Load Balance based Dynamic Inter-Cell Interference Coordination for Relay Enhanced Cellular Network

Jun Wang, Jianguo Liu, Dongyao Wang, Jiyong Pang, Gang Shen, and Jinhui Chen
Research & Innovation Center, Alcatel Lucent Shanghai Bell, Shanghai 201206, China
{jun.k.wang, jianguo.a.liu, dongyao.wang, jiyong.a.pang, gang.a.shen, jinhui.chen}@alcatel-sbell.com.cn

***Abstract*—The relaying technologies have been considered in cellular networks (such as LTE-A and WiMAX) as one of the advanced techniques to extend the network coverage and enhance the cell edge performance. However, the relays will bring extra interference to macro cell and the popular solution is to allocate different bandwidth for relays and base stations. In this paper, we use proportional fairness mode to formulate this frequency resource allocation optimization problem and presented a new adaptive method (both centralized and distributed algorithm) with interference coordination based on dynamic traffic load for cell-edge relay deployment. This resource allocation scheme with both intra and inter cell interference coordination (ICIC) can greatly improve the spectrum efficiency compared with conventional static ICIC schemes, in which the cell-edge bandwidth is equally allocated among the neighboring base stations or relays. Based on our performance evaluation, the proposed method can flexibly adapt the case when the traffic load distribution is non-uniformed or mobility occurs frequently, which accordingly exploit the cellular capacity with the experience enhancement of the cell-edge users.**

I. INTRODUCTION

Recently, multi-hop relay techniques have been widely discussed [1][2] in the 3GPP long term evolution advanced (LTE-A) and worldwide interoperability for microwave access (WiMAX), both of which choose OFDMA as the downlink transmission scheme. In a LTE-A relay-assist system, each user equipment (UE) can access to an eNode-B (eNB) or a relay node (RN) based on some UE association principles, such as maximum receive signal power, minimum distance etc.. Therefore, three types of links are formed: links between the eNB and its serving UEs (named macro UEs) are called direct links; links between the relay node and its serving UEs (named relay UEs) are called relay access links; links between the eNB and its subordinate RN are called relay backhaul links. For in-band relaying, these three kinds of links occupy the whole frequency band of a cell.

However, in this relay-enhanced multi-cell network, Inter-cell Interference (ICI) is the major source of downlink interference [1]. By deploying RNs at the cell edge and assuming relay UEs are served through the cell-edge band, it is expected that cell-edge UEs could experience not only no inter-cell interference but also an improved receiving signal power from the serving RN [2]. Some inter-cell interference coordination (ICIC) techniques based on fractional frequency reuse (FFR) have been proposed [3][4]. In FFR, cell-edge UEs are only allowed to operate on a fraction of all available subbands. This subbands fraction is allocated in such a way that adjacent

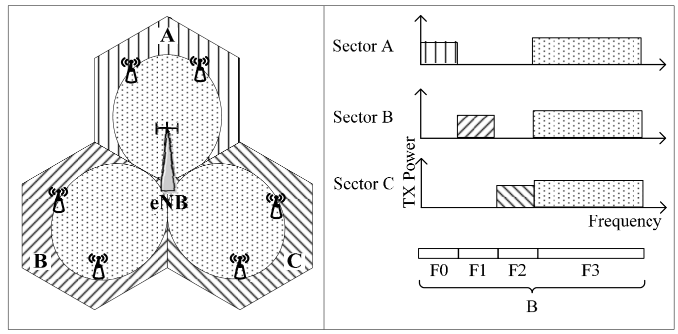

Fig. 1. Frequency Division for Macro and Relay UEs

cells edges will operate on orthogonal sets of subbands so as to avoid inter-cell interference. Cell-center UEs could operate on all or main fraction of all available subbands without orthogonality limitation since cell-center UEs are closer to an eNB and then particularly immune to co-channel interference. When taking relay into consideration, a variant of FFR was proposed, as shown in Fig. 1, in which the whole frequency band is partitioned into two parts. The reuse factor 3 part of the frequency band (F0, F1 and F2) is called the cell-edge band (for relay UE) and the reuse factor 1 part (F3) is called the cell-center band (for relay backhaul and macro UE).

