Traffic Offloading with Rate-Based Cell Range Expansion Offsets in Heterogeneous Networks

Shi-Sheng Sun[1,3], Wanjiun Liao[1,2] ,and Wen-Tsuen Chen[3]
[1]Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan
[2]Graduate Institute of Communication Engineering, National Taiwan University, Taipei, Taiwan
[3]Institute of Information Science, Academia Sinica, Taipei, Taiwan
Email: {d96921023, wjliao}@ntu.edu.tw, chenwt@iis.sinica.edu.tw

Abstract*—A heterogeneous network (HetNet) with macro base stations (BSs) together with low power small cells, such as pico BSs and femto BSs, is a promising solution to enhance network capacity. In HetNet, the transmission range of pico BSs are limited due to the large transmission power difference between macro and pico BSs, and thus pico BSs are typically underutilized. Cell Range Expansion (CRE) is a way to increase the opportunity of the user equipment (UE) associations to pico BSs so that more traffic from the macro cell can be offloaded to the pico cells. However, the expansion region of pico UEs with unbalance downlink and uplink signal qualities suffer from bad downlink quality, and the macro UEs near the expansion region may also experience low uplink rates. Therefore, we propose a new scheme with rate-based CRE offsets in HetNet so that UEs can decide to their associations based on their traffic demands. We formulate this problem as a mixed integer programming problem and prove that it is NP-hard. We then propose a polynomial time heuristic algorithm to solve this problem. The simulation results show that our scheme indeed achieves good traffic offloading gain for HetNet.

Keywords- HetNet; traffic offloading; cell range expansion (CRE)

I. INTRODUCTION

With the rapid adoption of mobile devices and mobile applications with high data demand, the mobile traffic requirement in cellular networks is growing at an incredible rate and causing severe problems for mobile network operators [1]. To satisfy extremely high data demand of mobile communications, recent developments include new modulation techniques, wider range frequency spectrum access, and increase in frequency reuse [2]. Among these technologies, deploying heterogeneous networks (HetNet) with both conventional macro BSs and low power small cells (e.g., pico and femto BSs) is a potential and cost-effective approach to increase the spectral efficiency (bps/Hz/area), to enhance the network capacity, and to provide better user experience [2][3]. Besides, since macro BSs are more costly and with limited deployment locations, wireless operators intend to deploy macro BSs together with small cells. In such heterogeneous deployments, small cells can provide the network access closer to users and offload the mobile data traffic from macro BSs to reduce macro BSs' traffic load.

Deploying HetNet brings higher spectral efficiency and earns traffic offloading gains. However, the benefits of deploying HetNet are limited due to the high transmit power difference between macro BSs and low power small cell BSs such as pico BSs. In traditional homogeneous cellular networks, UEs are always associated with the BS which provides the highest downlink (DL) Signal to Interference plus Noise Ratio (SINR) as follows:

$$C_{u_j} = \arg\max SINR^{DL}_{u_j,b_i}, \tag{1}$$

where b_i and u_j represents BS b_i and UE u_j, respectively. $SINR^{DL}_{b_i,u_j}$ is the downlink SINR from BS b_i to UE u_j, and C_{u_j} denotes the BS which is associated by UE u_j. Such an arrangement works well in homogeneous cellular networks since a higher downlink SINR from a BS indicates a shorter distance to the BS and hence a higher data rate. However, since the transmit power difference between macro BSs (≈46 dBm) and pico BSs (≈30 dBm) is very large, the conventional highest downlink SINR association strategy limits the utilization of pico BSs. When a pico BS is closer to the macro BS, the pico BS will have smaller coverage and placed lower utilization BS[4]. This reduces traffic offload from macro BSs, resulting in spectral inefficiencies in the HetNet.

