A Novel Inter-Cell Interference Coordination Scheme in LTE System

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***Abstract*—In this paper, an Inter-Cell Interference Coordination (ICIC) scheme is proposed for the uplink transmission in Long Term Evolution (LTE) systems. Firstly, an efficient ICIC scheme which combined a semi-static resource allocation plan is presented. Secondly, applied by High Interference Indicator (HII), a Physical Resource Block (PRB) reuse avoidance algorithm is proposed to reduce multi-cell co-channel interference. Thirdly, a power control method is applied based on the Overload Indicator (OI), by setting transmit power of cell-center users. Simulation results show that the proposed algorithm improves the cell-edge throughput and increases total throughout performance effectively.**

***Index Terms*—inter-cell interference coordination, soft frequency reuse, semi-static**

I. Introduction

Single Carrier FDMA (SC-FDMA), aimed at mitigating the peak-to-average-power ratio problems typically encountered by OFDMA on the uplink [1], has been adopted on the uplink of the 3G Long Term Evolution (LTE). Because of its orthogonality feature, the intra-cell interference is mostly mitigated and can be ignored. But neighboring cells transmit in the same frequency band which inevitably causes Inter-Cell Interference (ICI) [2]-[6].

To solve the problem and improve the system capacity, Inter-Cell Interference Coordination (ICIC) has been discussed as a promising solution. Soft Frequency Reuse (SFR) is one of the most classical ICIC approaches and firstly proposed in [7]. In SFR scheme, available spectrum is divides into two parts, called major bandwidth and minor bandwidth. User Equipments (UEs) within each cell are also divided into two groups: Cell-Center UEs (CCUs) and Cell-Edge UEs (CEUs), depending on their Channel Quality Information (CQI). CEUs are served to the major bandwidth, and CCUs are restricted to minor bandwidth. The major bandwidth are served with full transmit power, while the minor bandwidth are used with reduced power. Between adjacent cells the major bandwidth are planned orthogonally. The SFR scheme is a bandwidth efficient ICIC mechanism, but it wouldn't handle properly the situation with varying cell edge traffic load. Ref. [8] proposed a distributed heuristic ICIC scheme, the total available spectrum is divided into four parts, a part of the spectrum is defined as the spectrum pool. And the spectrum pool could be occupied by its neighbor cell when its load is high. Taking into account the balance and variation of cell edge load distribution among neighbor cells, the scheme can effectively improve the cell edge throughput performance, but it doesn't consider the frequency reuse between adjacent cells. Ref. [9] proposes PRB Reuse Avoidance (RA) algorithm for the uplink of LTE systems, and the PRB reuse could be detected via HII exchange. However, the scheme doesn't take into account the restriction of PRB borrowing between adjacent cells.

A new ICIC scheme is put forward to realize real-time coordination of the PRBs allocation and the transmitting power of users in various residential communities according to load condition. Therefore, the scheme is able to optimize resource allocation of whole system. The PRB borrowing algorithm is used to restrict the lendable resources among residential communities and HII is utilized to avoid resource reuse. Meanwhile, the power is regulated based on the Overload Indicator (OI) message so as to establish a perfect uplink ICIC scheme. As demonstrated in simulation results, this scheme shows superiority and feasibility compared with traditional schemes.

II. System Model

Suppose that there are M cells in the cellular system, among which, total amounts of UEs in any a cell m is K_m, and the number of CEUs is K_m^E, and let K_m^C be the number of CCUs. There are N PRBs in a cell in total, and each PRB can be scheduled for no more than one UE at a TTI. Owing to the orthogonality of sub-carriers in the LTE system, and there are no interferences between different sub-carriers, therefore, the inter-cell interference and the white Gaussian noise are considered as main factors influencing system performance. Assume that PRB n is used by UE k in cell m at a time, transmitting power and channel gain to the base station of k are P_{mk}^n and G_{mk}^n respectively, and transmitting power of the UE using same PRB with k in adjacent cell is $P_{m'k'}^n$, its channel

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gain to base station as $G^n_{m'k'}$, then the signal to interference and noise ratio (SINR) of the PRB is:

$$SINR^n_{mk} = \frac{P^n_{mk} G^n_{mk}}{\sum_{m' \neq m} P^n_{m'k'} G^n_{m'k'} + N_0 B} \quad (1)$$

where, N_0 is power spectral density of the channel noise and B is bandwidth of each PRB.