Also, the related coordination scheme can be static [3][4] or dynamic [5]. Static schemes for interference mitigation are relatively easy to implement and no additional signalling overhead among eNBs. The existing solutions [4][5] are realized mainly by directly extending the conventional FFR scheme in the cellular network without relay. Generally, cell-edge band is allocated to relay UEs and cell-center band is allocated to macro UEs, and relay backhaul links could share the cell-center band with macro UEs. However, considering that UEs are not always uniformly distributed, the traffic load of each relay can be quite different, so these static schemes (equally allocating bandwidth resource among cell edges) limit the utilization of the available frequency spectrum in the edge area [6][7]. Let us take the case in Fig. 1 as an example, when the number of relay UEs (cell-edge) in sector A is much more than that of other 2 sectors, heavy overload occurs in sector A and the other 2 sectors even have some free PRBs (physical resource block) that have not been used. In this situation, the dynamic ICIC scheme is more flexible and can dynamically borrow the free PRBs from its neighboring sectors. In this

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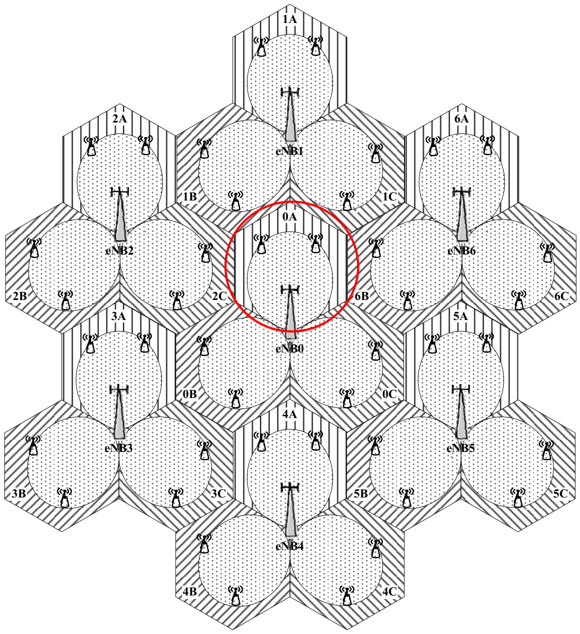

Fig. 2. Network Layout: Wrap Around, 7 eNBs, 3 Sectors/Site

paper, we will introduce a new adaptive resource allocation scheme for ICIC based on UE's distribution (adaptively allocating bandwidth resource among cell edges). The simulation results illustrate this adaptive resource allocation based on UEs distribution is a better choice compared to static ICIC schemes.

The organization of this paper is as follows: The system model is introduced in Section 2. In Section 3, the dynamic ICIC scheme (both centralized and distributed solutions) is proposed. In Section 4, numerical results based on system simulation are presented and Section 5 concludes the paper.

II. System model

In this section, we will discuss the system model including network layout, assumptions on transmission and interference, UE categories and frequency division principles, and scheduling mechanism.

A. Network Layout

As illustrated in Fig. 2, a two-hop relay-based cellular network with 7 cell sites (wrap around) and 3 hexagonal sectors per cell sites is considered here. In each cell, two position-fixed RNs are deployed at the cell edge with the position indicated as shown in Fig. 2. Furthermore, each cell sector is equipped with 120 degree directional transmit antennas, whilst the receive/transmit antennas for RNs and UEs are considered to be omni-directional. Herein, the relaying scenario works as follows: firstly, eNB transmits information symbols to RNs and macro UEs, and then RNs decode the symbols and retransmit them to the relay UEs which is directly associated with RNs. We further assume that the retransmission of relay access links (RN-UE) is in different time slots or frequency bands from the transmission of relay backhaul links (eNB-RN).

B. Inter and Intra Cell Interference

For the given network layout, it is apparent that for a down link transmission to a UE in any sector (e.g. the sector 0A), its neighboring sectors (i.e. 1B, 1C, 2C and 6B) would be the most dominant interferences due to their relative locations and antenna direction. The UE located at the cell boundary experiences higher path-loss and receives significant interference from the sectors of nearby cells than the UE closer to the donor sites, as a sequence, these cell-edge UEs are expected to see more poor-quality chunks having low signal-to-interference-plus-noise ratio (SINR).

