geq 2$, then

$$e_{i,j} + e_{j,i} = f\left(\chi(G)\right)\left(\alpha p_{i,j} + p_{j,i}\right) < p_{i,j} + p_{j,i} . \tag{26}$$

If eNBs implement two-way inter-CR cooperation between i and j, we have $z_{i,j} = z_{j,i} = 1, x_{i,j} = x_{j,i} = y_{i,j} = y_{j,i} = 0, \chi(G) \geq 2$, then

$$e_{i,j} + e_{j,i} = f\left(\chi(G)\right)(1+\beta)\left(p_{i,j} + p_{j,i}\right) < p_{i,j} + p_{j,i} . \tag{27}$$

Thus, the cooperative utility of each other under inter-CR cooperation in any case are less than intra-CR cooperation.

Therefore, Theorem 2 is proved. □

Remark 2. If the size of a CR is infinite, i.e., constraint (16) in section 3.2 is untenable, the cooperative utility will gets maximum because all eNBs are in the same CR, which guarantee the cooperation of any two eNBs is internal, i.e., if two eNBs cooperation by intra-CR or inter-CR in the optimization process, they priority select intra-CR.

Theorem 3. For any coloring scheme, the upper bound of the cooperative utility is obtained when the cooperation between any two eNBs of different CRs are two-way inter-CR cooperation.

Proof: We assume $V' \subseteq V$, V' represents the eNBs which from intra-CR to two-way inter-CR.

If $V' = \varnothing$, i.e., all eNBs are in a same CR, they implement intra-CR cooperation with each other.

If $V' \subset V$, and then $\forall a,b \in V'$. Based on theorem 2, we know that is the upper bound of the whole system. The utility of this case is expressed as equation (28).

$$\sum_a \sum_b e_{a,b} = \sum_a \sum_b p_{a,b} . \tag{28}$$

If $V' = V$, the system is divided into B-eNB CR and change cooperation from intra-CR to two-way inter-CR based on the cooperative principles in section 3.1. In this case, $x_{i,j} = y_{i,j} = 0,\ \alpha = \beta = 0$. And then, the whole cooperative utility in system by two-way inter-CR cooperation is expressed as equation (29).

$$\sum_a \sum_b e_{a,b} = f\left(\chi(G)\right) \sum_a \sum_b p_{a,b} . \tag{29}$$

Base on equation (28) and (29), the cooperative utility of decrease is denoted by Δ, and then describe it as equation (30).

$$\Delta = \sum_a \sum_b p_{a,b} - f\left(\chi(G)\right) \sum_a \sum_b p_{a,b} = \left(1 - f\left(\chi(G)\right)\right) \sum_a \sum_b p_{a,b} \tag{30}$$

Because of the value of equation (28) is permanent. When equation (29) gets maximum, i.e., the cooperation between any two eNBs of different CR are two-way inter-CR cooperation, equation (30) will gets maximum value at the same time.

Therefore, Theorem 3 is proved. □

Remark 3. If two eNBs with different colors cooperation by inter-CR, they priority select two-way inter-CR.

Theorem 4. The cooperative utility function is monotone decreasing function when $\chi(G)$ increasing.

Proof: We consider the scenario under section 2.1, there are two constraints in the scenario:

1) $B=3$, i.e., there are 3 eNBs in a CR except some edge CRs. From theorem 1, we have the division of CRs is optimal in this case. We assume the system area is large enough, and we will not take the non-9-Cell CRs into consideration.

2) Neighbor CRs are in different colors and there nonexistence BRs. Different color CRs are authorized in turn with the time slots by RR, and the authorized probability is equal.

