Adaptive Configuration of Time-domain eICIC to Support Multimedia Communications in LTE-A Heterogeneous Networks

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***Abstract*—Long term evolution-advanced (LTE-A) supports high-speed communications for cellular systems. It allows different types of base stations to form a heterogeneous network to provide service. However, signal interference between a macrocell and its picocells is inevitable. Thus, LTE-A adopts enhanced intercell interference coordination (eICIC) to conquer the interference problem. In the time-domain eICIC strategy, a number of subframes are selected as *almost blank subframes (ABSs)* during which data transmission of the macrocell is suspend, so as to improve the utilization of spectral resource in picocells. How to configure the number of ABSs in each period, namely the ABS ratio, has significant impact on system performance. Most of existing studies aim to decide the ABS ratio to increase network throughput according to channel condition or traffic demands of user devices. However, none of them considers delay requirement of multimedia flows. Consequently, the paper proposes an adaptive configuration mechanism to dynamically change the ABS ratio to support quality of service (QoS) for multimedia communications by measuring the transmission capacity of each cell and the amount of urgent multimedia data. Through LTE-Sim experiments, we demonstrate that the proposed configuration mechanism can efficiently improve throughput of macrocells and picocells, while reducing video packet dropping due to expiration.**

***Keywords*—eICIC, heterogeneous network, interference management, LTE-A, multimedia communications.**

I. Introduction

Nowadays, LTE-A has operated in most countries to satisfy the explosive growth of wireless Internet access. To support diverse range of network coverage, LTE-A allows different types of base stations (BSs) to coexist in the same service area and organize a *heterogeneous network*. Specifically, macrocell BSs are responsible for providing whole coverage to the service area, while picocell BSs aim to strengthen signal power in small regions. The benefits of using a heterogeneous network include, for example, data offloading for load balance [1] and tactical deployment to save the system cost [2].

As small picocells usually locate inside large macrocells, signal interference between each other is unavoidable. Fig. 1 shows an example, where each user equipment (UE) in a picocell encounters high interference from the macrocell BS. Besides, when a macrocell UE moves close (or into) a picocell,

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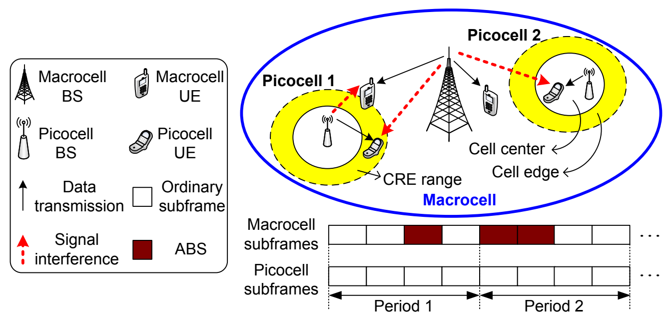


Fig. 1. The time-domain eICIC strategy in LTE-A, where some subframes are selected as ABSs to improve the channel quality in picocells.

the picocell BS also generates interference to it. However, the formal interference is much more serious than the latter interference, because the macrocell BS transmits data in much larger signal power than that of a picocell BS.

To overcome the interference problem, LTE-A employs the eICIC technique with both frequency-domain and time-domain strategies. The frequency-domain strategy allocates different frequency bands for macrocell and picocell BSs to separately transmit data, so as to avoid interference with each other. The time-domain strategy focuses on mitigating the interference problem in picocells. In particular, the macrocell BS chooses a number of subframes to be ABSs in every period, during which it transmits nothing but merely control signals through very low power. Therefore, the UEs in picocells are able to receive data from their BSs nearly without signal interference from the macrocell BS.

The time-domain eICIC strategy is more popular and flexible than the frequency-domain one, because it can better utilize the spectral resource by allowing different cells to share the same frequency band [3]. Moreover, by changing the number of ABSs in a period, called *ABS ratio*, we can adjust the throughput in different cells. Many studies attempt to find the optimal ABS ratio to improve the overall throughput by referring to some network conditions such as the number of UEs or the traffic load in a cell. However, the stringent delay requirement of multimedia flows is not well addressed. Consequently, it deserves further investigation to take QoS concern of multimedia communications into account for the time-domain eICIC strategy.

This paper proposes an adaptive configuration mechanism for LTE-A time-domain eICIC by dynamically changing the ABS ratio in each period with two objectives: 1) increasing the overall network throughput and 2) reducing packet dropping (due to expiration) of multimedia communications. To do so, our configuration mechanism first estimates the transmission capacity of each cell in ordinary subframes and ABSs. Moreover, it measures the amount of data received by UEs in a cell and also finds out the potentially urgent data. According to the above information, we can compute a feasible ABS ratio to improve the throughput of each cell while sending out as much multimedia data in danger of discard as possible. Experimental results by simulation verify the effectiveness of the proposed configuration mechanism in terms of these two objectives.

