Enhanced Dynamic Inter-cell Interference Coordination Schemes for LTE-Advanced

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Abstract—**In LTE-Advanced, macro-pico heterogeneous networks (HetNet) are extensively discussed. Cell range expansion (CRE) and inter-cell interference coordination (ICIC) are introduced to improve the HetNet system performance. In this paper, semi-static ICIC and dynamic ICIC methods are discussed, and the problems facing conventional dynamic ICIC methods are analyzed and investigated. Joint decision and multiple feedback schemes are proposed to enhance the system performance through appropriate selection of normal/mute transmitting status and accurate scheduling for dynamic ICIC. Simulation results show that the proposed schemes achieve better average system performance and edge user performance than the semi-static ICIC and conventional dynamic ICIC methods, even when a reduced feedback method is used in the proposed schemes. The performance gain is as high as 9% for the average throughput and 30% for the edge user throughput with a proper bias and muting ratio.**

Keywords-HetNet; enhanced-ICIC; cell range expansion; muting; joint scheduling; CQI feedback

I. INTRODUCTION

With the growing data traffic demand, the 3rd Generation Partnership Project (3GPP) has been working on further improving spectrum efficiency for Long Term Evolution (LTE) and LTE-Advanced. The requirements for LTE-Advanced were agreed upon in [1] and the work item (WI) specifications on LTE-Advanced started from Release 10, in which heterogeneous networks (HetNet) were extensively discussed. HetNet improves the spectral efficiency per unit area by shrinking the cell size through deployment of various base stations (BSs), such as remote radio heads (RRHs), low-power picocells, femtocells, and relay nodes [2]. Low power nodes can be deployed to eliminate coverage holes in a macro-only system and improve the capacity in hotspots. However, this approach brings challenges at the same time.

We mainly focus on macro-pico networks in this paper. The introduction of picocells in a macro network creates an imbalance between the downlink and uplink coverage as indicated in Fig. 1(a). The downlink coverage area of a Pico eNodeB (PeNB) is much smaller than that for a Macro eNodeB (MeNB) due to low transmit power. However, the uplink coverage areas of different BSs are similar since the size of the coverage area mainly depends on the user transmit power. On the other hand, PeNB resources may be not fully utilized due to the small number of pico users (PUE). In order to address these two issues, the 3GPP introduced the concept of cell range expansion (CRE) [3] through biasing handover criteria between MeNBs and PeNBs. By using CRE, users do not always connect to a cell with the highest reference signal received power (RSRP), but to the cell with the highest 'RSRP+bias' value. The CRE bias value will increase the proportion of users connected to PeNBs. This mechanism allows for flexible load balancing and sufficient resource utilization, but it brings with it interference problems. Users connected to a PeNB due to CRE will suffer severe interference from the MeNB, as in the case of the PUE in Fig. 1(a). So an inter-cell interference coordination (ICIC) [3] method with CRE is proposed to improve the offloading gain. MeNBs reduce the transmit power or stop transmitting (muting) in specific time/frequency resources to protect CRE PUEs. Fig. 1(b) shows an example when half of the MeNB resources are muted to protect the PUEs. The muted subframe can be either an almost blank subframe (ABS) or multi-broadcast single frequency network (MBSFN) subframe [4]. The muted resources of the MeNBs are signaled using radio resource control (RRC) signaling and since they are not changed frequently, this method is referred to as the semi-static ICIC method. It is clear that the semi-static ICIC method is not sufficiently flexible and limits the improvement in performance. Currently more flexible and effective ICIC methods are under discussion in the 3GPP such as the dynamic ICIC method, which is also referred to as coordinated scheduling (CS) [5] by some companies. Dynamic ICIC allows resource switching between normal and mute statuses in a very short time, e.g., one subframe. However, dynamic muting of each MeNB will cause interference fluctuation and a Channel Quality Indicator (CQI) mismatching problem. Moreover, the method for selecting the proper status (normal/mute) for MeNBs is very important.