Assume there are $\frac{|V|}{B}$ CRs in the system and transmission conditions are same (i.e., $p_{i,j}$ are same, hence we use p instead of $p_{i,j}$). For $B=3$, every eNB have intra-CR cooperation with 2 eNBs nearest and inter-CR cooperation with 4 eNBs nearest. From theorem 3, we have the upper bound function of $\chi(G)\geq 2$ is denoted as $E\left(\chi(G)\right)$ and thenexpress it as (31):

$$E\left(\chi(G)\right)=2p\frac{|V|}{B}+\frac{4p\frac{|V|}{B}(1+\alpha)}{\chi(G)}=\frac{2p|V|\left(\chi(G)+2+2\alpha\right)}{3\chi(G)}. \tag{31}$$

The derivative of equation (32) is:

$$\frac{\mathrm{d}E\left(\chi(G)\right)}{\mathrm{d}\chi(G)}=-\frac{4p|V|(1+\alpha)}{3\left(\chi(G)\right)^2}<0 \tag{32}$$

Therefore, the upper bound function is monotone decreasing function.

Therefore, Theorem 4 is proved. □

Based on the theorems above, we produce a feasible algorithm named Chromatic Number Search Algorithm Base on 9-CAA (CNS-9CAA) to get the optimal solution:

Algorithm 1. *Chromatic Number Search Algorithm Base on 9-CAA (CNS-9CAA).*

```
Initialization: Set chromatic number $\chi(G)=1$.
Step 1: Set $\chi(G)^*=\chi(G)+1$.
Step 2: Calculate the upper bound optimum base on equation (31) under $\chi(G)^*$.
Step 3: If the upper bound under $\chi(G)^*$ is feasible, return to Step 1; otherwise, set
            $\chi(G)^*=\chi(G)^*\text{-}1$,
end.
```

4.2 An Optimal Solution Under the CoMP Scenario

We implement CNS-9CAA in section 4.1 to produce the optimal solution in this scenario:

When $\chi(G)=2$, based on equation (9) to (11), we cannot guarantee that the colors of any two neighbor CRs are different or there are no BRs in the system. Thus, we cannot find a feasible solution when $\chi(G)=2$.

When $\chi(G)=3$, an unique solution satisfying the above constraints is presented in **Fig. 5**. We find that R_1 and R_2 need to build two-way inter-CR cooperation with R_3. However, the resources of eNB_1 in R_3 which are used by CR R_1 and R_2 are overlapped. It cannot satisfy the equation (20). Thus, there is no feasible solution when $\chi(G)=3$.

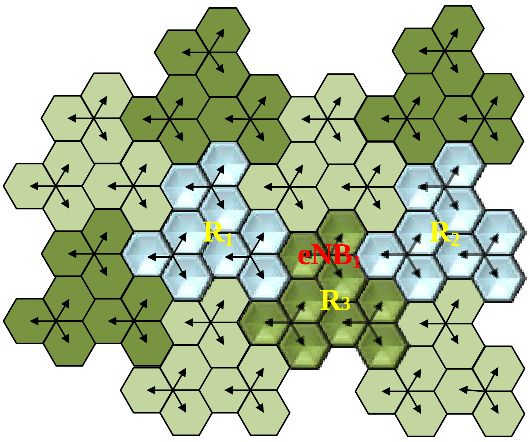


Fig. 5. A unique color scheme when $\chi(G)=3$

When $\chi(G)=4$, based on equation (31), we have a feasible coloring scheme which is shown in **Fig. 6**. It reaches the upper bound of cooperative utility, i.e., $E(\chi(G))=E(4)=\frac{p|V|(3+\alpha)}{3}$. Because the theorem 4, $E(\chi(G))$ is monotone decreasing function. Then, we get the global optimum when $\chi(G)^*=4$.

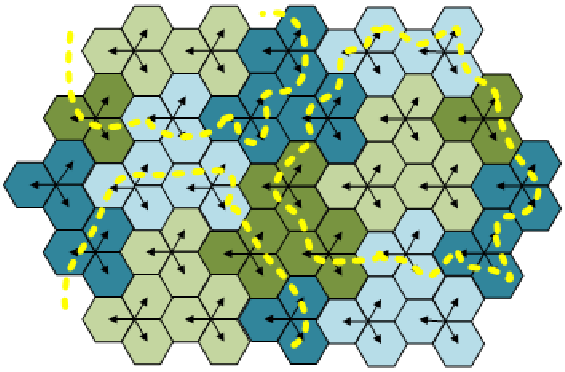


Fig. 6. An optimal solution of the cooperative utility based CNS-9CAA

There are four advantages in this method:

1) It ensure that each eNB cooperate with the nearest 6 eNBs around it, and its cells are intra-CR cooperation or two-way inter-CR cooperation with cells of the 6 neighbouring eNBs. UEs of each cell select cooperating nodes from 20 cells. So the cooperative area is large enough.