We organize this paper as follows. Section II introduces LTE-A and time-domain eICIC, followed by related work. Section III formulates the problem while Section IV proposes our mechanism. Afterward, performance evaluation is given in Section V, and a conclusion is drawn in Section VI.

II. Preliminary

A. LTE-A and Time-domain eICIC

LTE-A materializes the spectral resource to *physical resource blocks (PRBs)* as the basic unit for resource allocation. Depending on the channel quality of a UE, which is evaluated by the signal-to-interference-and-noise ratio (SINR), each PRB can carry different number of data bits by using various modulation and coding schemes (e.g., QPSK, 16QAM, and 64QAM). Therefore, the amount of downlink data received by each UE will be determined by the number of PRBs allocated to it and the UE's SINR value.

Traffic flows in LTE-A are categorized into *guaranteed bit rate (GBR)* and *non-GBR* groups. Generally speaking, GBR flows have stringent delay requirement and support real-time service such as VoIP and video streaming, while non-GBR flows are usually used in TCP-based applications (e.g., www and email). Consequently, multimedia communications in LTE-A can be implemented by GBR flows.

Since a macrocell BS emits much higher transmitted power than picocell BSs, most UEs may trend to connect with the macrocell BS. To reduce traffic load of the macrocell BS, we should make more UEs associate with nearby picocell BSs. This technique is called data offloading and it is realized by *cell range expansion (CRE)* in LTE-A. Specifically, for each UE, we add its reference signal received power (RSRP) from a picocell BS by a small bias value. In this way, the UE could have a larger RSRP value to the picocell BS as comparing with that to the macrocell BS, which increases the opportunity to connect with the picocell BS. Fig. 1 gives an example, where there was no UE connecting to picocell 1's BS based on the original RSRP value. However, by adding the bias value, picocell 1 can virtually expand its cell range and thus cover one UE. With CRE, a picocell is divided into two parts: cell center and cell edge (i.e., CRE range), as shown in Fig. 1.

To alleviate signal interference by the macrocell BS to picocell UEs, especially for those UEs in the cell-edge regions, the time-domain eICIC strategy divides the time axis into fixed-length periods and selects some subframes in each period to be ABSs, as illustrated in Fig. 1. In an ABS, the macrocell BS uses very low power to transmit merely control signals such as common reference symbols, primary/secondary synchronization signals, and physical broadcast channel signal. Therefore, picocell UEs will receive almost no interference from the macrocell BS. On the other hand, in an ordinary subframe, all BSs normally transmit downlink data, so picocell UEs will encounter higher signal interference. The ABS ratio is a tunable parameter to adjust the throughput in different cells, and the LTE-A standard leaves its configuration to researchers and implementers.

B. Related Work

Some work assumes a full-buffer traffic model, where each UE has infinite data, and tries to find the best ABS ratio based on the assumption. Pang et al. [4] adopt dynamic programming to schedule the sets of UEs that can receive data in ABSs and ordinary subframes, and compute the ABS ratio to achieve network-wide proportional fairness. The work of [5] searches all possible combinations of ABS ratios and CRE bias values, and finds the optimal combination through a brute-force approach. The work of [6] adopts the similar combination to derive the rate distribution of the whole network, and finds the best combination to improve network throughput. However, the above work may incur high computation complexity and the full-buffer traffic model is not practical.

Thus, numerous studies consider how to compute the ABS ratio based on dynamic network condition. Al-Rawi et al. [7] use the number of UEs in each cell to derive the ABS ratio, but different UEs may have various demands. The work of [8] computes the ABS ratio by referring to the data rate and queue length of each UE located in regions of macrocell, picocell center, and picocell edge. Bartoli et al. [9] address both traffic demands of UEs and actual loads of cells to find a suitable number of ABSs in a period. Daeinabi et al. [10] adopt fuzzy logic to output the ABS ratio, where the inputs include the number, channel quality, and throughput of picocell UEs. Lu et al. [11] propose a concept of interference index, which is defined by the throughput difference when UEs encounter signal interference. Depending on the index, the ABS ratio is iteratively changed by a value of 12.5% to improve performance. Apparently, these studies do not address packet delay for multimedia communications.

