A Sequence Frequency Reuse Scheme for Coordinated Multi-Point Transmission in LTE-A

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Abstract—OFDMA communication technology becomes for the next generation mobile communication systems (4G) standards. Decreasing Inter-Cell Interference (ICI) is one of important issues in OFDMA. A new technology of LTE-A (Lone Term Evolution-Advanced) is CoMP(Coordinate Multi-Point, CoMP) transmission, which purpose is to solve low performance and poor quality of transmission due to interference cause by. Even through there are many LTE research papers are presented to explore the use of frequency reuse mechanism to solve the ICI, but they are inappropriate for CoMP technology. In this paper, we propose an efficiently Sequence Frequency Reuse (SeFR) scheme to improve low performance that cause by ICI, and making restrict in ICI seriously region to work smoothly on CoMP. According to the results of simulation, the proposed mechanism makes the CoMP transmission to achieve higher efficiency in the use of, and improves the SINR value of CEU (Cell Edge Users).

Keywords: CoMP, LTE-A, Frequency reuse, ICI

I、Introduction

In recent years, wireless networks and broadband networks have the majority of the market as well as the public high acceptance. In response to the needs of the general public, the constant evolution and progress of the wireless communication network are approaching to the next Internet generation. The aim is to provide user convenience and high-speed transmission. Orthogonal Frequency Division Multiplexing Access (OFDMA) communication technology is the standard of next generation mobile communication system [1-2]. Both of the standards of Institute of Electrical and Electronics Engineers (IEEE) 802.16e and Long Term Evolution (LTE) of the 3rd Generation Partnership Project(3GPP) select OFDMA as Downlink transmission scheme [1-2]. Due to the Cellular system network exists the problem of signal interference. OFDMA could be an effective solution to Intra-Cell Interference (ISI) by the characteristics of the orthogonal but Inter-Cell Interference (ICI) problem still exists, the cell-edge (CE) is particularly serious especially. ICI problem in general is solved by frequency reuse mechanism [8-10, 12, 16].

Including the Coordinated Multi-Point (CoMP) transmission is one of major technology characteristics in the evolution of LTE to the LTE-A process. The technological purpose of CoMP is to solve the low performance and poor quality of transmission caused by ICI. However, a number of frequency reuse mechanisms of LTE are not entirely support the CoMP, this new technology of the LTE-A. So that Jingya Li etc. proposed a Cooperative Frequency Reuse (CFR) [11] to apply CoMPinto frequency reuse mechanism.

Although the CFR can support CoMP technology, but it can not effectively use the CoMP technological characteristic. To use technically the CoMP to coordinate and allocate the resources among neighboring cells, it is necessary to design a more efficient frequency reuse mechanism. The purpose of our study is based on the CoMP technology to improve the existed frequency reuse mechanism and propose a suitable frequency reuse mechanism to enhance the overall effectiveness of the overall cell.

To accomplish this objective, this paper proposes an efficient Sequence Frequency Reuse (SeFR) mechanism to improve the CFR mechanism, ensure that the CoMP to be applied fully, and solve the low performance problem caused by interference between cells. The proposed SeFR offers different frequency allocation of resources in different regions of a cell and give the order of use restrictions [14], use different frequency reuse assignment to reduce the ICIs among the neighboring cells. So that the operations of CoMP not only can reach better results, but also will to avoid interference.

The remains of this paper is divided into four sessions. Session II presents the related technologies and researches, they include several different frequency reuse mechanisms. The proposed mechanism contains the definition and related processes are proposed detail in session III. Session IV simulates and analyzes SeFR with different frequency reuse mechanisms and make comparison. Finally, session V is conclusion summarizes the objective and contribution of the proposed SeFR mechanism and illustrates the future research directions.

