Effective Frequency Plan Scheme for Downlink Coordinated Multi-point Transmission in LTE-A System

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***Abstract*—Coordinated multi-point (CoMP) transmission for LTE-Advanced is to improve system performance, especially to enhance cell coverage and cell-edge data rate. With efficient resource allocation schemes, CoMP transmission could be a promising technology to increase system throughput. Existing frequency plan schemes on downlink CoMP transmission limit the performance of the system since they do not take the changes in traffic load as well as link quality into consideration. In this paper, an optimized scheme is proposed that each base station could allocate different proportion of bandwidth to different users' equipments (UEs) according to their traffic load and link quality, to make the system more flexible and efficient. The scheme is more effective in both system throughput and cell-edge throughput as verified through system level simulation.**

Keywords-frequency plan; CoMP; LTE-A; system throughput; cell-edge throughput

I. INTRODUCTION

Coordinated multi-point transmission/reception is considered for LTE-Advanced as a tool to improve the coverage of high data rates, the cell-edge throughput and system throughput. Downlink coordinated multi-point transmission implies dynamic coordination among multiple geographically separated transmission points [1], that could improve cell-edge performance and to improve system throughput with efficient resource allocation [2][3]. In general, the cost of downlink CoMP for single user (SU) is found only beneficial to the cell-edge users where the perceived Signal-to-Interference-and-Noise Ratio (SINR) is low [4].

In order to improve system performance, several frequency plan schemes have been proposed. The fixed frequency plan scheme divides each cell's frequency into two parts, that is, CoMP Frequency Zone and Frequency Band for Single Cell Operation [5]. Such scheme maybe easy to implement, however, when considering the complexity of wireless communication environment, it lacks flexibility and may cause a decrease in system throughput performance. Another type of frequency plan scheme is the completely dynamic frequency plan scheme, known as the flexible frequency allocation plan (FFAP) scheme. Such plan ensures the cells which have formed more CoMP links to UEs being allocated more resource. The FFAP scheme allocates resource according to the number of cell-edge UEs, which makes it more flexible than the former fixed frequency plan scheme. However, such scheme allocates a certain proportion of frequency resource, which decreases system performance; and its complexity problem of joint schedule algorithms will become increasingly high [5].

Some of the recent works focuses on the FFAP scheme and its optimization [6]. However, since a certain proportion of frequency resource should be allocated to ensure CoMP transmission in such scheme, system performance may as well be decreased. Other recent works mainly focuses on schemes without frequency zone partition as well as algorithms to reduce implementation difficulties [7].

This paper proposes a frequency plan scheme to optimize the performance of the system considering both the traffic load as well as the link quality of UEs. Since it allocates frequency resource according to the cell's traffic load distribution and the link qualities, the proposed frequency plan scheme could achieve better fairness and system performance.

The remainder of the paper is organized as follows: Section II introduces the models of the system; Section III describes the proposed scheme for downlink SU-CoMP transmission. Simulation scenario and results are shown in Section IV. Section V concludes the paper.

II. SYSTEM MODEL WITH COMP TRANSMISSION

In CoMP transmission systems, cells could be classified into two different types: the serving cells and the coordinated cells. Each base station possess N_t transmit antennas while each UE consists of N_r receive antennas. The transmission model is described as follows.

A. Baseline Transmission

Baseline transmission refers to a situation of non-CoMP transmission. Under such system, each base station delivers data with individually selected codebook. Thus, the subordinate UE receive both data signal and interference from neighboring cells, with additive white Gaussian Noise. As in baseline transmission, there is no

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cooperation performed between the serving cell and the neighboring cells. Under baseline transmission mode, considering N_t as transmit antennas and N_r as receive antennas, the received signal can be formulated as

$$r(i,j) = H(i,j)\cdot U_j \cdot s(i,j) + \sum_{\substack{m=1 \\ m\neq i}}^{M}\sum_{n=1}^{N} H(m,j)\cdot U_n \cdot s(m,n) + n(i,j). \quad (1)$$

where i and m are the indexes of base station, j and n are the indexes of UE, $r(i,j)$, $H(i,j)$, U_j, $s(i,j)$, $n(i,j)$ are the $N_r \times 1$ received signal, the $N_r \times N_t$ channel matrix, the $N_t \times 1$ precoding matrix, the transmit signal, and the $N_r \times 1$ additive white Gaussian noise (AWGN) matrix respectively [7]. Here, the first term on the right side of the equation denotes the power of desired signal ($s_{desired}$), the second denotes the power of interferences received (I), and the third denotes the power of noise received (N). The SINR under such mode could be calculated through the following equation