Only few research efforts address multimedia communications in LTE-A time-domain eICIC. The work of [12] adopt video quality to determine resource allocation in ABSs and ordinary subframes, where the video quality is evaluated by the mean square error of each video frame. However, it does not consider the packet urgency of multimedia flows, which motivates us to propose the adaptive configuration mechanism to adjust the ABS ratio in each period, so as to alleviate packet dropping of multimedia communications and support QoS.

III. PROBLEM FORMULATION

Fig. 1 illustrates the network model, where a picocell does not overlap with more than one macrocell. In other words, each macrocell BS is able to determine its ABS ratio, denoted by δ, solely and independently. Therefore, our discussion will aim at one macrocell and its picocells, and we use notations $\hat{B}_{macro}$ and $\hat{B}_{pico}$ to represent the sets of macrocell and picocell BSs, respectively. In addition, we divide all UEs into $\hat{U}_{macro}$ and $\hat{U}_{pico}$, which associate with macrocell and picocell BSs, respectively, where $\hat{U}_{macro} \cap \hat{U}_{pico} = \emptyset$ (i.e., each UE is allowed to join only one cell). Every UE has either GBR traffic (for multimedia communication) or non-GBR traffic (for non-real-time service). For convenience, we also denote by $\hat{U}_k$ the set of UEs that associate with a BS b_k.

Given the period length T (in subframes), $\hat{U}_{macro}$, and $\hat{U}_{pico}$, our problem asks how to compute the number of ABSs in every period (and determine δ accordingly), such that the overall network throughput is maximized while the average packet dropping ratio of GBR UEs is minimized. Moreover, because the UEs in $\hat{U}_{macro}$ cannot receive any data in ABSs, we also define an upper-bound threshold γ_{macro} of packet dropping ratio for the GBR UEs in the macrocell to prevent them from starvation.

IV. ADAPTIVE CONFIGURATION MECHANISM

Our adaptive configuration mechanism for LTE-A time-domain eICIC has the following three steps:

- **Step 1:** We first estimate the transmission capacity of each cell in ordinary subframes and ABSs. To do so, we have to evaluate the channel quality of every UE (in terms of SINR) in the cell.
- **Step 2:** Then, we measure the amount of total and GBR data expected to be received by all UEs in a cell. Moreover, for GBR UEs, we also find out their potentially urgent data in order to alleviate packet dropping.
- **Step 3:** Based on the information from the above two steps, we finally calculate the number of ABSs required in a period so as to improve network throughput while sending out more urgent GBR data.

In the following, we present the detailed design of each step. Table I summarizes the common notations used in our adaptive configuration mechanism.

TABLE I
SUMMARY OF COMMON NOTATIONS.

notation	definition
T	the length of a period
δ	the ABS ratio
γ	the packet dropping ratio of the GBR UEs in the macrocell
γ_{macro}	a threshold on γ
Φ^O_{macro}	the macrocell's capacity in an ordinary subframe
Φ^O_{pico}	all picocells' capacity in an ordinary subframe
Φ^A_{macro}	the macrocell's capacity in an ABS
Φ^A_{pico}	all picocells' capacity in an ABS
$E^O(b_k)$	the amount of data expected to be received by all UEs in a cell with BS b_k in an ordinary subframe
$E^A(b_k)$	the amount of data expected to be received by all UEs in a cell with BS b_k in an ABS
L_i	the amount of buffered data of UE u_i
L_i^{urgent}	the amount of urgent data of UE u_i
$\hat{B}_{macro}$	the macrocell BS
$\hat{B}_{pico}$	the set of picocell BSs (within in the same macrocell)
$\hat{U}_{macro}$	the set of UEs associating with the macrocell BS
$\hat{U}^G_{macro}$	the set of GBR UEs associating with the macrocell BS
$\hat{U}_{pico}$	the set of UEs associating with picocell BSs
$\hat{U}_k$	the set of UEs associating with BS b_k
$\hat{C}$	the set of available subchannels

A. Estimate Transmission Capacity of Cells

We compute the theoretical throughput of a UE u_i acquired from a subchannel c_j in an ordinary subframe by

$$\phi^O_{i,j} = \beta_j \log_2(1 + S^O_{i,j}), \tag{1}$$

where β_j is the bandwidth of subchannel c_j and $S^O_{i,j}$ denotes SINR of UE u_i on subchannel c_j in an ordinary subframe. Given the received power $P(u_i, c_j, b_k)$ of UE u_i from its associating BS b_k on subchannel c_j, we calculate u_i's SINR value in an ordinary subframe by

$$S^O_{i,j} = \frac{P(u_i, c_j, b_k)}{FN_0\beta_j + \sum_{b_l \in \hat{B}_{macro} \cup \hat{B}_{pico} - \{b_k\}} \psi(u_i, b_l)}, \tag{2}$$

where F is the noise figure, N_0 is the power spectral density of noise, and $\psi(u_i, b_l)$ represents the signal interference of UE u_i from a BS $b_l (\neq b_k)$. Let $\hat{C}$ be the set of all available subchannels. Then, we can estimate the aggregate transmission capacity of the macrocell in an ordinary subframe by

$$\Phi^O_{macro} = \sum_{u_i \in \hat{U}_{macro}} \sum_{c_j \in \hat{C}} \phi^O_{i,j}. \tag{3}$$