In this case, as mentioned earlier that conventional static FFR scheme can effectively avoid the inter-cell interference through reasonable frequency fraction management and guarantee the performance of those disadvantaged UEs. In order to further exploit the cellular capacity with the new feature after introducing RN into the conventional cellular network, the proposed load balance based dynamic ICIC scheme considers more on cell-edge traffic requirement by negotiating frequency division among neighboring cells.

C. Category of UEs and Frequency Division

Based on the received power of cell-specific reference signal (CRS), the UEs can be classified into cell-center UEs and cell-edge UEs. The cell-center UEs directly communicate with eNB, whilst the cell-edge UEs are generally located nearby the cell boundary and will communicate with eNB through two-hop RNs.

The total available spectrum of B Hz in each cell consists of F PRBs which are orthogonal to each other. Suppose that the F PRBs in each cell can be divided into four orthogonal sub-bands: F0, F1, F2 and F3 as shown in Fig. 1. Each cell of 3-sector cell site uses one of the sub-bands as the cell-edge band (F0, F1 and F2), which is only reserved for the relay UEs. Furthermore, the cell-edge bands among the three adjacent cells are orthogonal so as to avoid severe inter-cell interference caused by frequency reuse at cell boarder region. We refer the remaining frequency bands (F3) as the cell center band which is restricted to be used by direct links (to serve the cell-center UEs) or relay backhaul links (to serve the subordinate RNs).

D. Scheduling Mechanism

According to the channel state information (CSI) from UEs, eNB and RNs can independently schedule its connected UEs. Generally, a per-hop proportional fairness (PF) scheduler is used in the case of out-band relay, where the network-to-relay link does not operate in the same band as direct network-to-UE links within the donor cell [8]. In this case, eNB only allocates the resource of cell-center band to its cell-center UEs, whilst RN only allocates the resource of its relay band to its relay UEs. As for the in-band relay, the network-to-relay link shares the same band with direct network-to-UE links within the donor cell [8]. The resource of cell-center band for our proposed dynamic ICIC scheme need to be allocated among the direct link (to serve its cell-center UEs) and relay backhaul link (to serve subordinate RNs) since the transmission of

TABLE I
NOTATIONS

Notation	Meaning
k	Cell id
i	Sector id, $i = 0, 1, 2$
n_{eki}	Number of edge UEs in Cell k Sector i
n_{cki}	Number of center UEs in Cell k Sector i
f_{ki}	PRB allocated for edge UEs in Cell k Sector i
f_3	PRB allocated for center UEs in Cell k Sector i
$Nei(k,i)$	Set of (k,i)'s neighbour sectors
$\delta_{k,i,m}$	Data rate of a PRB for UE m in Cell k Sector i

relay backhaul link use the same frequency resource with the transmission of direct link. In this case, eNB-RN transmission in 3GPP LTE-A is designed to be triggered by data-request signals from RN, which will be sent to the donor eNB in case that the data buffer for relay UEs at RN alerts (e.g. below a given level). Moreover, the available unscheduled resources will be allocated to macro UEs in order to improve the whole system efficiency.

III. DYNAMIC ICIC SCHEME

In this section, we proposed a new dynamic ICIC scheme based on UE's distribution to overcome the problems mentioned above. The basic idea of this method is to adaptively allocate the bandwidth resource according to the relay UE's distribution. All the served UEs will be categorized into two types: relay UE (at cell edge) which is served by RNs and cell-center UEs which is served by eNB. In a tri-sector network, the reserved part for cell-center UEs is the same for all the cells. And the reserved part for cell-edge UEs is orthogonal allocated among the neighboring cells. The eNB is able to schedule users over sub-bands and has the capability to communicate load information across interfaces which allows for inter-cell interference coordination (ICIC) techniques able to be utilized. Neighboring cells can coordinate which sub-bands are used in each cell edge base on the load information (UE's distribution). When the UE distribution is non uniformed or UE's mobility is considered, this adaptive resource allocation with interference coordination among the neighboring cells can greatly improve the spectrum efficiency compared with conventional static ICIC schemes in which the cell-edge bandwidth is equally allocated among the neighboring cells.