2) The size of a CR is recommended by 3GPP, and the interaction process is efficient. This scheme conveniently deployment with a proper extension of X2 interface.

3) Negotiation and signal overheads between CRs are reduced effectively compared with distributed scheduling methods.

4) The complexity of CNS-9CAA in terms of running time depends on the cycle times, the main calculate only for equation (31). The time complexity of CNS-9CAA is $O(n)$, which is much better than $O(n^3)$ of similar work [24].

Especially, our scheme can be deployment in 3-Cell Scenario. The 3-CAA scheme is similar to the 9-CAA scheme, the difference is that in 3-CAA scheme, there are 3 cells in a CR instead of 9 cells. The optimal solution of 3-CAA is shown in **Fig. 7**.

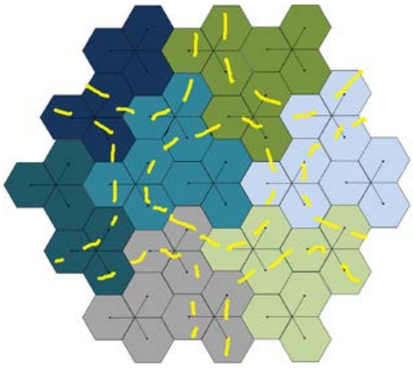


Fig. 7. An optimal solution of the cooperative utility based model for 3-CAA

5. Simulation Results

We use a LTE-A CoMP simulation platform based on LTE system level simulation platform provided by Vienna University of Technical [25]. The simulation scenario consisting of 57 BSs. We assume that the Inter-eNB distance is 500m. The channel model includes shadow fading, macroscopic path loss, and microscale fading. We adapt close loop spatial multiplexing (CLSM) as transmission model. Users are scheduled by SB, and then we use full buffer as traffic model. For further performance analysis, we classify all users into central and edge user, edge user is defined as the 5%-tile user. The main system simulation parameters are listed in **Table 1**.

Table 1. System simulation parameters

Parameters	Values
Carrier frequency	2.0 GHz
Bandwidth	10 MHz
Thermal noise density	-174 dBm/Hz
Receiver noise figure	9 dB
Antennas number	2×2
MIMO	Single-User MIMO (SU-MIMO)
Cells	57 cells
Inter-eNB distance	500 m
eNobeB Tx power	43 dBm
Simulation loop	10×100 TTIs
Shadow fading	lognormal, space-correlated, $\mu = 0, \sigma = 10(dB)$
Macroscopic path loss	$128.1 + 37.6\log_{10}(R)$
Microscale fading	PedB uncorrelated time-correlated
Transmission model	CLSM
UE position	Homogeneous, 10 UEs/Cell
UE speed	3 km/h
Traffic model	Full buffer
User scheduling	Score Based

System level simulations are employed to evaluate the practical performance under our scheme (9-CAA) and other different resource scheduling scheme.

1) All CU CoMP: In this scheme, each user is scheduled by a CU only. It is a centralized scheduling methods, and as the theory of upper bound.

2) 9C CU CoMP: This is also a centralized scheduling methods, and it is recommended by 3GPP. It is deployed in 9-Cell scenario like 9-CAA.

3) DLC: This is a semi-dynamic distributed COMP scheme.

4) Non-CoMP scheme.

Cell average user normalized throughput and edge user normalized throughput are always the key factors to evaluate the system performance. We evaluate cell average user normalized throughput and edge user normalized throughput of these schemes by cumulative distribution function (CDF). The results are shown in **Table 2**, **Fig. 8** and **Fig. 9**.