II、 Related Work
A. Partial Frequency Reuse

The idea of Partial Frequency Reuse [9, 12] of all available spectrum resources F is split into two parts, denoted as F_1 and F_3, and F_3 is divided into three subset: F_{3-A}, F_{3-B} and F_{3-C}, Cell Edge (CE) will be assigned to the resources of the F_3, Cell Edge Users (CEUs) can only use their own part of the F_3, Cell-Center users (CCUs) use only F_1, too. Shown as figure 2.1 [9].
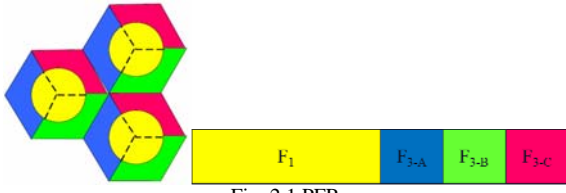
Fig. 2.1 PFR

B. Soft Frequency Reuse

Soft Frequency Reuse (SFR) [3] collects three neighboring cells into a set, all of the resources are available to the band will be divided into three sections: F_1, F_2, F_3, shown as figure 2.2. The CE of the three cells is allocated one of the three different sections, respectively.
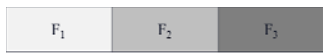

Fig. 2.2 Frequency resource division

Assume the CE in cell A is using the resource section, F_1, and the assignment to the Cell-Center (CC) of cell A are sections, F_2 and F_3 integrality. Figure 2.3 describes this assignment.

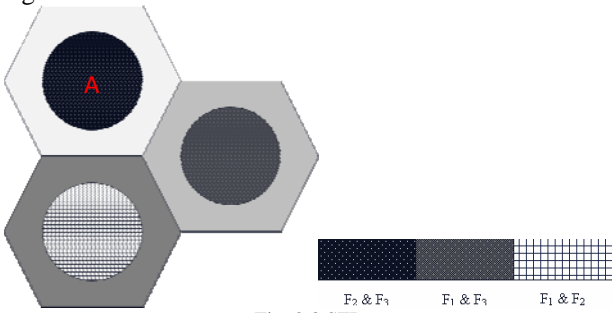F_2 & F_3 F_1 & F_3 F_1 & F_2
Fig. 2.3 SFR

C. Incremental Frequency Reuse

Incremental Frequency Reuse (IFR) [10] assigns also three neighboring cells as a set. It defines a different starting point to each cell in same set. When it will allocate resource, illustrated in figure 2.4 [10], black frame represents the starting position of each cell to allocate resources, so that can avoid ICI when traffic load is not heavy. However, the interference problem will be caused more serious than SFR or PFR when the load is increasing.
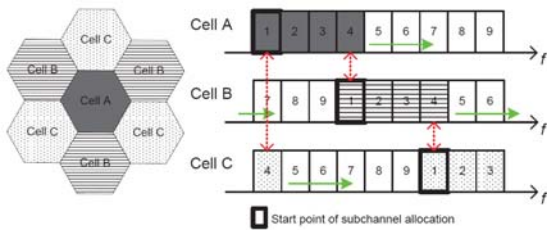

Fig. 2.4 IFR

D. Cooperative Frequency Reuse

Cooperative Frequency Reuse (CFR) is published in 2009, and proposed by VTC conference in 2010[3]. The mechanism divided into three steps.

The **first step** assumes that every three neighboring cells as a cluster. The CE regions will be separated according to six different positions of neighboring cells. The CE is cut into six zones, shown in figure 2.5. Each cell periphery is expressed as $A_i^{\,j}$. For examples:

Zone A_1^2：The zone of cell edge Belongs to cell 1 and the possible interference of user is come from recent neighboring cell 2.