The throughput of UE k in PRB n is represented as:

$$T^n_k = B \sum_{n=1}^{N} \log_2 \left(1 + SINR^n_{mk}\right) \quad (2)$$

The maximum total throughout is the target of the system, namely:

$$\max \left(\sum_{m=1}^{M} \sum_{k=1}^{K_m} \gamma^n_{mk} T^n_k \right) \quad (3)$$

In the formula, γ^n_{mk} indicates whether or not PRB n is allocated to k in cell m at a TTI, if it is, then γ^n_{mk} =1, otherwise γ^n_{mk} =0.

Constraint conditions are as follows:

$$\sum_{k=1}^{K_m} \gamma^n_{mk} \leq 1 \quad (4)$$

$$P^n_{mk} \leq P_T \quad (5)$$

$$\sum_{k \in \Phi^E_m} \gamma^n_{mk} = 1 \quad (6)$$

$$\sum_{k \in \Phi^E_{m'}} \gamma^n_{mk} = 0 \quad (7)$$

where Φ^E_m is the set of all UEs in the edge area of cell m, and $\Phi^E_{m'}$ is set of all CEUs in adjacent cell m'.

The traffic load reflects current load condition of each cell, and the cell-edge traffic load of cell m is defined as:

$$TL_m = \left(\sum_{n=1}^{N} \sum_{k \in \Phi^E_m} \gamma^n_{mk}\right) / N \quad (8)$$

III. ICIC SCHEME IN LTE UPLINK

Fig. 1 illustrates the design flow of the ICIC scheme in the paper. Firstly: basic PRBs are allocated to the CEUs and CCUs randomly based on the allocation scheme of SFR, assigning cell-center PRBs to CCUs and cell-edge PRBs to CEUs. Secondly: based on the results of the random resources allocation mentioned above, the reserved cell-edge PRBs is allocated according to the traffic load in each cell. Thirdly, by investigating HII message sent by adjacent cells, CCUs are required to reallocate resources based on the PRB reuse avoidance algorithm, and then they judge whether or not to receive new resource allocation scheme. Finally, power in CCUs is expected to be adjusted according to OI message.

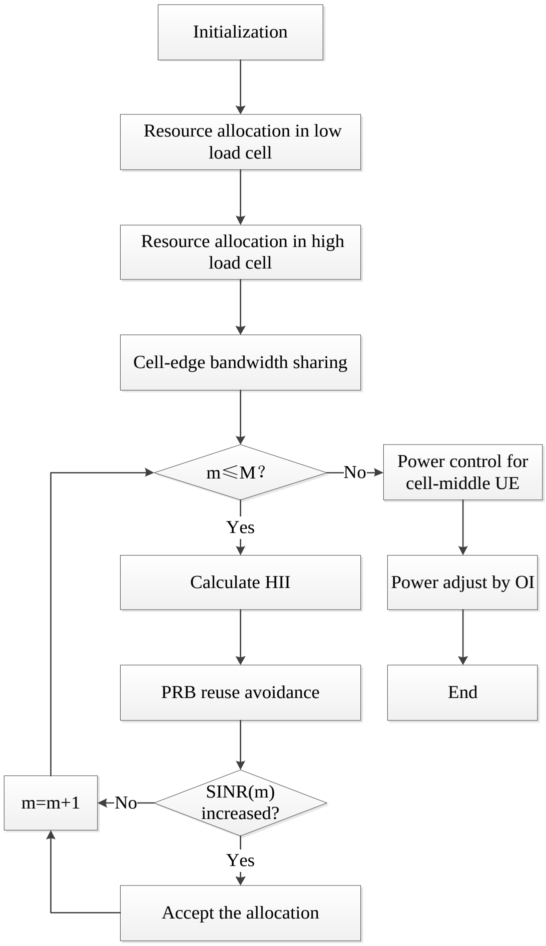

Figure 1. Flow chart for the proposed scheme.

A. *Allocation of PRBs*

Traditional SFR scheme fails to adapt to dynamic load change of the cell. Therefore, PRBs borrowing among adjacent cells are considered in this scheme to solve this problem [8]. That is to say, when the load of cell-edge area is high but its adjacent cell is low, then the cell with high load can borrow PRBs from low load cell, so that the resources allocation can change with the load condition. Specific allocation model is illustrated in Fig. 2.