Table 2. The contrast of throughput between 9-CAA and other resource scheduling scheme

Scheme	Cell average user normalized throughput (bits/s/Hz/cell)	Edge user normalized throughput (bits/s/Hz)
9-CAA	2.8656	0.09798
All CU CoMP	2.8565	0.09931
9C CU CoMP	2.8579	0.09021
DLC	2.7933	0.08780
Non-CoMP	2.8600	0.08359

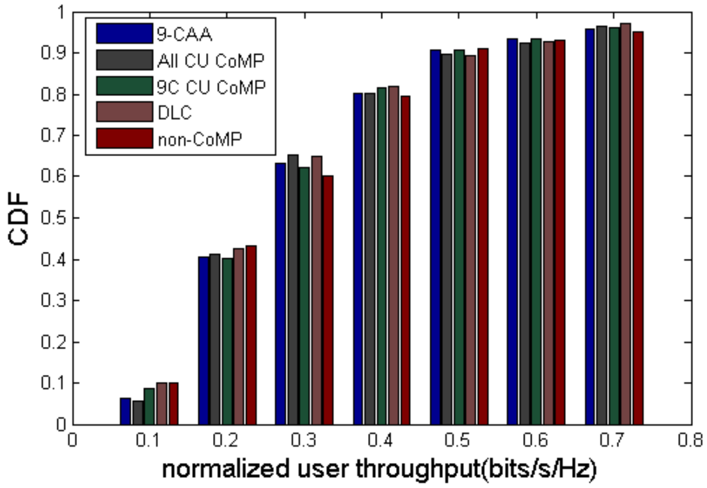


Fig. 8. CDF of cell average user normalized throughput of Scored Based with 9-CAA and other resource scheduling scheme

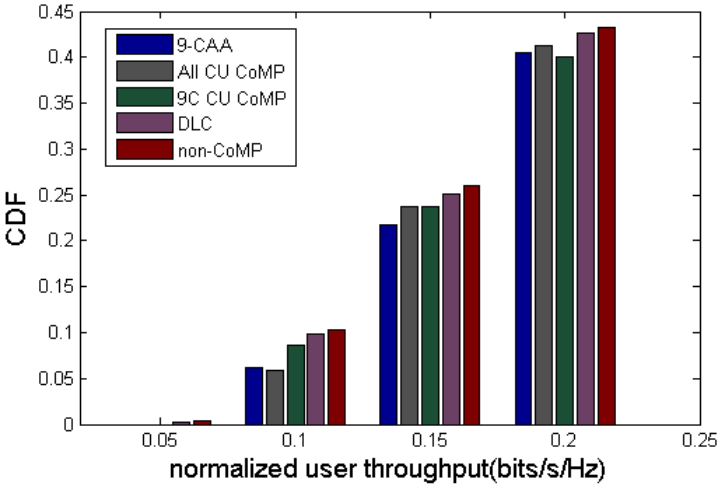


Fig. 9. CDF of edge user normalized throughput of Scored Based with 9-CAA and other resource scheduling scheme

The CDF histogram of cell average user normalized throughput for 9-CAA and four considered schemes are given in **Fig. 8**. In the statistical results of **Table 2**, it can be seen that 9-CAA scheme achieve the highest cell average user normalized throughput than the others, because it can efficiently improve the edge user normalized throughput. The CDF histogram of edge user normalized throughput for 9-CAA and four considered schemes are given in **Fig. 9**. From the statistical results of **Table 2** and **Fig. 9**, we see that 9-CAA scheme provides higher performance gain in edge user normalized throughput compared with 9C CU CoMP, DLC and non-CoMP, and it is only slightly lower than All CU CoMP which is the upper bound. The reason is that in 9-CAA scheme, it has inter-CR cooperation. What is more, each 9-Cell cluster is authorized alternately. Hence, the fairness is promoted especially for edge user performance in throughput. The edge user normalized throughput of the scheme is improved by about 8.6%, 11.6% respectively when compared with 9C CU CoMP and DLC, and improved notably compared with the benchmark scheme, non-CoMP, by 17.2% especially.

