A Novel Downlink ICIC Method Based on User Position in LTE-Advanced Systems*

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Abstract: **Inter-cell interference coordination (ICIC) is one of the key technologies in the multi-cell radio resource management of mobile systems. ICIC must be effectively used to reduce the mutual interference of edge users in heterogeneous network (Het-net), where the interference scenario becomes more complicated. ICIC plays a significant role in improving cell edge spectrum efficiency. In this paper, the limitation of traditional ICIC method is analyzed and a novel ICIC method based on User' position is proposed for the improvement of the downlink ICIC efficiency. By the system simulation, it is approved that the edge user throughput and system average throughput may be improved in different degree respectively.**

Keywords: ICIC, downlink, Position, LTE-Advanced;

I. INTRODUCTION

Generally, the downlink ICIC method based on Load Indication (LI) which contains interference information from neighboring cell has two approaches which are, to change frequency resources and to reduce transmit power respectively, to reduce the interference from Node B to that UEs located in neighbouring cell.

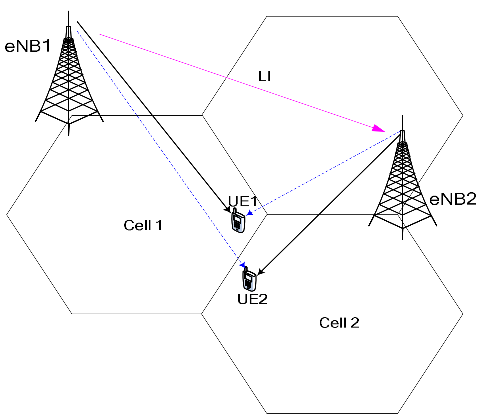

Fig.1 ICIC in LTE systems

As it is specified in Fig. 1, consider the case that UE_1 is interfered by eNB_2 because UE_2 which locates at the edge of Cell 2 near to UE_1 works at the same time and frequency resources as UE_1. With most existing systems, the most prevailing scheme is that eNB_1 would signal LI to eNB_2. After receiving LI information, eNB_2 would reallocate radio resource for UE_2 or reduce the transmit power on the designated set of ratio resources. However, for reducing transmit power scheme, there is a significant issue. The issue is that eNB2 does not decide whether the interference is caused due to itself or not, because it does not accurately know the position of the UE1. For example, if UE1 lies in the outer of main beam for UE2, then, the interference is not caused by UE2. Therefore, reducing the transmission power of UE2 is of no use for reducing the interference to UE1.

In recent years, a lot of work has been done on ICIC schemes based on power control, but there is no explicit study in discussing the accurate power reduction on the designated frequency resources.

This paper is organized as follows. In section 2, as more interference would be incurred in heterogeneous network, the analysis of interference and traditional ICIC scheme in heterogeneous network are showed. In section 3, a novel ICIC method is presented. Section 4 shows simulation results of proposed method compared with traditional ICIC method. Finally, conclusions are drawn in section 5.

II. TRADITIONAL ICIC ANALYSE

Considering the case of hot zone scenario in which one or more low-power Pico eNBs are deployed within the coverage area of a macro eNB, in which, more cells exist in same region, a large number of new "cell-edges" are created, thus creating more severe downlink interference for the UEs. As a result, Signal to Interference plus Noise Ratio (SINR) of UEs is reduced, which leads to a severe degradation of

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system performance. And when this case occurs, then ICIC is required to be used effectively.

In LTE-A system, the eNB (or pico eNB) determines the downlink transmit Energy per Resource Element (EPRE). The determination of reported Relative Narrow-band Transmit Power indication $RNTP(n_{PRB})$ is defined as follows:

$$RNTP(n_{PRB}) = \begin{cases} 0 & \text{if } \dfrac{E_A(n_{PRB})}{E_{\max\_nom}^{(p)}} \le RNTP_{threshold} \\ 1 & \text{else} \end{cases} \qquad (1)$$