$$SINR = \frac{s_{desired}}{I+N}. \quad (2)$$

B. Downlink SU-CoMP Transmission

CoMP transmission consists of SU-CoMP mode and multiuser (MU) CoMP mode, where SU-CoMP refers to single user CoMP transmission and MU-CoMP refers to multiple user CoMP transmission [8]. Under SU-CoMP mode, the serving cell and the coordinated cell maintain the same codebook, which means SU-CoMP users can receive desired signals from both cells. Therefore, SU-CoMP users experience only interference from other cells (besides the serving and coordinated cells), with additive white Gaussian Noise.

In addition, the serving cells can both serve its subordinate UE as well as serve UE that belongs to other cells as coordinated cells. In most of the cases, cell-center UE would maintain better SINR, which leads to its often being served by their serving cells only. For cell-edge UE, their SINR may be so unpleasant that calls for coordinated cells to co-serve themselves. Therefore the definition of cell-center UE and cell-edge UE is very important in deciding the transmission scheme.

In our work, cell-edge UE could be defined as such UE, whose position is very near the boundary of its original serving cell, maintain a SINR that is relatively low. Such UE often calls for downlink CoMP transmission. Otherwise, UE whose position is in the center of its serving cell possesses a SINR that is relatively high denotes cell-center UE. Cell-center UE does not require coordinated cells to serve themselves; in other words, they have only one access point.

Under SU-CoMP transmission mode, the received signal could be formulated as:

$$r(i,j) = H(i,j)\cdot U_{p,j} \cdot s(i,j) + H(p,j)\cdot U_{p,j} \cdot s(p,j) + \sum_{\substack{m=1 \\ m\neq i,p}}^{M}\sum_{n=1}^{N} H(m,j)\cdot U_n \cdot s(m,n) + n(i,j). \quad (3)$$

where p is the index of coordinated cell base station [7]. Likewise, the first two terms on the right side of the equation denote signals received from the serving cell and the coordinated cell respectively, and combined as the desired signal $s_{desired}$. The third term denotes the interferences I , and the forth one denotes the noise received N . Therefore, the SINR under SU-CoMP transmission could be analyzed through (2).

When CoMP transmission is performed, resource is allocated according to frequency plan schemes. The fixed frequency plan scheme allocates a certain fixed portion of frequency band for CoMP transmission. Therefore, the frequency band of each cell is divided into two parts: the CoMP transmission frequency band and the serving frequency band, as shown in Fig. 1.

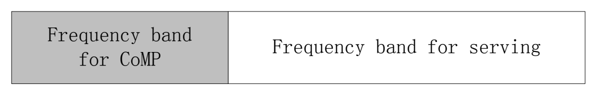

Figure 1. Fixed Frequency Plan Scheme

In such case, each cell retains bandwidth for CoMP transmission when CoMP happens. We could also estimate the best distribution method with good system performance. Such spectrum plan, though easy to operate, could hardly take into consideration the different situations between different cells. The FFAP scheme will have better utilization of the spectral bandwidth since it allocates frequency band according to the number of CoMP links in a certain cell. However, if CoMP Frequency Zone of one cell changes, other cells may also need adjustment to maintain CoMP operation. The FFAP scheme allocates a certain proportion of frequency bandwidth according to (4), which leads to the fact that is the same within each of the three cells.

$$\alpha = \frac{N_{cell-edge\,UE}}{N_{cell-center\,UE} + N_{cell-edge\,UE}}. \quad (4)$$

where $N_{cell-edge\,UE}$ and $N_{cell-center\,UE}$ represent the number of cell-edge UEs and the number of cell-center UEs in a certain cell, respectively.

III. The Proposed Frequency Allocation Plan Scheme

In our work, a new scheme is proposed to increase the flexibility and effectiveness of the system and system

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performance under such plan could be greatly improved. The proposed scheme suggests that the proportion of frequency band allocates to SU-CoMP transmission is dynamic, that is to say, base stations could gather traffic load information of the system and link quality and therefore make decisions about the proportion could be chosen based on such knowledge.

The proposed frequency allocation plan scheme could be seen in Fig. 2, where BW is the total bandwidth of the spectrum.