Zone A_2^3：The zone of cell edge Belongs to cell 2 and the possible interference of user is come from recent neighboring cell 3.
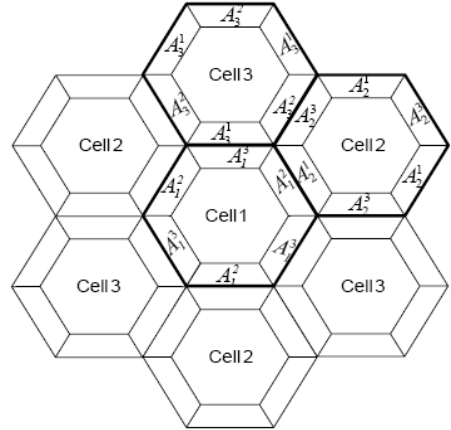

Fig. 2.5 Cell-Edge areas partition for each cell

The **second step** assigns the resource to users of each cell cluster according to the following rules:

Step 1：All the resources in each cell is divided into two sets: G and F, G is assigned to the CCUs of each cell, while the resources of F is assigned to the CEU of each cell.

Step 2：F will cut further into three equal portions, labeled F_1, F_2 and F_3, respectively. Any two F_i and F_j, $i \neq j$, are disjoint.

Step 3：For each cell cluster, F_i of cell i is a cooperation frequency, which is make use of CoMP with CEUs of adjacent cells for coordinated multi-point data transmission.

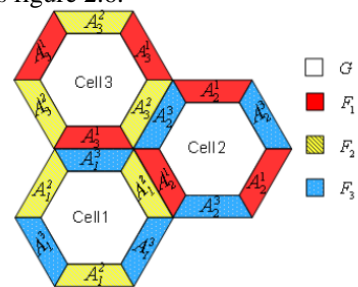Step 4：F_j is assigned to the CEU, expressed as $A_i^{\,j}$. It is illustrated as figure 2.6.

Fig. 2.6 Frequency allocation for each cell in the cluster

A CEU who locates in the heart of $A_i^{\,j}$, the cell i and cell j are classified in the CCS (CoMP Cooperating Set). It means both of cell can execute CoMP cooperation transmission for the CEU. It is the cell i and cell j could joint transmission in the same frequency resources. As show in figure 2.7, the CEU1 is position in the A_1^3, it can be regarded as CoMP CEU, the original service cell 1 and the original interfered cell 3 will be classified together in the CCS
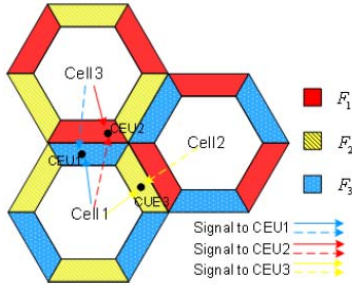
collection.

Fig. 2.7 CoMP joint transmission in the CFR system

The **third step** uses the algorithm as follows, proposed by G. Piñero [15] to the implementation of the CoMP Cooperating Set (CCS) selection.

Algorithm: CCS Selection

① Initialization
$\Psi_k \leftarrow \varnothing$, $count \leftarrow 0$.

② Calculate G_k^i between the kth CEU and the ith cell, for $i = 0,...,N-1$.
$G \leftarrow \{G_k^0, G_k^1,...,G_k^{N-1}\}$

③ Find serving cell for k^{th} CEU
$i \leftarrow \arg\max(G_k^i), G_k^i \in G$
$s \leftarrow i$

④ Update
$\Psi_k \leftarrow \Psi_k \cup \{i^{th}\ cell\}$
$count \leftarrow count + 1$

⑤ If $count < M$,
$G \leftarrow G - \{G_k^i\}$
$i \leftarrow \arg\max(G_k^i), G_k^i \in G$
Else stop.

⑥ If $G_k^s - G_k^i \leq thr$, go to ④
Else stop.

The 3GPP document [5] mentioned that if the number of cell in UE CCS is 2, it is enough to reach the CoMP gain effect. Therefore, the CFR set the value of the M is 2.

However, one drawback of CFR is it lacks a rule to allocate the frequency resources of CE. Thus, it is possible that the frequency in the CE CCS maybe allocated by other CEU and CoMP transmission can't work effectively and the totally throughput is decreasing.

SeFR will proposed to offers different frequency allocation of resources in different regions of a cell and give the order of use restrictions [14], use different frequency reuse assignment to reduce the ICIs among the neighboring cells and increases the total throughput.