In addition, the aggregate transmission capacity of all picocells in an ordinary subframe will be

$$\Phi^O_{pico} = \sum_{u_i \in \hat{U}_{pico}} \sum_{c_j \in \hat{C}} \phi^O_{i,j}. \tag{4}$$

In an ABS, the theoretical throughput of UE u_i obtained from subchannel c_j is given by

$$\phi^A_{i,j} = \beta_j \log_2(1 + S^A_{i,j}), \tag{5}$$

where $S^A_{i,j}$ denotes the SINR value of UE u_i on subchannel c_j in an ABS. Because there is no data transmission in the macrocell in an ABS, we have $S^A_{i,j} = 0$ for each $u_i \in \hat{U}_{macro}$. Therefore, according to Eq. (5), the transmission capacity of the macrocell in an ABS will be

$$\Phi^A_{macro} = \sum_{u_i \in \hat{U}_{macro}} \sum_{c_j \in \hat{C}} \phi^A_{i,j} = 0. \tag{6}$$

The UEs in $\hat{U}_{pico}$ are interference-free from the macrocell BS, but they could still receive signal interference from neighboring picocell BSs. Hence, their SINR values are derived by

$$S^A_{i,j} = \frac{P(u_i, c_j, b_k)}{FN_0\beta_j + \sum_{b_l \in \hat{B}_{pico} - \{b_k\}} \psi(u_i, b_l)}. \tag{7}$$

Therefore, the aggregate transmission capacity of all picocells in an ABS is computed by

$$\Phi^A_{pico} = \sum_{u_i \in \hat{U}_{pico}} \sum_{c_j \in \hat{C}} \phi^A_{i,j}. \tag{8}$$

B. Measure Received and Urgent Data of UEs

In LTE-A, the spectral resource is partitioned into PRBs for allocation, and each PRB can be assigned to at most one UE (when SISO or single-user MIMO techniques are adopted). Thus, the amount of downlink data that can be received by a UE u_i will be $\omega(S_i) \times n_i$, where $\omega(S_i)$ is the number of data bits carried by a PRB under SINR S_i and n_i is the number of PRBs allocated to UE u_i. However, unless we finish running the resource scheduling algorithm can we get the exact value of n_i, which is not efficient in computation. Therefore, we use the average number of PRBs $\overline{n}_k$ that a BS b_k allocates to its UEs to replace the term n_i. In this way, we can quickly calculate the amount of downlink data expected to be received by all UEs in a cell with BS b_k by

$$E^O(b_k) = \sum\nolimits_{u_i \in \hat{U}_k} \omega(\overline{S}_i^O) \times \overline{n}_k, \tag{9}$$

in an ordinary subframe, and

$$E^A(b_k) = \sum\nolimits_{u_i \in \hat{U}_k} \omega(\overline{S}_i^A) \times \overline{n}_k, \tag{10}$$

in an ABS, where

$$\overline{S}_i^O = \sum\nolimits_{c_j \in \hat{C}} S_{i,j}^O / |\hat{C}| \text{ and } \overline{S}_i^A = \sum\nolimits_{c_j \in \hat{C}} S_{i,j}^A / |\hat{C}|, \tag{11}$$

which are the average SINR values among all possible subchannels in ordinary subframes and ABSs, respectively.

Let L_i denote the amount of buffered downlink data of a UE u_i. If u_i is a GBR UE, we are also interested in its amount of 'urgent' data, which is denoted by L_i^{urgnet}. In particular, a packet p_x of UE u_i is considered as urgent once the following condition is satisfied:

$$d_x + \varepsilon(p_x) + T\tau \geq D_i^{\max}, \tag{12}$$

where d_x is the timestamp to indicate when packet p_x was put into UE u_i's queue, $\varepsilon(p_x)$ is the amount of time required by the BS's physical layer to send packet p_x, τ is subframe length, and $D_i^{\max}$ is UE u_i's maximum tolerant time for packet delay. Eq. (12) implies that if packet p_x cannot be sent out in the current period, it must be dropped as the deadline should be passed. Therefore, L_i^{urgent} will be the length summation of those packets that satisfy the condition in Eq. (12).