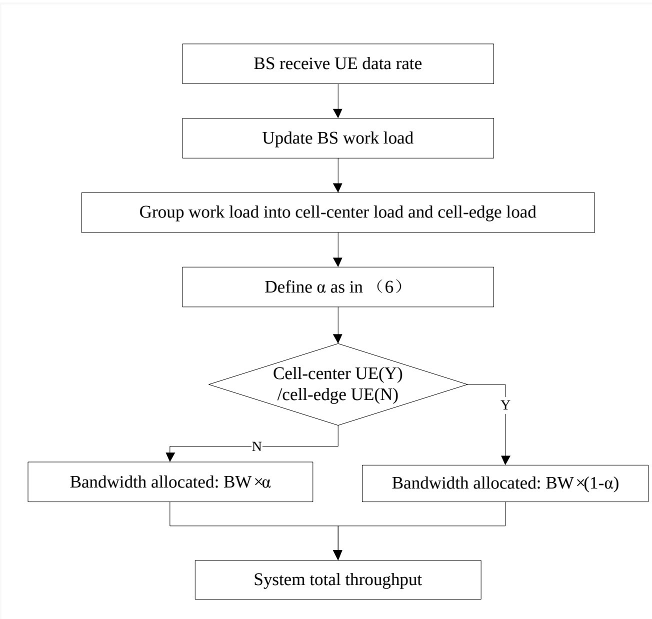

Figure 2. Flow Chart of Proposed Frequency Allocation Plan Scheme

On the first step, base stations receive information about data rate from both cell-center UEs and cell-edge UEs. In order to determine the access mode of a UE, that is, whether this user is served by a single serving base station or is served by both serving base station and coordinated serving station, a threshold ratio is defined. Different threshold ratio may result in different cell edge coverage. Therefore in our work the threshold ratio is decided according to the most likely percentage of CoMP users by simulation. In our work, the decision of CoMP transmission mode is operated by examining the following inequality among each UE.

$$\frac{RSRP_{neighbor}}{RSRP_{serving}} > threshold\ ratio. \qquad (5)$$

Here, RSRP refers to the Reference Signal Receiving Power. If (5) is true, we define the UE as cell-edge UE and it is served by both serving and coordinated cell, in other words, is under coordinated multipoint transmission mode. Otherwise, it is a cell-center UE and it is served by only its serving cell.

Then, base stations work out both the cell-center load and the cell-edge load based on the traffic load and link qualities of UEs. Such information could be acquired by base stations using channel information feedback. Therefore, the proportion of bandwidth assigned for CoMP users could be defined as:

$$\beta = \begin{cases} \dfrac{\log_2\left(\dfrac{1}{cell-edge\,load}\right)}{\dfrac{1}{cell-center\,load} + \dfrac{1}{cell-edge\,load}}, & \text{cell-edge load} \neq 0, \\ 0, & \text{cell-edge load=0.} \end{cases} \qquad (6)$$

where $cell-edge\,load$ and $cell-center\,load$ are the total load of cell-edge UEs and the total load of cell-center UEs in a certain cell, respectively. Here, the use of function log is to ensure that β will not be overly high when $cell-edge\,load$ is relatively light. The algorithm is fairer than the FFAP plan since it allocates more resource to UEs that maintain relatively low link quality.

IV. SIMULATION RESULTS

TABLE I. SIMULATION PARAMETERS

Parameter	Assumption
Cellular Layout	Hexagonal grid, 3 sites,
Inter-site distance	100m
Load	Different number of UE per sector uniformly dropped
Subcarrier bandwidth	60kHz
Number of subcarriers per cell	128
Bandwidth	$60kHz \times 128 = 7.68MHz$
BS TX power per channel	-20dBm
Noise figure at UE	9dB
Lognormal Shadowing with shadowing standard deviation	8 dB
Distance path loss model	$PL(dB) = 34.5 + 35 \times log_{10} d$ d is in meters [9].
Traffic model	Random request
Channel Estimation	Ideal

A. Basic Scenario

We assume a three cell system with several UEs scenario to perform system level simulation.