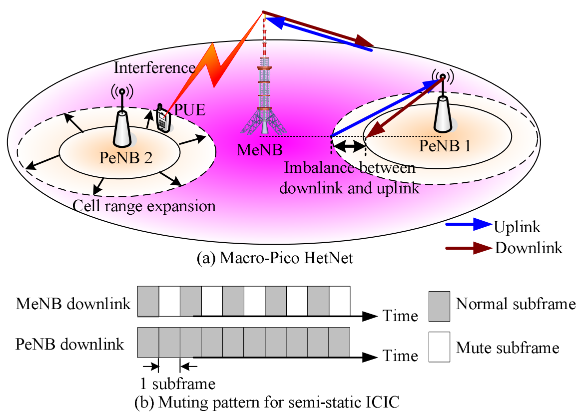

Figure 1. CRE and ICIC for macro-pico HetNet

Some related work has been done for ICIC with CRE in HetNet. In [6], the performance of the semi-static ICIC and dynamic ICIC methods was evaluated and dynamic ICIC was found to exhibit lower performance compared to semi-static ICIC due to a mismatching problem of UE activity. It showed that slower change of muted resources was better for cell edge users who need a stable environment. However, details of the mismatching problem were not analyzed and no enhanced method was proposed for dynamic ICIC. Simulation results for semi-static ICIC from different aspects were given in [7], [8], and [9] but dynamic ICIC was not discussed. In [10], the CQI mismatching problem was analyzed for dynamic ICIC, and a conservative CQI feedback method was proposed to resolve this issue, which meant that users always feed back the CQI assuming all the surrounding MeNBs were transmitting normally. However, this method can only partly solve the problems and obtain a limited gain since eNBs will always choose a low modulation and coding scheme (MCS) even when the interfering MeNBs are muted and the channel conditions are good. In [11], semi-static ICIC and dynamic ICIC were compared. The paper indicated that dynamic ICIC has interference fluctuation problems while semi-static ICIC with a common muting scheme may lead to a performance loss and was not suitable for practical networks. However, no enhanced scheme was proposed for either of the methods.

To address the problems of dynamic ICIC and obtain a significant performance gain, this paper proposes three enhanced dynamic ICIC schemes, in which a scheme is a combination of two other schemes proposed herein. The remainder of this paper is organized as follows. Section II gives an overview of the system model for dynamic ICIC and analyzes two main issues. Section III proposes two schemes to address the two issues, respectively. Section IV describes the combined and enhanced scheme to improve the system performance. Results and analysis are discussed in Section V. Finally, conclusions are drawn in Section VI.

II. System Model and Problem Analysis

The procedure for dynamic ICIC is introduced first, and then two issues that face dynamic ICIC are described and analyzed. The first issue concerns inappropriate normal/mute decision and the other concerns CQI mismatch for scheduling after the decision is made.

We assume that K users and N_p PeNBs are uniformly distributed in the coverage area of a MeNB. The total bandwidth for MeNB and PeNB is divided into L sub-bands of equal bandwidth. Each MUE measures the received signal to interference and noise ratio (SINR) and feeds back the CQI to its MeNB in subframe t-τ. After the transmission delay, τ, MeNBs receive the feedback and perform pre-scheduling to estimate the performance by summing that of all the sub-bands.

$$R_{M-i}(t) = \sum_{l=1}^{L} F(CQI_{i,j}^{l}(t-\tau)), \tag{1}$$

where $R_{M-i}(t)$ could be the estimated capacity, estimated scheduling priority, or a combination of the capacity and priority. F represents the mapping function from CQI to $R_{M-i}(t)$, and $CQI_{i,j}^{l}$ is derived from $SINR_{i,j}^{l}$, which is received at MUE j from MeNB i in sub-band l.