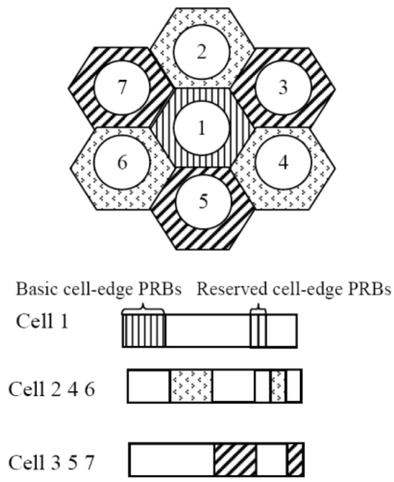

Figure 2. Frequency planning.

Mode of the PRBs allocation of the scheme is shown in Fig. 2. In the scheme, PRB is divided into 4 parts with same size, among which, the allocation models adopted in the first three parts are same with the that in SFR scheme, and the last part is served as reserved PRBs. Meanwhile, 1/3 of the reserved PRB is distributed to the CEUs, which can also serve as borrowing PRBs among neighbor cells. As a result, PRBs utilized by the CEUs includes basic and reserved cell-edge PRBs, but basic cell-edge PRBs shows priority over the reserved cell-edge PRBs. After completion of resource allocation, the rest of reserved PRB can be allocated to CCUs.

B. Resources Allocation Algorithm Using PRB Borrowing

According to the PRB borrowing algorithm, the CEUs have greater priority. Therefore, the system firstly allocates PRB for CEUs, and then the rest of cell-edge PRBs are expected to be allocated to CCUs. With regard to the system of 7 cells in Fig. 2, cells 2, 4 and 6 shares the same cell-edge PRBs, while cells 3, 5 and 7 share another different one. Besides, the cell-edge PRBs without being used by the three cells sharing the same cell-edge PRBs are called free PRBs.

Load conditions of cells are divided into three grades including high, medium and low according to their traffic load. Definition $L(i)$ represents load condition of cell edge, and N_d is the number of PRB required by CEUs. Therefore, according to difference on the number N_d of each cell, load condition of the cell-edge can be divided according to the following ways.

$$L(i)=\begin{cases} l, & N_d \le N/4 \\ m, & N/4 < N_d \le N/4+N_r, \quad i=\{1,2,\ldots,7\} \\ h, & N_d > N/4+N_r \end{cases} \tag{9}$$

where, N is the total number of PRBs in a cell and N_r indicates the number of reserved cell-edge PRBs, and *l*, *m*, *h* represent low, medium and high load levels of the cell edge respectively.

The system of 7 cells is divided into 3 sets. Where set 1 contains cell 1 and set 2 includes cells 2, 4, 6, and set 3 consists of cells 3, 5, 7. Definitions of these sets were presented by C_i, $i=\{1,2,3\}$. Load levels of cell sets are denoted by $L(C_i)$, and then $L(C_i)$ in various conditions are defined in the following ways:

$$L(C_1) = L(1) \tag{10}$$

$$L(C_2)=\begin{cases} l, & \text{all of } L(2), L(4) \text{ and } L(6) \text{ are low} \\ m, & \text{else} \\ h, & \text{one or more of } L(2), L(4) \text{ and } L(6) \text{ are high} \end{cases} \tag{11}$$

$$L(C_3)=\begin{cases} l, & \text{all of } L(3), L(5) \text{ and } L(7) \text{ are low} \\ m, & \text{else} \\ h, & \text{one or more of } L(3), L(5) \text{ and } L(7) \text{ are low} \end{cases} \tag{12}$$

Steps of algorithm are as follows:

Step 1: calculate traffic load of each cell according to the formula (8);

Step 2: arrange traffic load of each cell from low to high;

Step 3: according to allocation mode for PRBs mentioned in the section above, the system firstly allocates PRBs to the CEUs with low load cell and then distributes PRBs to its CCUs;

Step 4: allocate PRBs to the CEUs and CCUs of high load respectively;

Step 5: investigate the application of reserved cell-edge PRBs in each cell and lend the rest of reserved cell-edge PRBs in the cell of low load to the cell of high load.

Among which, due to difference on the load of adjacent cells, the PRBs borrowing in step (4) is further grouped into three cases. Suppose that center cell 1 shows high load in its edge area, conditions of PRBs borrowing among neighbor cells are below:

(1) If loads in the edge areas of cell set C_2 and C_3 are both low, namely, $L(C_2)=l$ and $L(C_3)=l$, and there are surplus reserved cell-edge PRBs, the CEUs of cell 1 can borrow free PRBs from cell with the maximum surplus PRBs;

(2) If there are at least one high load in edge areas of the cell set C_2 or C_3, namely $L(C_2)=h$ or $L(C_3)=h$, then the CEUs of cell 1 cannot borrow free PRBs from this high load cell but from another 1/3 cell-edge PRBs;

(3) If loads in the edge areas of cell set C_2 and C_3 are both high, namely $L(C_2)=h$ and $L(C_3)=h$, the lendable PRB are all occupied, and therefore, there is no PRBs for borrowing.