Cell Range Expansion (CRE), which allows a UE to associate with a BS with lower downlink SINR, is a simple yet effective method to extend the coverage of low power pico BSs. CRE also allows more traffic offloading from the macro cell to the pico cell, thereby increasing the total system capacity [5]. With CRE, each UE will not always select the BS with the highest DL SINR. Instead, the BS with the highest DL SINR plus a positive value of CRE offset (CREO) with the following setting is selected:

$$C_{u_j} = \arg\max \left(SINR^{DL}_{u_j,b_i} + CREO_{b_i}\right) \tag{2}$$

$$CREO_{b_i} = \begin{cases} CREO, \text{if } b_i \text{ is a pico BS} \\ 0, \text{if } b_i \text{ is a macro BS} \end{cases}. \tag{3}$$

Thus, the coverage area of a pico BS and the association opportunity from UEs to the pico BS is increased by adding a positive value of CRE offset to the received SINR of pico BSs. More macro UEs (MUEs) close to pico BS can be associated with pico BS and become pico UEs (PUEs). As a result, the offloading gain is increased. The authors in [6] show the merits of CRE and demonstrate that a UE can connect to a pico BS even if the downlink signal from the macro BS is higher. They also propose new criteria for a UE to associate with a serving BS and obtain better spatial reuse in HetNet. The system capacity and fairness of CRE together with the inter-cell interference coordination (ICIC) are investigated in [7]. The

978-1-4799-3083-8/14/$31.00

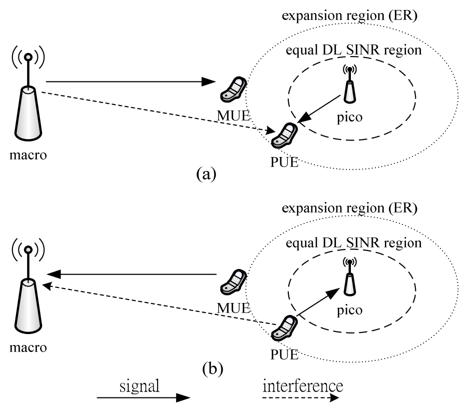


Fig. 1. Low SINR conditions in HetNets with CRE. (a) Low DL SINR of ER PUEs. (b) Low UL SINR of near ER MUEs.

authors analyze the CRE offloading benefits and spectral efficiencies in HetNet through CDFs with respect to DL SINRs, and suggest a guideline to set the CRE offset. The downlink ftp traffic performance of both macro and pico BSs and the user throughput gain of HetNet with different CRE offset settings are also shown in [8]. The authors highlight the influence of downlink interference mitigation of Control Channels (CCHs) and then integrate Lightly Load CCH transmission Subframe (LLCS) to support ICIC. Their system level simulations show that a large CRE offset with ICIC can enhance user throughput efficiently. In [4], the authors formulate some closed-form models to analyze the appropriate CRE offsets with downlink (DL) and uplink (UL) ICICs. The pico BS's coverage radius with respect to different CRE offsets is analyzed using the equal DL RSS boundary (ESB) and the equal path-loss boundary (EPB) ellipse. A novel inter macro-pico cooperative scheduling scheme is also derived to reduce the interference of the macro BSs and to increase the performance of CRE. While there are existing efforts on the system performance and potential capacity gain of CRE, they are mainly focused on HetNet with homogeneous CRE offsets for all UEs within the umbrella BSs. The authors in [9] propose an adaptive setting of CRE offset and let UEs choose their optimal offsets to improve throughput of cell edge users. All UEs measure the SINRs from the donor BS and report their SINRs to the donor BS to gather the distribution of SINRs. UEs with low SINR use a higher value CRE offset and other UEs use a normal value offset. By this simple method, a cell edge UE with low SINR has higher opportunity to associate with a pico BS. However, enforcing a cell edge UE to associate with a pico BS by a higher CRE offset may not be the best strategy since this pico BS may be far away from the UE and the UE would waste too many resources of the pico BS, thus downgrading the total system throughput.