Each PUE feeds back two CQIs, which correspond to the cases of the overlay MeNB being normal or mute. The PeNB estimates the performance of these two cases, $R_{P-n,normal}(t)$ and $R_{P-n,mute}(t)$, and sends them to the MeNB. The MeNB compares the total performance of the normal status with that for the mute status to choose the better status for transmission as (2). In (2), λ is used to adjust the muting ratio, which represents the percentage of muted subframes in all subframes.

$$Status(t) = \begin{cases} mute, if\ R_{M-i}(t) + \sum_{n=1}^{N_p} R_{P-n,normal}(t) < \lambda \sum_{n=1}^{N_p} R_{P-n,mute}(t) \\ normal,\ else \end{cases} \tag{2}$$

A. Issue of Inappropriate Decision

Fig. 2 shows macro-pico networks using the dynamic ICIC method. We assume that in subframe t-τ, MeNB A is working normally and the other two MeNBs are muted. For MUE A1 served by MeNB A, it is assumed that its dominant downlink interference comes from MeNB C. For PeNB α located in MeNB A, it is assumed that it mainly receives interference from MeNB A. In subframe t-τ, MUE A1 has a high SINR and exhibits good performance since its dominant source of interference is muted.

In subframe t, MeNB A compares the overall performance including PUEs in its coverage when MeNB A is muted or normal. We assume that the performance loss of MUEs by muting MeNB A is greater than the performance gain of PUEs by muting MeNB A. Therefore, MeNB A chooses to be normal at subframe t based on the estimation results from (2). Similarly, MeNB C is assumed to choose normal status as well since its dominant source of downlink interference, MeNB B, is muted in subframe t-τ. This is where the problem arises. The reason why MeNB A decides on normal status is due to the anticipated high performance it would gain based on the feedback CQI. However, the dominant source of interference changes the status in transmission subframe t and causes interference to MeNB A. So in a real transmission subframe, we find that the first condition of (2) is satisfied and MeNB A should choose to enter mute status rather than normal status. We call this problem an inappropriate decision.

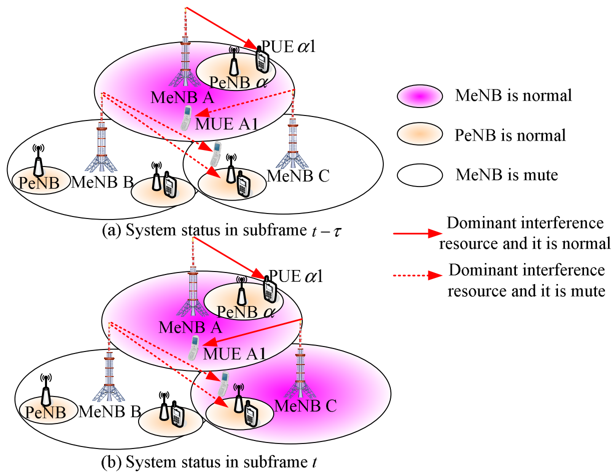

Figure 2. Macro-pico networks using dynamic ICIC method

B. Issue of CQI Mismatch

The other issue occurs after the decision and before transmission, which we refer to as CQI mismatch. The eNBs use feedback CQIs to schedule and choose an optimal MCS for each UE before transmission. In Fig. 2, when MUE A1 is scheduled, a high MCS is chosen because of the high feedback CQI. However, the real channel conditions become worse since the dominant interference MeNB C is normal. So MUE A1 will receive a high block error rate (BLER) and low performance.

III. PROPOSED SOLUTIONS

In fact, these two problems are not isolated and they are related to each other. Two main ideas are proposed in this paper to address these issues and to enhance the dynamic ICIC.

A. Joint Decision

Each MeNB independently decides to be muted or not, thus causing interference to be imparted in an unpredictable manner to the surrounding eNBs. To address the issue of inappropriate decision, the joint decision method is proposed. Several MeNBs and the PeNBs in their coverage comprise a cooperative set. All the MeNBs in the cooperative set will jointly decide to enter mute status or not simultaneously. Taking three MeNBs and their PeNBs as an example, after gathering the estimated performance from all the eNBs, the joint scheduler compares the performance when three MeNBs enter mute status with that when they enter normal status and then choose the better status. All the eNBs in the cooperative set are notified of the selected status and use the corresponding CQI for scheduling and for selecting the appropriate MCS to transmit to each user. This method improves the system performance by partly solving the problem of interference fluctuation, but the gain is limited by the group muting/non-muting scheme due to the limitation of the two kinds of status.