Further, the result in 3-CAA which is mentioned in section 4.2 is shown in **Table 3**, **Fig. 10** and **Fig. 11**.

Table 3. The contrast of throughput between 3-CAA and other resource scheduling scheme

Scheme	**Cell average user normalized throughput (bits/s/Hz/cell)**	**Edge user normalized throughput (bits/s/Hz)**
3-CAA	2.8780	0.09287
All CU CoMP	2.8607	0.09897
3C CU CoMP	2.8598	0.08646
DLC	2.7805	0.08513
Non-CoMP	2.8503	0.08217

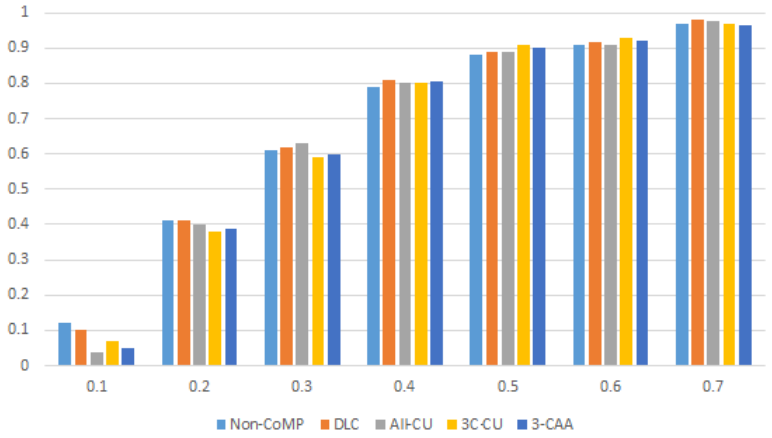


Fig. 10. CDF of cell average user normalized throughput of Scored Based with 3-CAA and other resource scheduling scheme

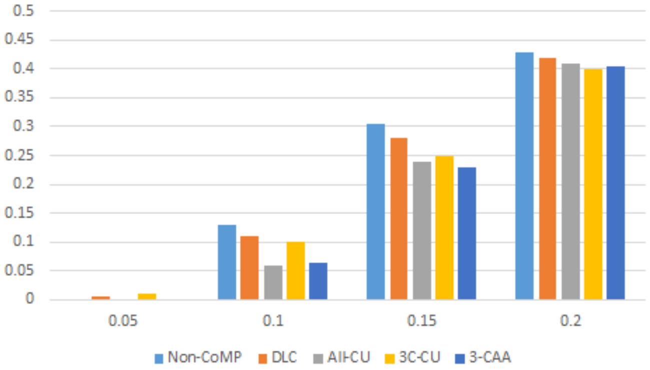


Fig. 11. CDF of edge user normalized throughput of Scored Based with 3-CAA and other resource scheduling scheme

In **Table 3** and **Fig. 10**, we see that 3-CAA scheme also exceed the other resource scheduling schemes in cell average user normalized throughput. From **Fig. 11**, the experimental result shows that 3-CAA is also close to All CU CoMP in edge user normalized throughput, and improve 13.0% compare with non-CoMP.

In general, from **Table 2** and **Table 3**, we compare with the other resource scheduling schemes, our schemes under their respective scenario get more benefit from CoMP technology. From the analysis in section 4, the extra benefit come from inter-CR cooperation. CUs enable the appropriate cluster CRs the ability to cooperate with each other in scheduling the resources for the edge users. As a results, compared with 9/3C CU CoMP, DLC and non-CoMP scheme, our methods provide higher throughputs of edge users.