A. Problem Formulation

For each cell (cell id k), there will be three sectors (Sector id i, $i = 0, 1, 2$). In cell k sector i, the number of cell edge UE is n_{eki} and cell center UE n_{cki}. Suppose there are total F PRBs available, the number of PRB allocated to cell edge UEs in cell k sector i is f_{ki}, and a fixed number of PRB f_3 is allocated for cell center UEs. All the notations are summarized in Tab. 1.

In average, each edge user in cell k sector $i (i = 0, 1, 2)$ can be allocated a number of PRBs f_{ki}/n_{eki}. Suppose a quasi-static flat fading channel is used here, that is, the channel is static in a subframe and changes between the different subframes. Then it is a non-frequency-selective channel, and for the same UE, the data rate ($\delta_{k,i,m}$) is the same for different PRBs in the same subframe. So UE m's data rate can be calculated as $\delta_{k,i,m} \cdot f_{ki}/n_{eki}$. Accordingly, for macro UE, the data rate is $\delta_{k,i,m} \cdot f_3/n_{cki}$. For proportional fairness (PF), we should maximize the product of all UEs' average data rate. So the utility function U can be described as Eq. (1):

$$U = \prod_{k,i,m \in relayUE} \frac{\delta_{k,i,m} \cdot f_{ki}}{n_{eki}} \cdot \prod_{k,i,m \in macroUE} \frac{\delta_{k,i,m} \cdot f_3}{n_{cki}} \tag{1}$$

For centralized solution, $f_i = f_{k,i}, \forall k$. Then the Eq. (1) can be simplified as:

$$U = \beta \cdot f_0^{\alpha 0} \cdot f_1^{\alpha 1} \cdot f_2^{\alpha 2} \tag{2}$$

in which: $\beta = \frac{\prod\limits_{k,i,m} \delta_{k,i,m}}{\prod\limits_{k,i} (n_{eki}^{n_{eki}} \cdot n_{cki}^{n_{cki}})} \cdot f_3^{\sum\limits_{k,i} (n_{cki})}$

and $\alpha i = \sum\limits_{k} (n_{eki}), \forall i \in 0, 1, 2$

Lemma 1: $\prod\limits_{i=1..k} (x_i^{n_i}) \leq (\frac{\sum\limits_{i=1..k} x_i}{\sum\limits_{i=1..k} n_i})^{\sum\limits_{i=1..k} n_i} \cdot \prod\limits_{i=1..k} n_i^{n_i}$ in which $x_i \geq 0, n_i \in N$, equality condition: $\forall i, j = 1..k$, $\frac{x_i}{n_i} = \frac{x_j}{n_j}$.

Now we could use the conclusion from Lemma 1 to find an upper bound of U. So, we have:

$$U \leq \beta \cdot (\frac{F'}{\sum\limits_{i=0..2} \alpha i})^{\sum\limits_{i=0..2} \alpha i} \cdot \prod_{i=0..2} \alpha i^{\alpha i} \tag{3}$$

Equality condition: $\frac{f_0}{\alpha 0} = \frac{f_1}{\alpha 1} = \frac{f_2}{\alpha 2}$.

Notice that, f_0, f_1, f_2 should also satisfy $f_0 + f_1 + f_2 = F' = F - f_3$.

Then we have:

$$U_{max} = \beta \cdot (\frac{F'}{\sum\limits_{i=0..2} \alpha i})^{\sum\limits_{i=0..2} \alpha i} \cdot \prod_{i=0..2} \alpha i^{\alpha i} \tag{4}$$

and $f_i = \frac{\alpha i}{\alpha 1 + \alpha 2 + \alpha 3} \cdot F', \forall i \in 0, 1, 2$

This conclusion means that to achieve an optimal PF for all UEs, the frequency allocation (F0, F1 and F2) should be proportional to the cell-edge traffic load in each sector. However, in realistic scenarios, it is difficult and communication-cost to give a dynamic statistic number of cell-edge UEs. In next section, based on centralized observation, we proposed a distributed solution with limited communications between neighboring cells.