III、Sequence Frequency Reuse

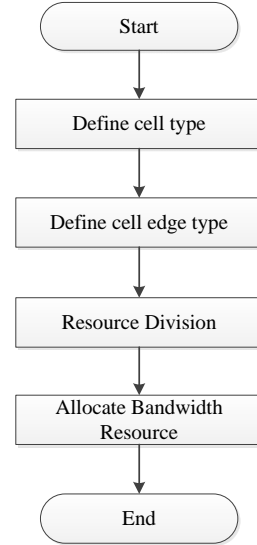This section, the proposed Sequence Frequency Reuse (SeFR) mechanism is divided into four steps, shown as figure 3.1.

Fig. 3.1 SeFR flow chart

1. Define Cell Tye

In phase one, all of cells are classified into three categories: type 1, type 2, and type 3. We can start at any one cell and define it as type 1. Next, the six neighboring cells can be defined as type 2 and 3, separated by clockwise. After that, the neighboring cells will apply the method to define their other neighboring cells which are undefined. Figure 3.2 presents the basic definition.

2. Define Cell Edge type

The second phase, SeFR will divide CE into six zones according adjacent cell and give zones sequence number (number 1~6) from top (clockwise). It shows in figure 3.3.

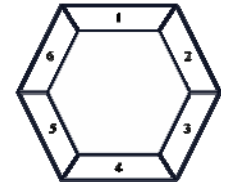Fig. 3.2 Cell type definition   Fig. 3.3 Division and Number

Fig. 3.4 Define cell-edge type flow chart

Some users suffer from seriously interference in region that covered from three cells because the user can receive three cell signals at the same time, as show in figure 3.4. The region we call Cell-Corner (CCr) [6], and the users located at CCr are called Cell-Corner User (CCrU).
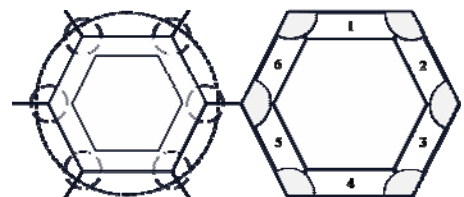

Fig. 3.4 Cell-Corner region

3. Resource Division

The Physical Resource Block (PRB) is minimum resource unit in LTE. We divide the resource into: Cell-Corner Resource (CCrR), Cell-Edge Resource (CER), Cell-Center Resource (CCR). At first, we divide the resource into two parts, called G and F. G is supported as CCR. F further divides into 4 parts, called R_1, R_2, R_3 and CCrR. The $R_{1\sim3}$ is allocated for CE, and CCrR is allocated for CCr. $R_{1\sim3}$ further divide into 6 partitions, and give a sequence number 1~6, shown in figure 3.5.
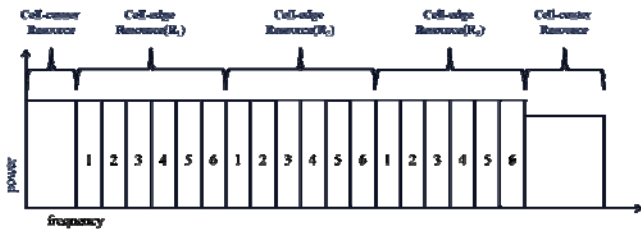

Fig. 3.5 Division of PRB

4. Allocate Resource

Because zone 1 of any cell type is serial number is 1, so that the frequency resource starts allocated from partition 1 of resource R_i, j =1. 2, or 3.