B. Multiple CQI Feedback

The issue of CQI mismatch occurs due to the fluctuation in the channel conditions caused by the muted MeNBs. A multiple CQI feedback method is proposed that uses the appropriate MCS for transmission. In this scheme, users feed back not only the CQI containing the serving signal strength but also the CQI with the dominant interference information. If one user has M dominant interference sources then it feeds back M+1 CQIs, including the serving information CQI. After the decision is made, each MeNB exchanges the status information. eNBs will update the feedback CQIs for each user to obtain a new CQI, which is in accordance with the real normal/mute status of the interfering MeNBs. The updated CQI will be used for scheduling, which matches the real channel conditions well. So the selected MCS is suitable and the BLER is low at user receiver, which can improve system performance.

Taking Fig. 2 as an example, we assume that MUE A1 suffers severe interference from MeNB C, and the dominant sources of interference to PUE $\alpha 1$ are MeNBs A and C. Fig. 2(a) shows the status of the feedback subframe and Fig. 2(b) gives the status after decision. In order to explain the problem more concisely, the CQI is expressed in terms of the SINR instead of the MCS index. MUE A1 feeds back 2 CQIs, the real CQI is from $CQI_{m1} = P_A/(I_{t-\tau}+N_0)$, and the interference indicator CQI is from $CQI_{m2} = P_C/(I_{t-\tau}+N_0)$, where $I_{t-\tau}$ represents the received interference in subframe $t-\tau$. Then the CQI needed for scheduling in subframe t can be obtained by

$$CQI_{m\_updated} = \frac{P_A}{P_C + I_{t-\tau} + N_0} = \frac{CQI_{m1}}{1+CQI_{m2}}. \tag{3}$$

For PUE $\alpha 1$, the two feedback CQIs for performance estimation are $CQI_{p2} = P_\alpha/(I_{t-\tau} - P_A + N_0)$ and $CQI_{p1} = P_\alpha/(I_{t-\tau}+N_0)$, which correspond to MeNB A being mute or normal, respectively. Since CQI_{p1} already contains the interference information from MeNB A, one more CQI is needed for the other source of interference, MeNB C: $CQI_{p3} = P_C/(I_{t-\tau}+N_0)$. The CQI needed for scheduling can be updated using

$$CQI_{p\_updated} = \frac{P_\alpha}{P_C + I_{t-\tau} + N_0} = \frac{CQI_{p1}}{1+CQI_{p3}}. \tag{4}$$

In this method, the inter-cell orthogonal Channel State Information - Reference Signal (CSI-RS) [12] will be useful in deriving feedback CQIs accurately. The multiple feedback method can guarantee the accuracy of CQIs used for scheduling and improve the system performance by decreasing the BLER at the receiver. However, the gain is not significant if the decision is not optimal.

IV. ENHANCED SCHEME

Considering the merits and limitations of the two methods described above, we propose a combined scheme using joint decision and multiple CQI feedback methods to maximize their advantages. The procedure is as follows.

a) Set up cooperative sets: N neighboring MeNBs and the PeNBs in their coverage comprise a cooperative set and they will jointly select the status for each other.

b) Feed back multiple CQIs: Each MUE feeds back N CQIs and each PUE feeds back N+1 CQIs. These CQIs should contain the signal strength and interference strength from all the MeNBs in the cooperative set. Fig. 2 shows an example when N is 3. In Fig. 2, the three feedback CQIs for MUE could be as follows.

$$CQI_i = \frac{P_i}{I_{out}+N_0} \quad (i=1,2,3), \tag{5}$$

where P_i represents the received signal strength from MeNB i, and I_{out} is the interference excluding the three MeNBs. The feedback CQIs for the PUE includes the same three CQIs as the MUE and an additional CQI

$$CQI_0 = \frac{P_p}{I_{out}+N_0}, \tag{6}$$

where P_p is the received signal strength from serving PeNB. It should be noted that the definition is a little different from the traditional CQI.

c) Update CQI: After receiving the CQIs, each eNB will update to get all the CQIs corresponding to each status for the cooperative set. In Fig. 2, there are 4 types of status for MUE and 8 for PUE. The status and corresponding updated CQIs for MUE A1 and PUE $\alpha 1$ are listed in Table I. In the status column, '1' means normal and '0' means mute.