B. Distributed Algorithms

In this section, we consider a distributed dynamic frequency resource allocation algorithm in which only local information exchanges between neighboring cells. The whole system bandwidth is divided into four subbands, e.g. F0, F1, F2 and F3 (as shown in Fig. 1). Here, we take LTE-A system configuration as an example to better illustrate the idea. Based on the simulation assumption of 10 MHz system bandwidth, there are total 50 PRBs in each subframe. Initially, in each sector, 6 PRBs out of the 50 PRBs are considered as cell-edge band (based on cell-edge UE's proportion), 32 PRBs out the 50 PRBs are reserved as cell-center band, and other 12 PRBs are free for removing inter-cell interference at the cell edge. In each cell, RNs schedule their relay UEs on the cell-edge band length of 6 PRBs, and eNB schedules macro UEs and relay backhaul links on the cell-center band length of 32 PRBs.

Suppose in cell k sector i, the number of cell-edge (served by RN) UEs is n_{eki} and the total number of PRBs allocated for relay UEs is f_{ki}. So the average PRBs allocated for each UE can be calculated as $m_{ki} = \frac{f_{ki}}{n_{eki}}$. Assume the eNB can communicate information of PRB allocation and the number of UEs in neighboring cells across X2 interface or by signal detection. Then the average PRBs allocated for neighboring cell edge UE can be calculated as

$$\overline{m_{k[(i+1)mod3]}} = \frac{\sum_{(k',i+1)\in Nei(k,i)} \frac{f_{k'[(i+1)mod3]}}{n_{ek'[(i+1)mod3]}}}{\sum_{(k',i+1)\in Nei(k,i)} 1} \quad (5)$$

$$\overline{m_{k[(i+2)mod3]}} = \frac{\sum_{(k',i+2)\in Nei(k,i)} \frac{f_{k'[(i+2)mod3]}}{n_{ek'[(i+2)mod3]}}}{\sum_{(k',i+2)\in Nei(k,i)} 1} \quad (6)$$

Based on our observation in last section, to achieve proportional fairness among neighboring cells, an optimal PRB allocation should be proportional to the UE's distribution. That means the average PRBs allocated for neighboring cell edge UE should be the same. Here we take the relays in cell k, sector i as a example, if $m_{ki} > \overline{m_{ki'}}$, it means the relays in neighboring sector i' are overloaded according to current PRB allocation, then cell k sector i will free some of the PRBs originally allocated for its relay UEs, and will not use these PRBs in the following subframes until the UE's distribution or the PRB allocation changes again. And the number of PRBs need to be freed can be calculated as $\lceil n_{ki} \cdot (m_{ki} - \overline{m_{ki'}}) \rceil$. On the other hand, if $m_{ki} < \overline{m_{ki'}}$, it means the relays in cell k sector i are overloaded, and if the neighbouring sectors i' has already freed some PRBs, then the common freed PRBs of all neighbouring sectors can be used in cell k sector i. In this way, we don't introduce new inter-cell interference, i.e, no neighboring cell-edge UE use the same frequency simultaneously). Since the time granularity of this PRB allocation is subframe by subframe, this dynamic resource allocation scheme can adapt to the situation in which UE distribution changes fast (eg. due to mobility). The detailed algorithm is described in Tab. 2.

TABLE II
DYNAMIC PRB ALLOCATION FOR CELL EDGE RELAYS

Alg. 1 - Distributed Dynamic ICIC

Input: this cell's f_{ki} and m_{ki}
UE distribution: $\{n_{ek'i'} | (k', i') \in Nei(k,i)\}$
frequency usage: $\{f_{k'i'} | (k', i') \in Nei(k,i)\}$
PRB freed: $\{f'_{k'i'} | (k', i') \in Nei(k,i)\}$
Output: new f_{ki}, f'_{ki}
Program:

```
m_ki = f_ki / n_eki
for j = 1 to 2
  i' = (i + j) mod3
  calculate m̄_ki' according to Eq. (5) or Eq. (6)
  if m_ki > m̄_ki'
    f_b = min{⌈n_eki · (m_ki − m̄_ki')⌉ , f'_k'i' | (k', i') ∈ Nei(k,i)}
    borrow PRBs f_b
    f_ki = f_ki + f_b
  else
    f'_ki = ⌈n_eki · (m_ki − m̄_ki')⌉
    free PRBs f'_ki
    f_ki = f_ki − f'_ki
  end if
end for
```