A. Resource allocated on CE

Formula (1) can use to decide the resource allocation:

$$\begin{cases} r = (x\%3)+1, \text{ if i is odd} \\ r = [(x+1)\%3]+1, \text{ if i is even} \end{cases}$$

x is express cell type, i and r express CE zone i use R_r resource. Figure 3.6 can express resource allocation of the cell type 1, for example. The black partition is restriction, means that the cell didn't use this part but use this part to do CoMP transmission.
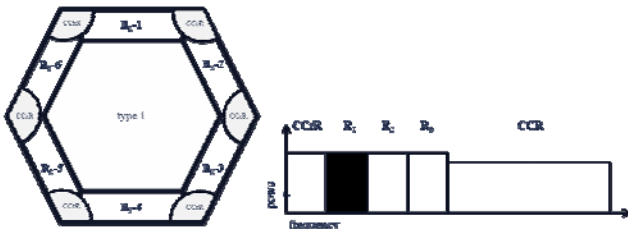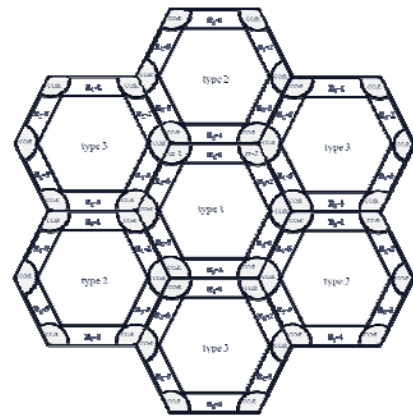

Fig. 3.6 resource allocated of the cell

Fig. 3.7 cell cluster

For example, the center cell of figure 3.9, it is one of type 1 cell, we can use Formula (1) to decide what resource could allocate if the zone 1 need resource. Such as zone 1 of this cell, it will allocate resources starting from partition 1 of R_2. The adjacent CE is zone 4 of a type 2 cell, this CE will allocate resource starting from partition 4 of R_3. We can observe from figure 3.7 that does not exist two adjacent cells of the CE are using the same frequency band resources. SeFR gives each cell edge a serial number and using resource allocation rule that can efficiently decrease interference. It will be better than CFR.

CoMP transmission from center cell to surround cells is shown in figure 3.8(a). CoMP transmission from surround cells to center cell presents in figure 3.8(b). For the center cell CE, all of CE surrounding center cell are use different resource. Type 1 didn't use R_1 resource, due to R_1 of type 1 cell will execute CoMP transmission to all surrounding CE of neighboring cells completely because that all of surrounding CE allocated resources are start from different partition.
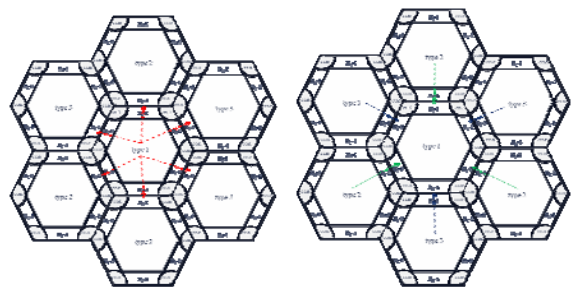

Fig. 3.8 CoMP diagram (a) and (b)

SeFR applies a resource rule to avoid resource allocated not uniform. For example, zone 1 and zone 3 and zone 5 allocated resources with starting from R_2-1, R_2-3, and R_2-5 of R_2, respectively in the cell of type 1. Therefore, they have highest priority for these partitions that other CE couldn't use. In zone 1 of type 1 cell, R_2-1 with highest priority; R_2-2 with high priority because R_2-2 is second sequence for zone 1, and R_2-3 and R_2-5 without priority because R_2-3 and R_2-5 belong to others zones highest priority. R_2-4 and R_2-6 with low priority because R_2-4 and R_2-6 belong to others zones high priority. Table 3-1 illustrates the resource rule.

Table 3.1 type 1 CE allocated resource priority

	R_2-1	R_2-2	R_2-3	R_2-4	R_2-5	R_2-6
zone 1	**highest**	high	without	low	without	low
zone 3	without	low	**highest**	high	without	low
zone 5	without	low	without	low	**highest**	high

Resource allocated on CCr

SeFR allocates resource to independent of cell corner (CCr) because the user in this region have lower SINR that easy get higher interference by more than two cells.