C. Avoidance of PRB Reuse

Owning to PRB borrowing is applied among adjacent cells, when the CEUs in adjacent cell and CCUs in target cell utilize the same PRB, the interference may be generated. In order to avoid interference, an avoidance scheme for PRB reuse is designed based on HII in the paper, and its main ideas are as follows:

(1) The eNodeB transacted HII message of each cell, and then all cells shares their potential interferences;

(2) After receiving HII message of adjacent cells, eNodeB in target cell calculates the sum of HII message of PRB;

(3) eNodeB in target arranges the sum of HII message of PRB from small to large;

(4) Based on the arrangement results, eNodeB in target cell firstly distributes PRB with low potential interference to its CCUs;

(5) When the distribution is finished, SINR of all users in the system are expected to be calculated based on the formula (1);

(6) Compare the new SINR with original SINR, if the former is greater than the latter, then, PRBs allocation is expected to be carried according to the current scheme, otherwise, conducting allocation on the original scheme.

D. The OI Based Power Adjustment

Although the avoidance of PRB reuse reduces the inter-cell interferences to some extent, the fixed transmitting power utilized by CCUs is unfavorable for improving system performance. Therefore, simple adjustments are conducted on power by employing OI message in the paper.

When a PRB is determined whether or not to send OI message to adjacent cells, it firstly calculates Interference over Thermal (IoT) of the PRB. Ref. [10] proposes the computational formula on IoT of PRB n in user *k*:

$$\mathrm{IoT}_k^n = \frac{\sum_{m' \neq m} P_{m'k'}^n G_{m'k'}^n + N_0 B}{N_0 B} \tag{13}$$

Comparing the calculated IoT with the given threshold of IoT, if the former is higher than the latter, OI message is expected sending out. Afterwards, when OI message is received by adjacent cells, UEs sharing the same PRB with that of target cell are required to reduce transmitting power, so as to avoid interference.

IV. Simulation Results and Analysis

Simulation platforms for LTE uplink system in 19 cells are established in the paper, so as to verify validity of the scheme. Basic parameters for simulation are shown in Table I. The SFR scheme and the scheme put forward in research [8], which is represented by Adaptive SFR (ASFR) in the paper, are selected as comparative objects.

TABLE I. Main Simulation Parameters

Parameter	Value
Carrier frequency	2 GHz
Bandwidth	10 MHz
Distance-dependent path loss	128.1 + 37.6 1og10(R/1000), R in m
Shadowing standard deviation	8 dB
Thermal noise	-174dBm/Hz
PRB number per cell	48 PRBs
PRB bandwidth	180 KHz
Cell radius / inner radius R	750m/600m
IOT threshold	8 dB

Cumulative Distribution Functions (CDF) of the average SINR in three schemes are illustrated in Fig. 3. It is observed from Fig. 3 that the ICIC scheme put forward in the paper possesses optimal average SINR. Because the resource adjustment of SFR is unable to adapt to load changes, when load in the edge area of cell increases, available PRBs for the CEUs are insufficient, leading to performance deterioration. Therefore, average SINR of the SFR scheme is minimum. The ASFR scheme adds reserved spectrum pool on the former basis. When the load in the edge of target cell is high but in adjacent cell is low, cell of high load can borrow reserved PRB from adjacent cells with low load. Therefore, this scheme has improved performance of the CEUs to some degree. However, the co-channel interference of the CCUs on the CEUs between adjacent cells is ignored by the scheme while allocating frequency resources, leading to insignificant improvement on the average user SINR. Owing to interference of the CCUs on the CEUs between adjacent cells is reduced by adopting the avoidance algorithm for PRB reuse, average SINR is thus improved significantly.