TABLE I. UPDATED CQIS FOR MUE AND PUE

Status 's' of MeNB A, B, C	Updated CQIs for MUE A1	Updated CQIs for PUE $\alpha 1$
1,1,1	$CQI_1/(1+CQI_2+CQI_3)$	$CQI_0/(1+CQI_1+CQI_2+CQI_3)$
1,1,0	$CQI_1/(1+CQI_2)$	$CQI_0/(1+CQI_1+CQI_2)$
1,0,1	$CQI_1/(1+CQI_3)$	$CQI_0/(1+CQI_1+CQI_3)$
1,0,0	CQI_1	$CQI_0/(1+CQI_1)$
0,1,1	-	$CQI_0/(1+CQI_2+CQI_3)$
0,1,0	-	$CQI_0/(1+CQI_2)$
0,0,1	-	$CQI_0/(1+CQI_3)$
0,0,0	-	CQI_0

d) Compare performance and select status: Each eNB estimates the system performance in different statuses by using updated CQIs. The estimated values are sent to the MeNB. The MeNB will compare the sum performance of the whole set and choose the status with the highest performance based on (7). Then all the eNBs in the set are notified of the selected status.

$$Status(t) = \{s \mid \underset{s}{Max}[\sum_{j=1}^{N} R_{MeNB-j,s}(t) + \sum_{j}^{N*N_p} R_{PeNB-j,s}(t)]\} \quad (7)$$

e) Schedule and transmit: Each eNB uses the appropriate updated CQI, which is in accordance with the selected status, for scheduling and real transmission.

The combined scheme improves the system performance by addressing the problems discussed in Section II. However, we note that the overhead for the feedback increases. To decrease the overhead, we recommend employing different feedback periodicity for different CQIs, or use differential CQI values that occupy fewer bits. Fig. 3 gives an example of a method for reducing the feedback with different feedback periodicity.

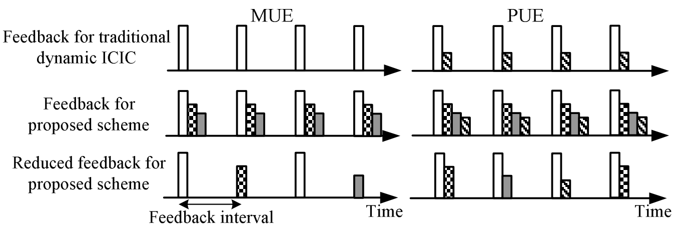

Figure 3. Proposed scheme with reduced feedback method

V. PERFORMANCE EVALUATION

A system level simulation is performed to evaluate the effect of the proposed combined scheme. The simulation configuration follows the assumptions given in the 3GPP evaluation methodology for LTE-Advanced [2]. A layout comprising 19 cells/57sectors is deployed for the macrocell and 4 PeNBs are uniformly located within each macro sector. The inter-site distance (ISD) for the MeNBs is 500 meters and the cell radius for the PeNBs is 20 meters. The transmit power of the MeNBs and PeNBs is 46 dBm and 30 dBm, respectively. The antenna gains are 17 dBi and 5 dBi, respectively. The ITU UMa channel model is used for the macrocells and the ITU UMi channel model is used for the picocells in the simulation [13]. The other key simulation parameters are listed in Table II.