C. Calculate the Number of Required ABSs

We finally compute the number of necessary ABSs in a period. A special case is that each picocell already has enough transmission capacity to satisfy traffic demands of all its UEs when every subframe in the period is ordinary; in other words,

$$\sum\nolimits_{b_k \in \hat{B}_{pico}} E^O(b_k) \times T \geq \sum\nolimits_{u_i \in \hat{U}_{pico}} L_i. \tag{13}$$

In this case, we can set the ABS ratio δ to zero, as it can maximize the overall network throughput (since there is no throughput loss due to ABSs in the macrocell).

Otherwise, we check whether it is efficient for the macrocell BS to assign ABSs. To do so, we calculate the total transmission capacity of all cells based on a given ABS ratio δ:

$$\begin{aligned}\Phi_{total} &= \delta \times (\Phi_{macro}^A + \Phi_{pico}^A) + (1-\delta) \times (\Phi_{macro}^O + \Phi_{pico}^O) \\ &= \Phi_{macro}^O + \Phi_{pico}^O + (\Phi_{pico}^A - \Phi_{pico}^O - \Phi_{macro}^O) \times \delta. \end{aligned} \tag{14}$$

In Eq. (14), δ is the only unknown, so the coefficient $\Phi_{pico}^A - \Phi_{pico}^O - \Phi_{macro}^O$ decides its effect on Φ_{total}. Thus, we separate our discussion into two cases based on the coefficient.

- Case of $\Phi_{pico}^A - \Phi_{pico}^O - \Phi_{macro}^O > 0$: It is efficient to use more ABSs to increase picocell throughput. In particular, we first evaluate the amount of throughput improvement in picocells by adding one ABS as follows:

  $$I_{pico} = \sum\nolimits_{b_k \in \hat{B}_{pico}} E^A(b_k) - E^O(b_k). \tag{15}$$

  Then, we can find the number of ABSs required in the period to send all buffered data of each UE in $\hat{U}_{pico}$ by

  $$T_{abs} = \frac{\sum_{u_i \in \hat{U}_{pico}} L_i - T \sum_{b_k \in \hat{B}_{pico}} E^O(b_k)}{I_{pico}}. \tag{16}$$

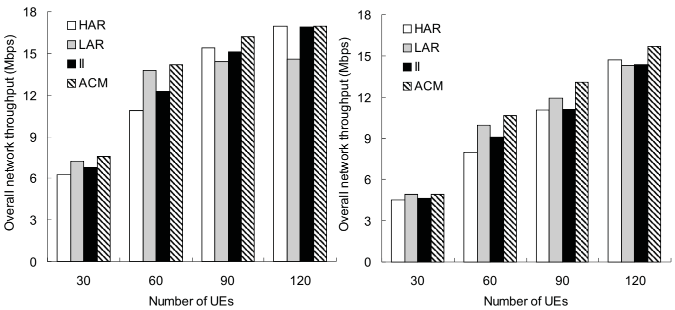
  When $T_{abs} \leq T$, we can achieve the maximum throughput in picocells. In case of $T_{abs} > T$, we set $T_{abs} = T$. However, since the UEs in $\hat{U}_{macro}$ cannot receive any data in ABSs, we may not assign T_{abs} ABSs, or the macrocell BS may fail to support QoS for its GBR UEs. Thus, we also measure the expected packet dropping ratio γ GBR UEs in the macrocell (denoted by the set $\hat{U}_{macro}^G$) under a given ABS ratio δ:

  $$\begin{aligned} L_{loss} &= \sum_{u_i \in \hat{U}_{macro}^G} L_i^{urgent} - (1-\delta)T \sum_{b_k \in \hat{B}_{macro}} E_G^O(b_k), \\ \gamma &= L_{loss} / \sum\nolimits_{u_i \in \hat{U}_{macro}^G} L_i^{urgent}. \end{aligned} \tag{17}$$