Where $E_A(n_{PRB})$ denotes the maximum intended EPRE of UE-specific Physical Downlink Shared Channel (PDSCH) REs in OFDM symbols not containing Reference Signal (RS), in this physical resource block on antenna port in the considered future time interval. n_{PRB} is the physical resource block number. $RNTP_{threshold}$ takes on one of the following values $RNTP_{threshold} \in \{-\infty, -11, -10, \cdots, +3\}$ and $E_{\max\_nom}^{(p)}$ is defined as[1]:

$$E_{\max\_nom}^{(p)} = \frac{P_{\max}^{(p)} \cdot \dfrac{1}{\Delta f}}{N_{RB}^{DL} \cdot N_{SC}^{RB}} \qquad (2)$$

When the ratio of $E_A(n_{PRB})$ to $E_{\max\_nom}^{(p)}$ exceeds the RNTP threshold in Cell 1, eNB shall provide higher transmit power on several PRBs because of the severe inter-cell interference condition. Then a RNTP message in load information (LI) will be sent to its neighboring cells to ask them to reduce the downlink transmit power on the appointed PRBs. Then neighboring cells would change PRBs or adjust the transmit power on the designated frequency resources to mitigate interference.

However, because neighbouring eNB does not accurately know if it produced really the related interference for the interfered UE which uses these resources indicated in LI, the power adjustment is blindfold. As a result, the benefit of ICIC to the system performance would be greatly diminished.

III. PROPOSED ICIC METHOD

With the developing of positioning technology, GPS positioning accuracy may be several meters. And accuracy in methods like radio frequency pattern module (RFPM) and WiFI, the positioning may be several meters too. Using the position information, the interference resource judge has been become more accurate. In proposed novel method, in LI, both RNTP and the corresponding user' position are sent to the neighboring eNB as well. Thus, based on the interfered user' position information and actual beam forming, the eNBs may judge if it produce such interference to interfered user.

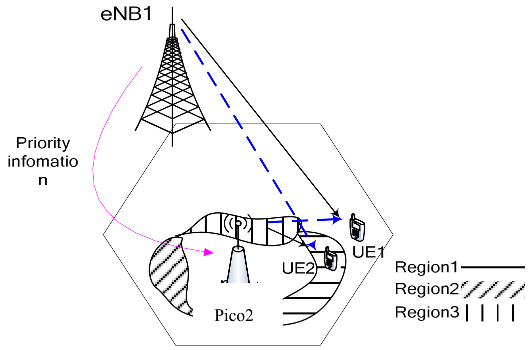

Fig. 2 ICIC in heterogenous network

- **Algorithms work steps**

Step 01: When the ratio of $E_A(n_{PRB})$ to $E_{\max\_nom}^{(p)}$ of UE_1 is bigger than the RNTP threshold, eNB would signal LI which contains priority and position information of victim user to neighboring cells.

Step 02: Receiving LI information, neighboring cell (Pico eNB2) may search involved region for UE_2 who uses the same PRBs indicating set S1.

Step 03: If S1 is null, then end. Else, it goes to step 04.

Step 04: In set S1, the users are searched which satisfies the relation,

[abs(RSRPi1-RSRP21) + abs(RSRPi2-RSRP22)] < Threshold1 (1)

RSRP21, RSRP 22 and RSRPi1, RSRPi2 are UE2 and UE i received RSRP from macro eNB1 and Pico eNB2 respectively. Threshold 1 is a design parameter. These users which satisfy relation (1) are marked set S2.

Step 05: In set S2, the user is locked whose coordinates satisfies,

$$\sqrt{(xi1 - x21)^2 + (yi1 - y22)^2} < \text{Threshold2} \qquad (2)$$

and $\sqrt{(xi1-x21)^2+(yi1-y22)^2}$ is the minimum. Assuming the user is UE2. Threshold 2 is a design parameter too.

Step06: Based on UE1 beam forming and UE2 coordinates, eNB may judge if UE2 locates in the main beam of UE1. If the statement is true, *Step 07* is executed. Else, the process is ended.

Step 07: If there are free RBs in Pico eNB2, UE1 is assigned to another RBs. Else, doing Step 08.