TABLE II. SIMULATION PARAMETERS

Parameters	MeNB / PeNB	Parameters	MeNB / PeNB
Carrier frequency	2 GHz	System bandwidth	10 MHz
UE moving speed	3 km/h	Number of UEs	30 per sector in all
Antenna configuration	2x2	Scheduling algorithm	Proportional Fairness (PF)
HARQ combining	Chase combining	CQI feedback delay	6 ms
Round trip delay (HARQ)	8 ms	CQI feedback periodicity	10 ms

In order to adjust the muting ratio of the dynamic ICIC scheme, λ in (2) satisfies the equation below in the simulation.

$$\lambda = k \cdot {SF_{normal}}\big/{SF_{mute}}, \quad (8)$$

where SF_{normal} and SF_{mute} represent the recorded number of normal or mute subframes by MeNBs in a past period, e.g., in the past 200 subframes, respectively. By using (8), we obtain the simulation results with the muting ratio of $k/(k+1)$. The results with a muting ratio from 0.2~0.8 will be discussed in detail in Part B of this section.

To demonstrate the performance gain of the proposed combined scheme, simulation results from aspects of CRE bias, muting ratio, feedback interval, and user distributions are given. They are compared to the results of the traditional dynamic ICIC and semi-static ICIC methods.

A. Comparison of Three Methods

The results of the traditional dynamic ICIC method, semi-static ICIC method, and the proposed combined scheme (also referred to as enhanced dynamic ICIC method in this section) are compared in Fig. 4. The upper and lower figures show the cell average throughput (including throughput of a MeNB with 4 PeNBs in its coverage area) and the fifth percentile of the cell edge user performance, respectively. In Fig. 4, the muting ratio varies from 0.2 to 0.8 and the bias equals 0 dB. The figure clearly shows the relationships of three methods. We find that the proposed combined scheme achieves the highest performance both for the cell average throughput and edge user throughput. As for the other two methods, semi-static ICIC has better cell average throughput and similar edge user throughput compared to the traditional dynamic ICIC method. These results regarding the performance relationship between semi-static ICIC and traditional dynamic ICIC methods are similar to those reported in [6], in which the traditional dynamic ICIC exhibited performance degradation both in cell average and edge throughput compared to semi-static ICIC method in an FTP traffic model. So it is evident that the problems analyzed in Section II are severe and have a clear negative impact on the system performance. By using the proposed combined scheme, the performance can be improved greatly. In order to make our performance gain more convincing, we compare the proposed scheme to the better method, i.e., the semi-static ICIC, instead of the traditional dynamic ICIC in the following section.

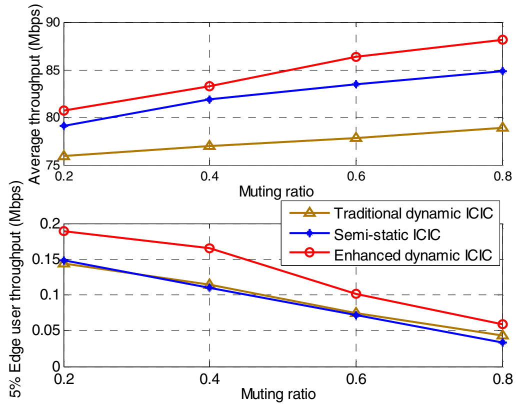

Figure 4. Performance comparison of three methods

B. *Results of Different CRE Bias Values and Muting Ratios*

The cell average throughput and edge user performance for the semi-static ICIC and that for the proposed combined method are compared in Fig. 5 and Fig. 6. In the CRE scheme, low to medium bias is recommended because a large bias would cause unreliability in the control channel, e.g., the PBCH and PHICH [14]. So the bias values of 4 dB and 8 dB are used in the simulation. Fig. 5 shows that the proposed scheme achieves a higher cell average throughput than that for the semi-static ICIC method. With an increase in the muting ratio, the gain becomes larger. This is because in the normal subframe of semi-static ICIC, all MUEs and PUEs have the lowest SINR and performance, and in a muted subframe, MUEs devote nothing while PUEs achieve the highest SINR and performance. However, in the enhanced dynamic ICIC method, all MUEs and PUEs obtain a medium SINR for all subframes. Moreover, after choosing the appropriate status, PUEs can reach nearly the highest SINR when the dominant interfering MeNBs are mute. This is the reason why the proposed combined scheme has higher cell average throughput.