  In Eq. (17), $E_G^O(b_k)$ denotes the amount of downlink data expected to be received by all GBR UEs in the cell with BS b_k in an ordinary subframe (whose definition is similar to Eq. (9) but with the condition that u_i is a GBR UE). It is obvious that we should keep the packet dropping ratio γ below the threshold γ_{macro}. Thus, we set $\delta = \lfloor T_{abs}/T \rfloor$ and check if $\gamma > \gamma_{macro}$ by Eq. (17). If so, we repeatedly decrease T_{abs} by one and recalculate γ, until $\gamma \leq \gamma_{macro}$. In this way, we can increase picocells' throughput while decrease the packet dropping ratio of GBR UEs in the macrocell.
- Case of $\Phi_{pico}^A - \Phi_{pico}^O - \Phi_{macro}^O < 0$: It is inefficient to assign many ABSs in the period, or the macrocell's throughput may significantly degrade. As UEs in $\hat{U}_{pico}$ can still receive data in ordinary subframes (but in lower data rates), our idea is to increase the number of ABSs under the premise that the macrocell BS can meet QoS demands of its UEs (i.e., the packet dropping ratio of the UEs in $\hat{U}_{macro}$ is below the threshold γ_{macro}). Thus, we begin from $T_{abs} = 0$ and repeatedly increase it by one, until $\gamma \geq \gamma_{macro}$ by Eq. (17). In this way, we can ensure data transmission of GBR UEs in the macrocell, while increase the overall throughput in picocells.

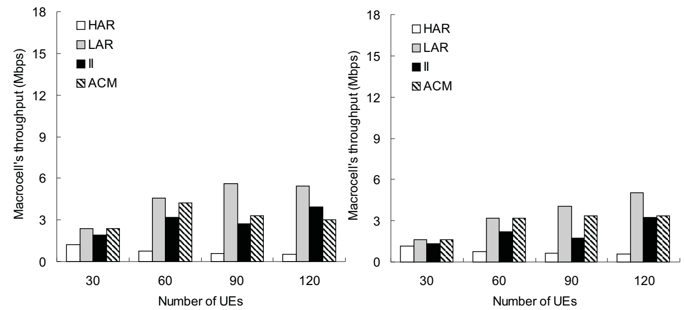
V. Performance Evaluation

We measure the performance of our configuration mechanism through LTE-Sim [13], which is an open-source simulator to model communication behavior in LTE/LTE-A. Below,



(a) PMC scenario (b) HTF scenario

Fig. 2. Comparison on the overall network throughput.



(a) PMC scenario (b) HTF scenario

Fig. 3. Comparison on the macrocell's throughput.

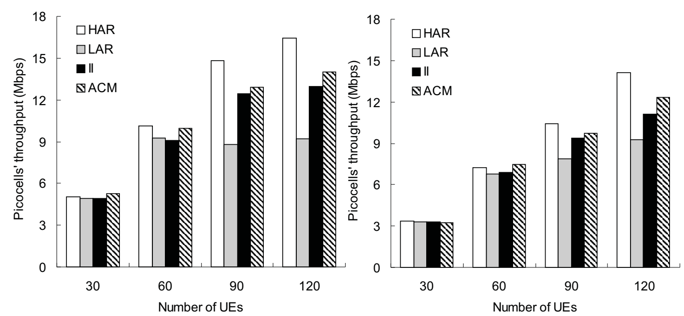
we first present the parameters used in our simulations, followed by the discussion on experimental results.

A. Simulation Parameters

We consider a heterogeneous network in Fig. 1 that consists of one macrocell and two picocells. All BSs operate on the same 5MHz channel to send data, which provides 25 PRBs in a transmission time interval (TTI = 1ms). The coverage range of macrocell and picocell is 1km and 100m, respectively. Moreover, the CRE bias value is 9dB for each picocell. The loss and and fading effect on wireless communications is set as follows [14]. For the macrocell, its path loss is calculated by $128.1 + 37.6 \times \log_{10}(\text{distance}(b_k, u_i))$. The distance between a BS b_k and a UE u_i is measured in kilometers. The path loss of a picocell is derived by $140.7 + 36.7 \times \log_{10}(\text{distance}(b_k, u_i))$. The penetration loss is set to 10dB. We adopt the log-normal distribution with the mean of 0dB and the standard deviation of 8dB to model slow fading. For fast fading, We follow the Jakes model [15] to simulate Rayleigh fading.

A number of UEs move in the network by the random-walk model [16], where the average moving speed is set to 3km/h to simulate human walking. In the beginning, each cell has a similar number of UEs. For each GBR UE, it has a H.264 video streaming flow with 242Kbps traffic demand. On the other hand, we generate a 12Kbps constant-bit-rate (CBR) flow for each of other UEs. In addition, every BS employs the modified largest weighted delay first (M-LWDF) algorithm [17] to determine PRB allocation. Two scenarios are also considered. In the scenario of *pure multimedia communications (PMC)*, every UE is a GBR UE. We use the PMC scenario to observe the situation where the heterogeneous network is congested by a lot of large-demand multimedia flows. On the other hand, in the scenario of *hybrid traffic flows (HTF)*, around two-thirds of UEs are GBR UEs and other UEs are non-GBR UEs. The HTF scenario helps us observe the performance of different schemes in a normal network situation (i.e., there are various types of traffic flows in the heterogeneous network).