Step08: If the relation $0<\alpha^*<\alpha_H$ is satisfied, α_f will be selected based on maxing the system throughput, and $(1-\alpha_f)P_2$ is given UE2. Else, the process is ended.

- **Theory analysis for one interference user**

As it is specified in Fig. 2, the case that UE_1 is interfered by UE_2 in the neighboring is considered. After received LI information from eNB_1, based on position information of UE1, Pico1 would search for UE_2 which is allocated the same PRBs as UE_1. According to Shannon theorem, channel capacity of UE_1 and UE_2 are defined as follow:

$$C_1 = B\cdot\log_2(1+\frac{P_1\cdot g_{11}}{N_1}) \tag{3}$$

$$C_2 = B\cdot\log_2(1+\frac{P_2\cdot g_{22}}{N_2}) \tag{4}$$

Parameters in (1) and (2) are defined as follow.

C: channel capacity of UE

P: Node transmit power on the appointed frequency

g: pass gain from Node to UE

B: band width

N: UE received total interference

g_{11}: pass gain from eNB to UE_1

g_{22}: pass gain from pico to UE_2

If P_2 is reduced because of lower priority. We assume the transmit power is reduced to $\alpha\cdot P_2$, so,

$$P_2^* = (1-\alpha)P_2 \tag{5}$$

where $\alpha\in[0,1)$. Obviously, C_1 and C_2 might change, and turn out to be C_1^* and C_2^* respectively. For the improvement of system spectral efficiency, the following formula must be achieved.

$$\Delta C = (C_1^*+C_2^*)-(C_1+C_2)>0 \tag{6}$$

According to (3)~(6), ΔC can be presented as follow:

$$\Delta C = B\cdot\log_2(1+\frac{P_1\cdot g_{11}}{N_1-\alpha\cdot P_2\cdot g_{21}})(1+\frac{(1-\alpha)\cdot P_2\cdot g_{22}}{N_2}) - (C_1+C_2) \tag{7}$$

Let: $f(\alpha)=(1+\frac{P_1\cdot g_{11}}{N_1-\alpha\cdot P_1\cdot g_{21}})(1+\frac{(1-\alpha)\cdot P_2\cdot g_{22}}{N_2})$,

Obviously for the maximum $\Delta C(\alpha)$, we must get the maximum of $f(\alpha)$. It is easy to prove that $f(\alpha)$ is continuous and differential. As a result, the maximum value of $f(\alpha)$ could only be achieved when $\alpha\in\{0,1,\alpha^*\}$, where α^* is the congregation of α that make $f'(\alpha^*)=0$.

$$f'(\alpha)=\frac{AD\cdot\alpha^2+2AE\cdot\alpha+BE-CD}{(D\cdot\alpha+E)^2} \tag{8}$$

Parameters in (8) are defined as follow:

$A=P_2^2 g_{21}g_{22}$,

$B=-(P_2^2 g_{21}g_{22}+N_1p_2g_{22}+p_1g_{11}p_2g_{22}+N_2p_2g_{21})$

$C=N_1p_2g_{22}+N_2p_1g_{11}+p_1g_{11}p_2g_{22}+N_1N_2$

$D=-N_2P_2g_{21}$, $E=N_1N_2$

Therefore, α^* can be expressed as:

$$\alpha^*=\frac{-AE\pm\sqrt{A^2E^2-AD(BE-CD)}}{AD} \tag{9}$$

Obviously, α^* is unacceptable if $\alpha^*\notin[0,1)$. However, as the transmit power of eNB_2 is reduced, SINR of UE_2 would be diminished inevitably, results in the decline of C_2. In the actual action, the basic traffic requirement of UE_2 should be maintained, which implies pico1 would not turn off power ($\alpha=1$) on the appointed resources. We assume $C_{2,\min}$ (depends on traffic) is the minimum rate that UE_2 could bearing, according to (4), we could get another formula:

$$C_{2,\min} \le C_2^* \Rightarrow \alpha \le \frac{N_2}{g_{22}}(1-2^{\frac{C_{2,\min}}{B}})+1=\alpha_H \qquad (10)$$

Based on the analysis, if $\alpha^* \in [0,\alpha_H)$, then we could make a comparison among $f(0), f(\alpha_H), f(\alpha^*)$ to get the α for the maximum of $f(\alpha)$ and denote it as α_f. Therefore, we could achieve effective interference mitigation and improve system performance by reducing P_2 to $(1-\alpha_f)P_2$.