Fig. 6 shows that cell edge user performance of the proposed combined scheme is better than that for semi-static ICIC when the muting ratio is high and is similar to that for the semi-static ICIC when the muting ratio is low. The cell edge users are mainly PUEs when the muting ratio is low with CRE. As for dynamic ICIC, cell edge PUEs have a much lower SINR than that for semi-static ICIC in the synchronized muted subframes when the muting ratio is low, which limits the improvement in the edge user performance for dynamic ICIC. With an increase in the muting ratio, the SINRs for the cell edge PUEs in dynamic ICIC approaches the highest SINR when using semi-static ICIC with a lower muting ratio. Thus dynamic ICIC reaches a cell edge gain as high as 25.2% over the semi-static ICIC case when the muting ratio is 0.4 ~ 0.6. When the muting ratio is large, i.e., 0.8, majority of cell edge users are MUEs. Since MUEs in semi-static ICIC can only transmit in normal subframes and have the lowest SINR, the edge user performance is worse than that for dynamic ICIC.

As for a comparison among different bias values, since more users are connected to PeNBs as the bias increases, the PeNB average performance will decrease due to low transmit power, while the PeNB edge performance will increase since more edge users in the MeNB are connected to the PeNB and they can achieve better performance with the muting scheme.

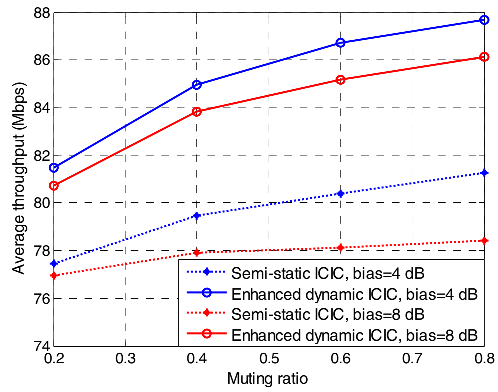

Figure 5. Cell average performance with different bias values and muting ratios

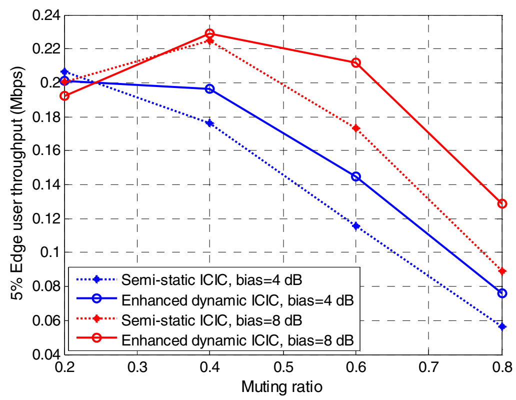

Figure 6. Edge user performance with different bias values and muting ratios

TABLE III. PERFORMANCE WITH DIFFERENT FEEDBACK INTERVALS

Feedback Interval (ms)		***10***	***20***	***40***
Semi-static ICIC	***Avg. thr.(Mbps)***	78.13	76.57	76.46
	Avg. gain	0%	-2.00%	-2.14%
	Edge UE thr.(Mbps)	0.173	0.152	0.149
	Edge gain	0%	-12.14%	-13.87%
Enhanced dynamic ICIC	***Avg. thr.(Mbps)***	85.16	83.65	83.62
	Avg. gain	0%	-1.77%	-1.81%
	Edge UE thr.(Mbps)	0.213	0.198	0.195
	Edge gain	0%	-7.04%	-8.45%

C. *Results of Different Feedback Intervals*

The feedback interval is extended to compare the performance of the proposed combined scheme with that for the semi-static ICIC method and the results are given in Table III. From Fig. 5 and Fig. 6 we find that with a medium muting ratio, both the cell average performance and cell edge performance are good. Thus the muting ratio of 0.4 and the bias value of 8 dB are employed in the evaluation. As the feedback interval increases, the performance of both methods decreases. The semi-static ICIC decreases more severely, especially for edge performance. The edge user performance for the semi-static case decreases by 13.87% when the feedback interval is 40 ms while that for the dynamic case only decreases by 8.45%. If we compare the absolute throughput, we find that the performance of dynamic ICIC with a 40-ms feedback interval is even better than that for semi-static ICIC with a 10-ms feedback interval. Therefore, if we use a reduced feedback method such as that in Fig. 3 in the proposed combined scheme, the performance will slightly decrease and still be better than semi-static ICIC method when the users are in a low-mobility environment.