We compare our proposed mechanism (denoted by 'ACM') with three schemes: 1) the *high-ABS-ratio scheme* (denoted by 'HAR') keeps δ to 0.8 to observe the impact of a large ABS ratio on system performance, 2) the *low-ABS-ratio scheme* (denoted by 'LAR') set $\delta = 0.2$ to study the impact of a small ABS ratio on system performance, and 3) the *interference-index scheme* (denoted by 'II') [11] dynamically changes the ABS ratio by an amount of 12.5% based on the network condition. The length of each period T is set to 10 subframes. In our mechanism, we set the threshold γ_{macro} of packet dropping ratio for the GBR UEs in the macrocell to 0.3.

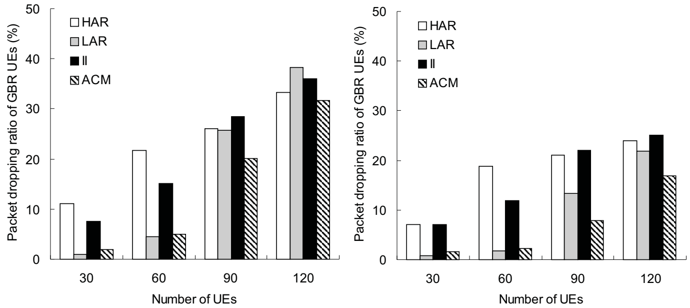


(a) PMC scenario (b) HTF scenario

Fig. 4. Comparison on the aggregate throughput of two picocells.

B. Discussion on Experimental Results

We first measure the overall throughput of the heterogeneous network, whose experimental result is given in Fig. 2. Since every UE has a large-demand video flow in the PMC scenario, its throughput would be higher than that in the HTF scenario. In addition, the overall throughput increases when the number of UEs grows. According to Fig. 2, the low-ABS-ratio scheme outperforms the high-ABS-ratio scheme when there are fewer UEs in the heterogeneous network, but the situation reverses when the number of UEs increases. This phenomenon implicitly indicates that using a fixed ABS ratio cannot always guarantee high throughput under different network conditions. On the other hand, the interference-index scheme dynamically adjusts the ABS ratio based on the network condition, so it may perform better than either the high-ABS-ratio or low-ABS-ratio schemes in some cases. Comparing with the above schemes, our configuration mechanism considers both the transmission capacity of each cell and the amount of buffered data of each UE, so it can always result in the highest throughput among all schemes in Fig. 2.



(a) PMC scenario (b) HTF scenario

Fig. 5. Comparison on the average packet dropping ratio of GBR UEs.

Next, we investigate the amount of throughput contributed by the macrocell and two picocells, as shown in Figs. 3 and 4. Due to the large δ value, the high-ABS-ratio scheme greatly improves the throughput in picocells, but results in very low throughput in the macrocell. On the contrary, the low-ABS-ratio scheme keeps higher throughput in the macrocell at the expense of data transmission in picocells. In contrast to these two schemes, both the interference-index scheme and our configuration mechanism seek to balance between the amount of throughput in different cells. Hence, they can prevent UEs from starvation, which shows the benefit of dynamically adjusting the ABS ratio.

Finally, we evaluate the average packet dropping ratio of GBR UEs in Fig. 5. Apparently, the packet dropping ratio is larger in the PMC scenario than that in the HTF scenario, because more UEs request for video communications. In addition, the packet dropping ratio significantly increases when there are more UEs in the network. Because our configuration mechanism tries its best to send out as much urgent GBR data as possible, it always has the lowest packet dropping ratio. Through this experiment, we demonstrate that the proposed configuration mechanism can better support QoS for multimedia communications as comparing with all other schemes.

VI. Conclusion

LTE-A supports heterogeneous networks for balanced data offloading and tactical BS deployment. However, signal interference among different cells is a critical problem and LTE-A adopts eICIC to solve it. The time-domain eICIC solution is more flexible than the frequency-domain one, where it allows the macrocell BS to suspend data transmission in ABSs to improve channel quality in picocells. How to decide the number of ABSs in a period has significant effect on system performance. Nevertheless, most of previous work aims at improving the overall throughput but ignores stringent delay requirement of multimedia communications. Consequently, we develop an adaptive configuration mechanism to calculate a feasible ABS ratio by estimating the transmission capacity of each cell and the amount of total and urgent data of UEs. Experimental results demonstrate the effectiveness of our configuration mechanism where it can improves the overall throughput while alleviates the average packet dropping ratio of video flows, which supports QoS for multimedia communications. For the future direction, we will combine our configuration mechanism with PRB allocation [18] to further improve system performance.