- **Theory analysis for N interfering user**

For the most complicated situation that UE_1 is interfered by N UEs in different cells.

$$C_i = B\log_2(1+\frac{P_i \cdot g_{ii}}{N_i}) \qquad (11)$$

Assuming UE_k is the most strongest interference user, we would reduce P_k to $(1-\alpha)P_k$. Based on the analysis before, ΔC can be expressed as follow:

$$\Delta C(\alpha) = B\cdot\log_2[(1+\frac{(1-\alpha)P_k}{N_k})\prod_{i\neq k}(1+\frac{P_i\cdot g_{ii}}{I_i-\alpha\cdot P_k\cdot g_{ki}})]-\sum_{j=1}^{n} C_j \qquad (12)$$

α_H is the same with (10). But the analytic solution of α_f in (12) is quite complicated. However, in the actual scenarios, we could figure out α_f by simulation, e.g. let $\alpha=(0,\frac{1}{10},\frac{2}{10},\ldots,\frac{9}{10},1)$, then figure out α that achieve maximum $\Delta C(\alpha)$ and denote it as α_f. if $\alpha_f<\alpha_H<1$, then we could reduce P_2 to $(1-\alpha_f)P_2$ to improve system performance.

IV. Performance Evaluation

To verify the proposed scheme, we simulated both traditional ICIC and proposed novel strategy in outdoor hot zone scenario. In this section, the simulator of heterogeneous ICIC system model is described in detail. The system parameters are assumed according to the 3GPP evaluation criteria case 1[1][2]. In this simulation, based on Queue (BQ) cell selection method is chosen [3]. There are 2 transmit antennas at each eNB and 2 receive antennas at each UE. The scheduler criterion is based on Proportional Fair (PF). Traffic model is full buffer. The other detailed simulation parameters are listed in table 1.

Table 1: Simulation Assumptions [2]

Parameter		Assumption
Scenario		Case 1: 2G carrier frequency, 500m ISD, 10M BW, speed 3km/h
Cellular layout		Hexagonal grid, 7 sites, 3 cells per site, wrap-around
Pico layout		4 picos per cell
Range Extension (RE)		3dB/6dB/9dB
topology	Configuration1	25 UEs / macrocell 10 UEs / picocell
Total eNB TX power		46dBm
Total pico TX power		30dBm
BS antenna gain plus cable loss		14 dBi
Pico antenna gain plus connector loss		5dBi
Distance-dependent path loss		$128.1 + 37.6\log_{10}(r)$ dB

Power reduction in traditional ICIC is fixed. In this simulation, we make a comparison between proposed strategy and traditional ICIC, in which α is assumed to be 1/4, 1/3, 1/2, respectively. According to 3GPP TR 36.913[4], the cell edge user throughput is defined as the 5% point of CDF of the user throughput normalized with the overall cell bandwidth. Comparison of system performance is given in table 2.

Table 2: Improvement of System Performance

Edge/average throughput improvement	$\alpha=1/4$	$\alpha=1/3$	$\alpha=1/2$
RE=3dB edge	13.62%	10.32%	9.05%
RE=3dB ave.	7.67%	6.68%	4.03%

RE=6dB edge	21.88%	16.66%	10.71%
RE=6dB ave.	6.05%	5.14%	3.11%
RE=9dB edge	33.71%	32.08%	25.69%
RE=9dB ave.	4.90%	4.25%	2.34%

V. CONCLUSIONS

In this paper, the interference environment of heterogeneous system and the limitation of traditional ICIC method are analyzed, and a novel downlink ICIC method is proposed. Compared with the traditional ICIC method, the proposed method, the cell edge throughput is improved 13.62%, 21.88% and 33.71% for RE 3dB, 6dB and 9dB respectively. The average throughput improvement is not obvious.

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