6. Conclusion

In this paper, we propose a novel cooperative scheduling scheme named 9-CAA. It combine the advantages of centralized and distributed scheduling strategies. In our scheme, we divide the system into some centralized regions of 9-Cell, and then use the orthogonal division of resources in time-domain to authorize centralized regions in turn for CoMP transmission. The proper designing of the authorized cycle reduces system complexity and interaction time delay. We performance RIG and RIGC as math models by graph theory. Based on RIGC, we establish a cooperative utility function in a novel cooperative model, and then formulate the optimization problem by 0-1 integer programming to find optimal chromatic number. But we find that it is too hard to find the solution. Then, we use 3 theorems to find a feasible solution which is named CNR-9CAA algorithm. At last, we find the optimal chromatic number by CNR-9CAA. The simulation results indicate that the proposed scheme is close to the centralized global scheduling method in cooperative performance with less negotiation than the distributed local scheduling method. In addition, 9-CAA scheme can be extended to the 3-Cell simply. In our experiment, 3-CAA scheme also outperforms the other schemes.

References

[1] Gary Boudreau, John Panicker, Ning Guo, Rui Chang, Neng Wang, Sophie Vrzic and Nortel, “Interference Coordination and Cancellation for 4G Networks,” in *Proc. of IEEE Communications Magazine*, vol. 47, no. 4, pp. 74-81, 2009. Article (CrossRef Link).

[2] 3GPP, TR.36.814, Further Advancements for EUTRA Physical Layer Aspects, 2009.

[3] Maissa BOUJELBEN, Sonia BEN REJEB and Sami TABBANE, “A Novel Mobility-based COMP Handover Algorithm for LTE-A/5G HetNets,” in *Proc. of Software, Telecommunications and Computer Networks (SoftCOM)*, pp. 143-147, September, 2015. Article (CrossRef Link).

[4] Juho Lee, Younsun Kim, Hyojin Lee, Boon Loong Ng, Mazzarese. D, Jianghua Liu, Weimin Xiao and Yongxing Zhou, “Coordinated Multipoint Transmission and Reception in LTE-Advanced Systems,” *IEEE Communications Magazine*, vol. 50, no. 11, pp.44-50, November, 2012. Article (CrossRef Link).

[5] Shaohui Sun, Qiubin Gao, Ying Peng, Yingmin Wang and Lingyang Song, “Interference management through CoMP in 3GPP LTE-advanced networks,” *IEEE Wireless communications*, vol. 20, no. 1, pp. 59-66, 2013. Article (CrossRef Link).

[6] 3GPP, TR.36.819, Coordinated Multi-Point Operation for LTE Physical Layer Aspects, 2011.

[7] Fan Huang, Yafeng Wang, Jian Geng, Mei Wu and Dacheng Yang, “Clustering approach in coordinated multi-point transmission/reception system,” in *Proc. of Vehicular Technology Conference Fall (VTC 2010-Fall)*, pp. 1-5, 2010. Article (CrossRef Link).

[8] Dario Pompili, Abolfazl Hajisami and Hariharasudhan Viswanathan, “Dynamic provisioning and allocation in Cloud Radio Access Networks (C-RANs),” *Ad HocNetworks*, vol. 30, pp. 128-143, July, 2015. Article (CrossRef Link).

[9] Yu-Jung Chiang, Zhifeng Tao, Jinyun Zhang and Kuo C.-C.J., “A graph based approach to multi-cell OFDMA downlink resource allocation,” in *Proc. of Global Telecommunications Conference*, pp.1-6, 2008. Article (CrossRef Link).

[10] Hao Tang, Peilin Hong, Kaiping Xue and Jinlin Peng, "Cluster-based resource allocation for interference mitigation in LTE heterogeneous networks," in *Proc. of IEEE VTC-Fall*, pp. 15, 2012. Article (CrossRef Link).

[11] Alexis Lamiable and Joanna Tomasik, "Spatial frequency reuse in a novel generation of PMR networks," in *Proc. of Wireless Communications and Networking Conference (WCNC)*, pp. 1410-1415, 2013. Article (CrossRef Link).

[12] G.J. Foschini, K. Karakayali, and R.A. Valenzuela, "Coordinating Multiple Antenna Cellular Networks to Achieve Enormous Spectral Efficiency," *IEEE Proceedings-Communications*, vol. 153, no. 1, pp. 548-555, 2006. Article (CrossRef Link).