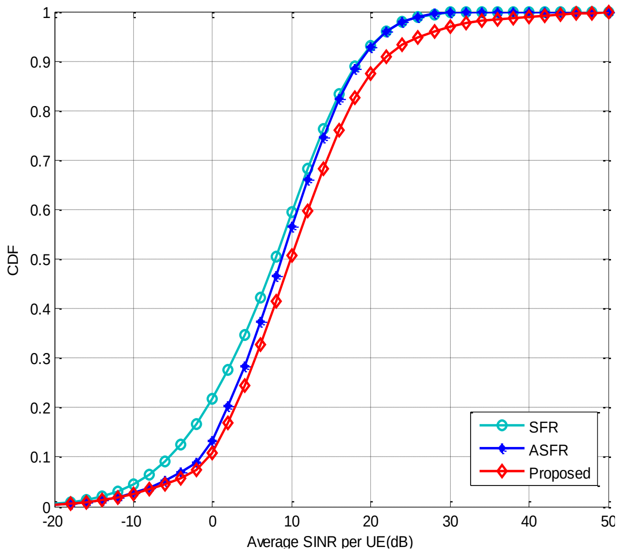

Figure 3. Average SINR comparison for different allocation scheme.

The cell edge throughput in three schemes is shown in Fig. 4. ASFR scheme is able to coordinately allocate PRBs between high load area and low load area in the edge of cell, which can solve problem of insufficient PRBs in cells with high load to a certain extent. Therefore, compared with SFR scheme adopting fixed resource allocation, ASFR has higher cell edge throughout. According to the scheme, basic cell-edge PRBs is firstly allocated to the CEUs in low load cell. In this way, most of the reserved cell-edge PRBs are lendable; this can preferably satisfies demands of the high load cells on PRBs. However, according to the ASFR scheme, PRBs which are allocated to the cells with low load randomly restrict the number of free and lendable PRBs. Therefore, this scheme has higher edge throughout than that of the ASFR.

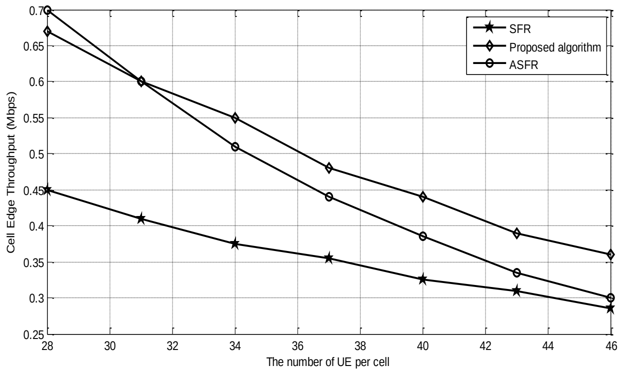

Figure 4. The cell edge throughput vs. the number of UE per cell.

The total throughput of the three schemes is demonstrated in Fig. 5. Both ASFR and the scheme put forward in paper can solve problem of insufficient PRBs in the high load cell to some extent. And compared with SFR, the total throughout in both schemes has increased. In addition, PRB reuse is avoided in the scheme by utilizing HII message. Meanwhile, the scheme regulates the transmitting power of UEs with high interference by applying OI information while improving transmitting power of CCUs. Therefore, ICI is effectively reduced, and total throughout reaches maximum.

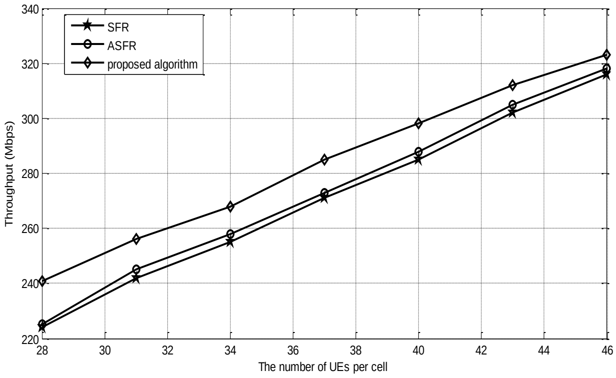

Figure 5. The total throughput vs. the number of UE per cell.

V. CONCLUSION

An ICIC scheme for LTE uplink is proposed in the paper. Firstly, allocation and borrowing of PRBs are introduced. Among which, PRBs borrowing between neighbor cells ensures timely adjustment on PRBs allocation as the load of the cell edge changes. Secondly, the avoidance algorithm for PRB reuse based on HII restricts co-channel interference between the CCUs and CEUs in adjacent cells. Finally, interference is further reduced by adjusting power of CEUs through OI message. As shown in simulation results, the scheme mentioned in the paper has not only improved performance of the CEUs, but also increased total throughout.

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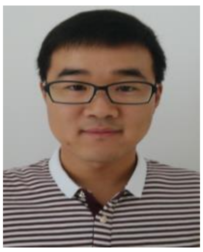

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