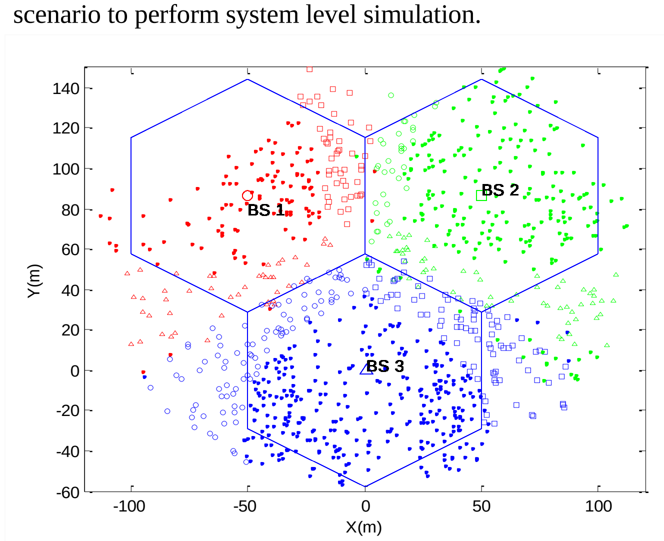

Figure 3. Location Map of Base Station and Mobile Pattern of Ues

As shown in Fig. 3, each marker denotes the location of UEs at a certain time. And the three base stations are marked as 'BS1', 'BS2', and 'BS3', with markers red ' ○ ', green ' □ ', and blue ' △ ', respectively. Each location point of UEs is stamped with a marker. The shape of the marker represents the coordinated cell of this UE, if exists, whereas the color of the marker represents the serving cell of this UE. If a user belongs to cell-center category, the shape of its marker will be a ' • '. For example, suppose UE_1 is served by cell 1 and is coordinated served by cell 2. The marker of UE_1 in the Location Map will be a red ' □ '.