IV. SYSTEM LEVEL SIMULATION

In this section, the system level simulation is presented to valid our proposed scheme. Simulation settings follow the latest TR 36.814 (v1.5.2) [8] including the updated pathloss model of access link and direct link. DL simulations are carried out for a 10 MHz system with 25 UEs per macro cell. It is assumed 2 fixed RNs are deployed with a distance of 8/15 ISD (Inter-site Distance) far from eNB as shown in Fig. 2 [9]. During simulation, the UE's distribution is set to be non-uniformed (the proportion of cell-edge UEs in Sector 0,1,2 is 1:2:3) and for each time period, the distribution will be randomly changed [10]. Detailed simulation assumptions are outlined in Tab. 3. And the following figures (Fig. 4 and Fig. 5) and Tab. 4 provide the simulation results of the proposed method.

TABLE III
SYSTEM SIMULATION PARAMETERS

Parameter	Value
Cellular layout	wrap around, 7 eNBs, 3 cells per site
Carrier frequency	2GHz
System bandwidth	10 MHz, downlink
ISD	500 m (3GPP Case 1)
eNB Tx power	46 dBm
RN Tx power	30 dBm
Number of RNs per sector	2
Number of UEs per sector	25
Scheduler	Proportional Fair
Scheduling delay	6 ms
Scheduling granularity	5 PRBs
Thermal noise	-174 dBm/Hz
Downlink HARQ	Asynchronous HARQ with CC, Maximum three retransmissions, hop-by-hop HARQ for relay
Channel	SCM urban macro high spread for 3GPP case 1
Transmission scheme	1x2 SIMO
Downlink receiver type	MRC
Pathloss model	As in 3GPP TS 36.814 V1.5.2
Traffic model	Full Buffer
Control Channel overhead, Ack etc.	LTE: L=3 symbols for DL CCHs, overhead for demodulation reference signals

Fig. 3 illustrates the considerable performance of downlink post SINR of the proposed method. It is shown that utilizing dynamic interference coordination technologies for relay enhanced cellular networks can greatly improve the performance

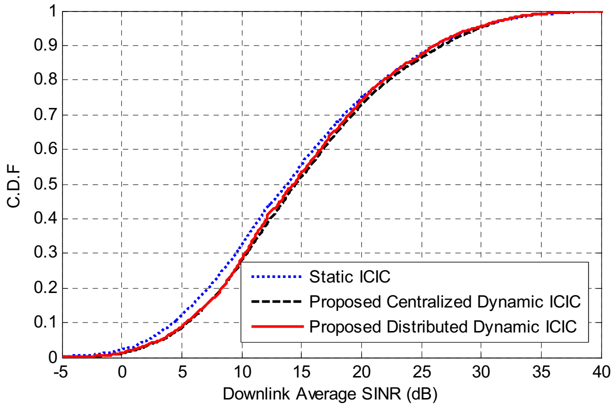

Fig. 3. Downlink Average SINR

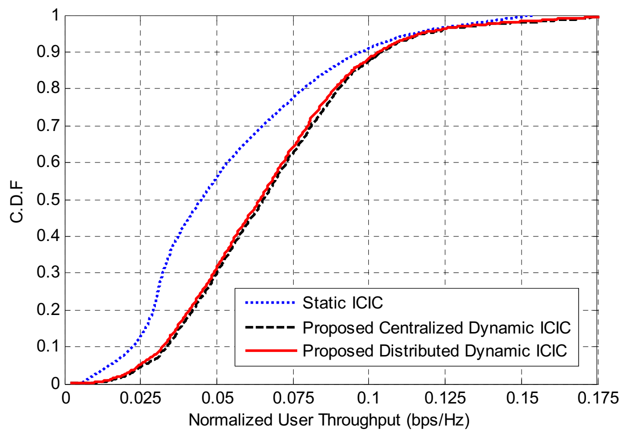

Fig. 4. Normalized User Throughput

of received post SINR in comparison with the static scheme for the conventional cellular network due to load imbalance for those relay UEs.

Fig. 4 illustrates the considerable performance gain (normalized user throughput) of the proposed method with PF scheduler. Tab. 4 records the corresponding cell-average and cell-edge (5%) UE throughput gains respectively for each method in Fig. 4. The proposed centralized solution can bring about 41.5% and 73.3% increases in the cell-average and cell-edge throughput separately, while the distributed algorithms can obtain 34.8% and 60.7% performance improvement on the cell-average and cell-edge throughput separately.