D. Results of Different UE Distributions

Performance with different UE distributions is evaluated based on four sets of parameters, i.e., bias of 4dB and 8dB, and the muting ratios of 0.4 and 0.6. In Fig. 7 and Fig. 8, 'uniform' means users are dropped uniformly in macrocell coverage, and 'cluster' represents a clustered placement in PeNBs.

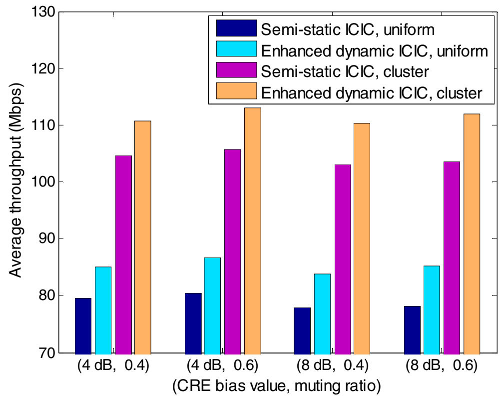

Figure 7. Cell average performance with uniform and cluster UE distribution

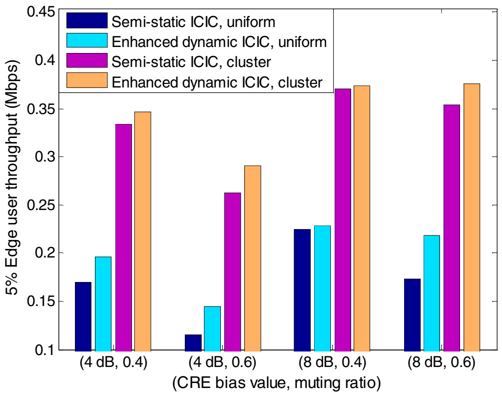

Figure 8. Edge user performance with uniform and cluster UE distribution

The two figures show that the proposed combined scheme exhibits better performance than the semi-static ICIC method, and cluster distribution yields better performance than the uniform distribution for all parameters. The average gain of the enhanced dynamic ICIC over semi-static ICIC in the two distribution scenarios is similar and approximately 6%~9%. An average throughput improvement from 5.5 Mbps to 8.4 Mbps is achieved. For the edge user performance, the gain of the proposed scheme is greater when with UE uniform distribution, and can achieve a gain as high as 30% compared to that for semi-static ICIC for the case where the bias is 8 dB and the muting ratio is 0.6. With the UE cluster distribution, the largest gain is approximately 12% when the bias is 4 dB and the muting ratio is 0.6.

VI. CONCLUSION

This paper compared the dynamic ICIC method to the semi-static ICIC method and analyzed the issues in these traditional dynamic ICIC methods with CRE in HetNet. In order to deal with the problems of inappropriate decision and CQI mismatching, we proposed joint scheduling and multiple CQI feedback schemes, in which eNBs can update the received CQI to obtain the corresponding CQI for performance estimation and scheduling. Based on the performance evaluation, we found that the proposed combined scheme achieves better cell average throughput as well as edge user throughput compared to either semi-static ICIC method or traditional dynamic ICIC method. A performance gain as high as 9% for the average throughput and 30% for the edge user throughput are attained with a proper bias and muting ratio. We also evaluated a reduced feedback method for the proposed scheme and we found that the performance gain is still significant. In the future we will report on the performance of non-full buffer traffic, i.e., FTP traffic, and the performance when considering interference from the common reference signal (CRS) in an ABS subframe.

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