Assume the resource *r* has already to be allocated to user *u* that *u* have nice signal with three source signals (CoMP transmission by *c1, c2* and *c3*), while user *v* also need resource *r* but *v* could not get three source signals because only *c4* and *c5* can joint transmission. Whether *u* or *v*, both users can achieve a good SINR. It shows in figure 3.9.
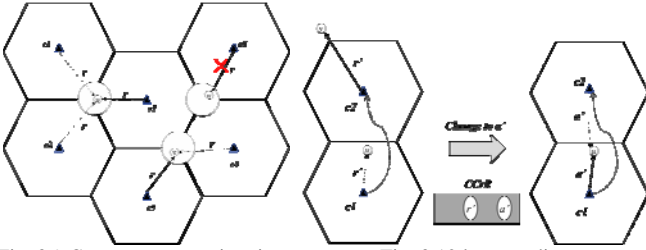

Fig. 3.9 Corner resource situation   Fig. 3.10 lent out diagram

However, if user *w* also needs same resource *r*, *w* only has one signal resource, but have more interference existed. The SINR of user w must be terrible, moreover it will waste resource, so that it will not allocate resource *r* to *w* instead change another resource or wait for release. In this case, in order to achieve better resource utilization, *r* resource of *c6* cell will be allocated to another user, not for the user w.

To solve this problem of Cell Corner, SeFR uses a lend mechanism [13], when CE needs more resources and CCrR have free resource. The priority of borrowed resource is low. The user *u* needs more resources and the CCrR of serving cell have free resource, so that *u* can borrow resource. Before CCrR lend out resource *r'*, serving cell will ask the adjacent cells that the resource *r'* is free or not? If yes, the serving cell will lent out *r'* and sent requirements to adjacent cells to do CoMP transmission on *r'*. Otherwise, the serving cell will change another free resource to *u*. Figure 3.10 shows the lend mechanism. Thus, SeFR gets best SINR using by CoMP transmission with borrowed resource.

Of course, SeFR provides the resource return mechanism for previous lend process. Figure 3.11 presents the return mechanism.
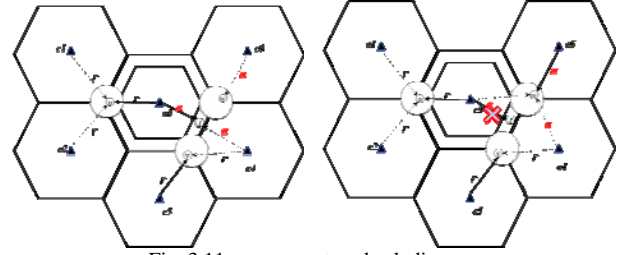

Fig. 3.11 resource return back diagram

IV、Simulation

We write a simulation program tool by C++, through the actual simulation to analyze the performance of SeFR. The comparison proves SeFR can achieve better results than CFR in the cell edge users.

A .Simulation Environment

Table 4.1 SIMULATION PARAMETERS

Parameters	Values
Carrier Frequency	2GHz
Bandwidth	10MHz
Subcarrier Spacing	15kHz
Number of PRBs	50
Number of Cells	19
Cell Radius	500m
Maximum power in BS	46dBm
Distance-dependent path loss	L=128.1+37.6log10d(dB). d in km
Shadowing Factor Variance	8dB
Shadowing Correlation Distance	50m
Inter cell Shadowing Correlation	0.5

We use the formula (2) [7] to calculate the SINR of each user. According to the Shannon theory [5], it calculates the SINR and the allocation of bandwidth to the user's capacity and the throughput of the cell as a whole.

For formula (2), *r* is the SINR, k^{th} user, i^{th} is serving cell which uses l^{th} PRB. The numerator represents the source of the signal strength, s^{th} represents as cells of CCS belong to k^{th} user. For CEU and CCrU, we take two and three cells, respectively [4]. $P_{s,l}$ is transmission power of sth on l^{th} PRB, G_s^k is long term gain between s^{th} cell and k^{th} CoMP user. Denominator is that all sources of interference the total, N_0 is noise, *n* is the cell not exist in the CCS of kth user, $x_{n,l}$ is n^{th} cell that using l^{th} PRB, $P_{n,l}$ is transmission power on l^{th} of nth cell, G_n^k is long term gain between n^{th} cell and k^{th} user.