B. *Simulation Flow Chart*

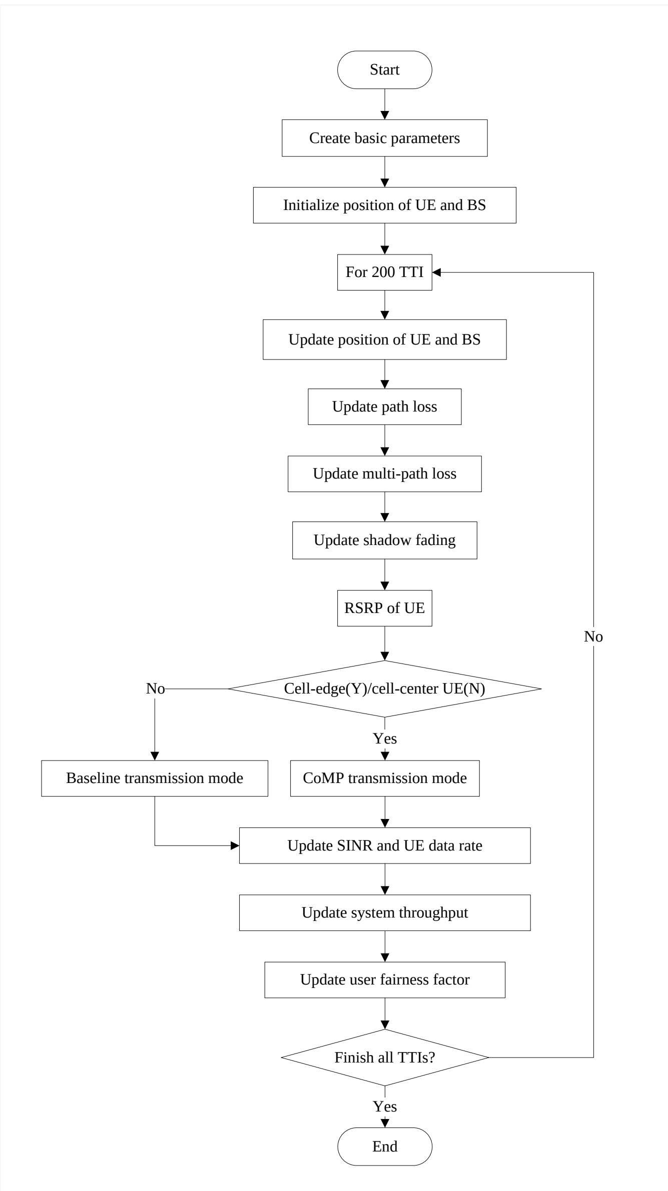

Figure 4. Flow Chart of System Level Simulation

Fig. 4 illustrates the steps of system level simulation of our work. The simulation applies 200 TTIs. First of all, in the step of initializing position of UE and BS, a scenario shown in Fig. 3 is set. Second, in every loop, path loss, multi-path loss, and shadow fading are updated. Then base stations are able to get information about channel matrix and therefore RSRP of UEs. After acquiring these qualities, the system group UEs into two categories, the cell-edge UEs and the cell-center UEs. Cell-edge UEs not only access to their serving cells, but also are assigned certain bandwidth to perform coordinated transmission, that is to say, is accessed by coordinated cells. Cell-center UEs, however, have only one access point, their serving cells, and exchange data through baseline transmission mode. Finally, the performance of the system under the proposed frequency allocation plan scheme is evaluated. SINR and user data rate are evaluated to obtain system throughput. Here, in order to keep the fairness of all UEs at a relatively high target, if the user data rate is below a threshold value, as:

$$Rate_{UE} < Rate_{threshold}. \quad (7)$$

This UE will be inactivated and rendered no spectrum resource at the moment, in other words, is disabled.

C. *Simulation Results*

Fig. 5 illustrates the total throughput of the system under three different frequency allocation plans, with the number of UE in three cells from 200 to 40,000. From the result of Fig. 5 we could conclude that the proposed scheme has a significant improvement in system throughput performance. For example, the gain of system throughput when performing the proposed scheme is 28.20% over the FFAP scheme (when the number of UE in the system is 1600).

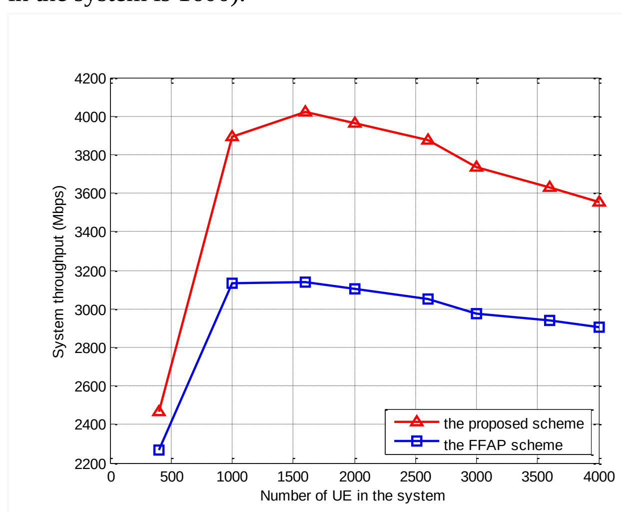

Figure 5. System Throughput Under Different Frequency Allocation Plan

Fig. 6 illustrates the system performance in cell-edge throughput, with the same condition as in Fig. 5. Cell-edge performance maintains an important indicator in SU-

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CoMP system, which is also the main reason for downlink CoMP transmission. The proposed scheme shows higher gains over the FFAP scheme. 30.46% of the cell-edge throughput is improved when performing the proposed scheme. Therefore, cell-edge throughput performance should reach a preferred value when operating the proposed frequency allocation plan scheme.

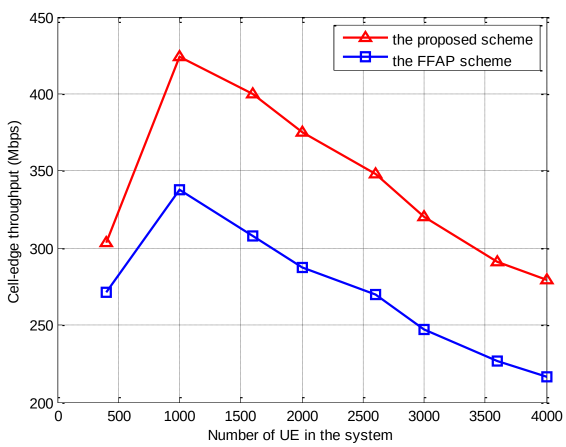

Figure 6. Cell-edge Throughput Under Different Frequency Allocation Plan

V. CONCLUSION

In this paper, we have evaluated the FFAP scheme in downlink CoMP transmission. A novel frequency allocation plan scheme is proposed, which takes both the traffic load of each cells and link quality into consideration. We have shown the effectiveness of the proposed scheme through system level simulation. About 30% gains of the system throughput and cell-edge throughput could be reached when performing the proposed scheme for resource allocation.

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