[13] Han YuNan, Chang YongYu, Cui Jie and Yang DaCheng, "A novel inter-cell interference coordination scheme based on dynamic resource allocation in LTE-TDD systems," in *Proc. of Vehicular Technology Conference (VTC 2010-Spring)*, pp. 15, 2010. Article (CrossRef Link).

[14] Ying Wang, Jing Xu and Wenxuan Lin, "A novel quantized time-domain compressed feedback scheme in coordinated multipoint LTE-advanced systems," *Transactions on Emerging Telecommunications Technologies*, 2014. Article (CrossRef Link).

[15] Sivarama Venkatesan, "Coordinating Base Stations for Greater Uplink Spectral Efficiency in a Cellular Network," *IEEE Personal, Indoor and Mobile Radio Communications (PIMRC)*, pp.1-5, 2007. Article (CrossRef Link).

[16] Wenan Zhou, Wei Chen, Zhongyi Tan, Si Chen and Yiyu Zhang, "A modified RR scheduling scheme based CoMP in LTE-A system," in *Proc. of IET International Conference on Communication Technology and Application (ICCTA 2011)*, pp. 176-180, October, 2011. Article (CrossRef Link).

[17] Agisilaos Papadogiannis, David Gesbert and Eric Hardouin, "A Dynamic Clustering Approach in Wireless Networks with Multi-Cell Cooperative Processing," *IEEE Communications (ICC)*, pp. 4033-4037, 2008. Article (CrossRef Link).

[18] Zhou Wen'an, Wang Guowei, Zhang Yiyu, Li Huiqin and Ren Xiaotao, "CoMP Performance When Considering X2 Backhaul Delay," *Journal of Beijing University of Posts and Telecommunications*, vol. 36, no. 4, pp. 104-109, August, 2013. Article (CrossRef Link).

[19] Kai Yang, Steven Martin and Tara Ali Yahiya, "LTE uplink interference aware resource allocation," *Computer Communications*, vol. 66, pp.45-53, July, 2015. Article (CrossRef Link).

[20] Shu Fu, Bin Wu, Hong Wen, Pin-Han Ho and Gang Feng, "Transmission Scheduling and Game Theoretical Power Allocation for Interference Coordination in CoMP," *IEEE Transactions on Wireless Communications*, vol. 13, no. 1, pp. 112-123, January, 2014. Article (CrossRef Link).

[21] Young-Han Nam, Dallas, Lingjia Liu, Yan Wang and Charlie Zhang, "Cooperating communication technologies for LTE-advanced," *IEEE Acoustics Speech and Signal Processing (ICASSP)*, pp. 5610-5613, March 14-19, 2010. Article (CrossRef Link).

[22] Kazi Mohammed Saidul Huq, Shahid Mumtaz, Firooz B. Saghezchi, Jonathan Rodriguez and Rui L. Aguiar, "Energy efficiency of downlink packet scheduling in CoMP," *Transactions on Emerging Telecommunications Technologies*, vol. 26, no. 2, pp. 131-146, February, 2015. Article (CrossRef Link).

[23] Thomas Bonald, "A score-based opportunistic scheduler for fading radio channels," in *Proc. of European Wireless*, vol. 5, 2004.

[24] Haijun Zhang, Hui Liu, Chunxiao Jiang, Xiaoli Chu, A. Nallanathan and Xiangming Wen, "A Practical Semidynamic Clustering Scheme Using Affinity Propagation in Cooperative Picocells," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 9, pp. 4372-4377, September, 2015. Article (CrossRef Link).

[25] Christian Mehlführer, Martin Wrulich, Josep Colom Ikuno, Dagmar Bosanska and Markus Rupp, "Simulating the long term evolution physical layer," in *Proc. of The 17th European Signal Processing Conference (EUSIPCO)*, Glasgow, Scotland, pp. 1471-1478, 2009.

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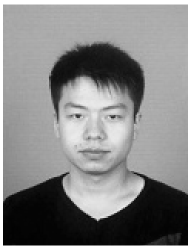

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