References

[1] F. Mehmeti and T. Spyropoulos, "Performance analysis of mobile data offloading in heterogeneous networks," *IEEE Transactions on Mobile Computing*, vol. 16, no. 2, pp. 482–497, 2017.

[2] Y. C. Wang and C. A. Chuang, "A two-phase heuristic for base station placement in long term evolution (LTE) networks with cell heterogeneity," in *ACM International Conference on Advances in Mobile Computing and Multimedia*, 2014, pp. 407–412.

[3] T. Hu and P. Godin, "Additional features of LTE Release 10," in *LTE–The UMTS Long Term Evolution: From Theory to Practice*. Wiley, 2011, pp. 701–714.

[4] J. Pang, J. Wang, D. Wang, G. Shen, Q. Jiang, and J. Liu, "Optimized time-domain resource partitioning for enhanced inter-cell interference coordination in heterogeneous networks," in *IEEE Wireless Communications and Networking Conference*, 2012, pp. 1613–1617.

[5] N. Trabelsi, L. Roullet, and A. Feki, "A generic framework for dynamic eICIC optimization in LTE heterogeneous networks," in *IEEE Vehicular Technology Conference*, 2014, pp. 1–6.

[6] S. Singh and J. G. Andrews, "Joint resource partitioning and offloading in heterogeneous cellular networks," *IEEE Transactions on Wireless Communications*, vol. 13, no. 2, pp. 888–901, 2014.

[7] M. Al-Rawi, J. Huschke, and M. Sedra, "Dynamic protected-subframe density configuration in LTE heterogeneous networks," in *IEEE International Conference on Computer Communications and Networks*, 2012, pp. 1–6.

[8] S. Vasudevan, R. N. Pupala, and K. Sivanesan, "Dynamic eICIC: a proactive strategy for improving spectral efficiencies of heterogeneous LTE cellular networks by leveraging user mobility and traffic dynamics," *IEEE Transactions on Wireless Communications*, vol. 12, no. 10, pp. 4956–4969, 2013.

[9] G. Bartoli, R. Fantacci, D. Marabissi, and M. Pucci, "Adaptive muting ratio in enhanced inter-cell interference coordination for LTE-A systems," in *IEEE International Wireless Communications and Mobile Computing Conference*, 2014, pp. 990–995.

[10] A. Daeinabi, K. Sandrasegaran, and P. Ghosal, "An enhanced intercell interference coordination scheme using fuzzy logic controller in LTE-advanced heterogeneous networks," in *IEEE International Symposium on Wireless Personal Multimedia Communications*, 2014, pp. 520–525.

[11] S. H. Lu, W. P. Lai, and L. C. Wang, "Time domain coordination for inter-cell interference reduction in LTE hierarchical cellular systems," in *IEEE International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness*, 2014, pp. 51–55.

[12] A. Argyriou, D. Kosmanos, and L. Tassiulas, "Joint time-domain resource partitioning, rate allocation, and video quality adaptation in heterogeneous cellular networks," *IEEE Transactions on Multimedia*, vol. 17, no. 5, pp. 736–745, 2015.

[13] G. Piro, L. A. Grieco, G. Boggia, F. Capozzi, and P. Camarda, "Simulating LTE cellular systems: an open-source framework," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 2, pp. 498–513, 2011.

[14] Y. C. Wang and C. A. Chuang, "Efficient eNB deployment strategy for heterogeneous cells in 4G LTE systems," *Computer Networks*, vol. 79, no. 14, pp. 297–312, 2015.

[15] P. Dent, G. E. Bottomley, and T. Croft, "Jakes fading model revisited," *Electronics Letters*, vol. 29, no. 13, pp. 1162–1163, 1993.

[16] W. H. Yang, Y. C. Wang, Y. C. Tseng, and B. S. P. Lin, "Energy-efficient network selection with mobility pattern awareness in an integrated WiMAX and WiFi network," *International Journal on Communication Systems*, vol. 23, no. 2, pp. 213–230, 2010.

[17] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R. Vijayakumar, "Providing quality of service over a shared wireless link," *IEEE Communications Magazine*, vol. 39, no. 2, pp. 150–154, 2001.

[18] Y. C. Wang and S. Y. Hsieh, "Service-differentiated downlink flow scheduling to support QoS in long term evolution," *Computer Networks*, vol. 94, pp. 344–359, 2016.