Here we need to emphasis that, the baseline performance of the static ICIC is deduced compared to our former results, the reason is that the UE's distribution is set to be non-uniformed and for each designated time period, the distribution will be randomly changed. That is why we propose a new adaptive resource allocation for the random distribution. From the simulation results, it is demonstrated that with the proposed method, both cell average and cell edge spectrum efficiency can be improved.

TABLE IV
SYSTEM SIMULATION RESULTS WITH ICIC (CELL EDGE DEPLOYMENT, NON-UNIFORMED DISTRIBUTED UE)

	Static ICIC	**Centralized**	**Distributed**
Cell average spectrum efficiency(bps/Hz/cell)	1.2713	1.7992 (+41.5%)	1.7136 (+34.8%)
Cell edge spectrum efficiency(bps/Hz)	0.0150	0.0260 (+73.3%)	0.0241 (+60.7%)

V. CONCLUSION

In this paper, a novel dynamic ICIC scheme is presented for non-uniformed UE distribution based on cell-edge relay deployment. In this relay enhance system, The RNs could adaptively reuses parts of neighboring cell-edge bands (orthogonal to cell-center and adjacent cell-edges) to serve relay UEs so as to achieve reuse gain. We formulate this adaptive resource allocation problem to maximize proportional fairness and proposed an optimal centralized solution. While suppose only the local information (such as PRB allocation and number of associated UEs) can be exchanged between neighboring eNB and relays, we provide a distributed PRB allocation algorithm. Based on our performance evaluation, comparing to conventional static ICIC schemes in which the cell-edge bandwidth is equally allocated among the neighboring cells, the proposed method can flexibly adapt the case when the UE's distribution is non-uniformed or mobility occurs frequently, which accordingly exploit the cellular capacity with the experience enhancement of the cell-edge users.

REFERENCES

[1] W. Lee, M. Nguyen and H. S. Lee, "A resource allocation algorithm and system architecture to extend the cell coverage and alleviate the inter-cell interference",IEEE Symposium on Computers and Communications (ISCC), pp. 222–227, July 2008.

[2] S. F. Meko and P. Chaporkar, "Channel partitioning and relay placement in multi-hop cellular networks",IEEE International Symposium on Wireless Communication Systems (ISWCS), pp. 66–70, Sept 2009.

[3] Y. Xiang, J. Luo and C. Hartmann, "Inter-cell interference mitigation through flexible resource reuse in OFDMA based communication networks", European Wireless, pp. 1-7, Apr. 2007.

[4] J. Liu, et al, "Inter-Cell Interference Coordination based on Soft Frequency Reuse for Relay Enhanced Cellular Network", IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 2302-2306, 2010.

[5] M. Rahman, H. Yanikomeroglu and W. Wang, "Interference Avoidance with Dynamic Inter-Cell Coordination for Downlink LTE System",IEEE Wireless Communications and Networking Conference (WCNC), pp. 1–6, Apr. 2009.

[6] X. Fan, S. Chen and X. Zhang, "An Inter-Cell Interference Coordination Technique Based on Users' Ratio and Multi-Level Frequency Allocations",IEEE International Conference on Wireless Communications, Networking and Mobile Computing (WiCom), pp. 799–802, Sept 2007.

[7] K. Son, S. Chong and G. Veciana, "Dynamic Association for Load Balancing and Interference Avoidance in Multi-cell Networks",IEEE Transactions on Wireless Communications, vol. 8, no. 7, pp. 3566–3576, July 2009.

[8] 3GPP TR 36.814 (v1.5.2), "Further advancements for E-UTRA physical layer aspects", v1.5.2, Dec. 2009.

[9] R1-100442, "Performance evaluation for Type II relay", Alcatel-Lucent Shanghai Bell, Alcatel-Lucent, RAN1#59bis, Valencia, Spain, January 2010.

[10] R1-100950, "DL Type 2 Relay/Macro HetNet Performance: Adaptive FFR", Alcatel-Lucent Shanghai Bell, Alcatel-Lucent, RAN1#60, San Francisco, U. S., February, 2010.