Formula (2) SINR to each user:

$$r_{i,l}^k = \frac{\sum_{s \in CCS} P_{s,l} G_s^k}{N_0 + \sum_{n \in CCS} x_{n,l} P_{n,l} G_n^k}$$

Formula (3) [7] is that calculate the user capacity. *C* is capacity, *k* is user number, *i* is serving cell number, l^{th} is PRB number, and *B* is the bandwidth.

Formula (3) user capacity of cell:

$$C_{i,l}^{k} = B \log_2 (1 + r_{i,l}^{k})$$

B. Analysis of simulation results

When users are uniform distribute in cell edge graph, it is shown in figure 4.1. SeFR avoids surrounding cell users use the lth PRB of ith the cells, so that the limit resources can average and complete allocated to neighboring CEU for i^{th} cell. Moreover, it can avoid the problem with i^{th} cell doing CoMP transmission.

SeFR mechanism can improve CoMP on the user's operational efficiency. The SINR is raise a lot in less number od users. Even the user number is increasing, SeFR still maintain the user in a higher SINR than CFR.
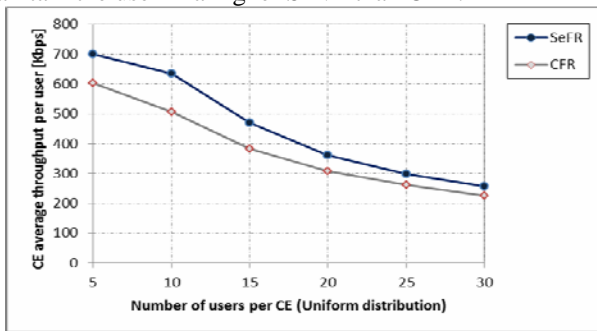

Fig. 4.1 Cell-Edge average throughput per user on uniform distribution

Observed in figure 4.2, the users are uniform distribution of the overall throughput of the cell edge in the case that Strengthen the the CoMP ability to CEU to SeFR mechanisms, while also focusing on users in less time as the user can accurately enhance CoMP the ability of the cell corner regions, the average throughput of each user is higher than the CFR.
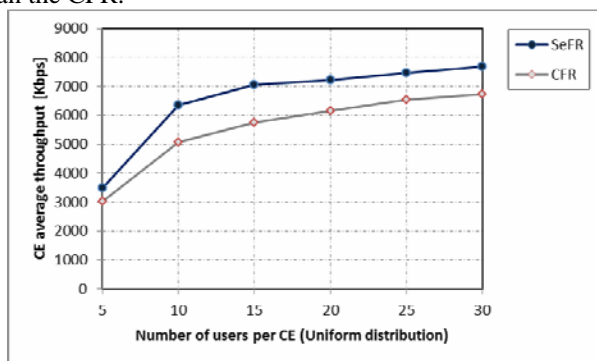

Fig. 4.2 Cell-average throughput as the number of users per cell

V、Conclusion

This paper presents a Sequence Frequency Reuse (SeFR) mechanism to improve the original technology that works on CoMP of LTE-A. SeFR uses the re-division of the frequency resources to the given six cell edge zones and allocates frequency resources to each corresponds to the zone number. It can make the CoMP transmission to achieve higher

efficiency in the use of, and does improve the SINR value of CEU. SeFR also applies the independent of the cell corners, and give part of a separate allocation of resources, at the corner of the cell. The user can effectively use the the CoMP bring the advantages of, and the reduce interference. The SINR value can be upgraded. Finally the proposed mechanism compares to the existing mechanisms to prove that it is more suitable for LTE-A CoMP technology.

In the future, this mechanism will consider to including transmission power and others technologies of LTE-A that can make some improves to this mechanism.

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