Although the existing works explore the offloading and capacity gain of CRE mechanisms, the UEs within and near the expansion region (ER) may still suffer from the unequal downlink and uplink channel quality. The UEs in the expansion region experience low DL SINR and poor DL rate since they switch from MUEs to PUEs by additional CRE offset as shown in Fig. 1. Therefore, the low-DL-rate PUEs may consume a lot of the downlink resources of pico BSs when these PUEs have downlink traffic. Besides, MUEs near ER may experience low UL rate due to the longer distance and larger path loss to the macro BS, and suffer uplink interference from the nearby ER PUEs. Hence, these MUEs with uplink traffic may consume more uplink resources of the macro BS.

In this paper, we let each UE select and associate with an appropriate BS according to the UE's traffic demand by using a rate-based CRE-offset mechanism. The UEs with higher uplink traffic demands are assigned with a larger CRE offset, hence these UEs have higher opportunity to associate with pico BSs and enjoy better uplink quality. On the contrary, the UEs with higher downlink traffic demands are allocated a lower CRE offset so that they will have a higher chance to access from the macro BS. To offload more traffic from the macro BS to pico BSs, we formulate this problem as a mixed binary integer programming problem to minimize the traffic load of the macro BS. We also prove that it is NP-hard. We then propose a heuristic algorithm which lets UEs associate with BSs according to the rate-based CRE offset. As a result, we could mitigate the under-utilization of pico BSs, and allow more traffic offloading to the pico cell.

The rest of the paper is organized as follows. In Sec. II, the system model is described. In Sec. III, the problem is formulated via mixed binary integer programming and proved to be NP-hard. In Sec. IV, a heuristic algorithm is proposed to solve this problem. The performance of the proposed mechanism is evaluated via simulations in Sec. V. Finally, this paper is concluded in Sec. VI.

II. System Model

A. Network Model

In this paper, we consider a cellular network with one macro BS, multiple pico BSs, and multiple UEs. Outside this macro BS, all macro BSs are interconnected through a high-speed backhaul and the inter-macro-BSs interference is assumed to be alleviated through some ICIC schemes. Thus, we can focus on the intra-macro-BSs interference (i.e., interference among macro and pico BSs). Under the umbrella of the macro BS, all pico BSs are interconnected through a high-speed backhaul and all resource information of BSs are exchanged through the backhaul. The cellular network is an orthogonal frequency division multiple access (OFDMA) system with the following parameters:

- The BSs set: $\boldsymbol{B} = \{b_0, b_1, \dots, b_n\}$, where b_0 indicates the macro BS and $b_1, b_2, \dots, b_n$ are pico BSs.
- The number of resource blocks (RBs): V_{b_i} and W_{b_i}. Each BS b_i has a total of V_{b_i} DL RBs and W_{b_i} UL RBs. In a general cellular system, all BSs have identical DL RBs and identical UL RBs.
- The UEs set: $\boldsymbol{U} = \{u_1, u_2, \dots, u_m\}$, where all UEs are located under the umbrella of the macro BS.
- The traffic demands of UEs: Each UE u_j has its downlink and uplink traffic demand DL_{u_j} and UL_{u_j}, respectively.
- The transmit power: Each BS b_i uses its fixed transmit power $P_{t_{b_i}}$ on DL RBs and each UE u_j uses a fixed

transmit power $P_{t_{u_j}}$ on UL RBs. We assume that all pico BSs' transmit powers are identical (i.e., $P_{t_{b_1}} = P_{t_{b_2}} = \ldots = P_{t_{b_n}}$) and all UEs' transmit powers are identical.

B. Propagation Model and Signal Quality

We consider both downlink and uplink channels of a heterogeneous cellular network and adopt a radio channel with path loss. The downlink receive power of UE u_j from BS b_i is

$$P_{r_{u_j,b_i}} = P_{t_{b_i}} \cdot \frac{g_{b_i} g_{u_j}}{\delta_{b_i u_j}}, \tag{4}$$

where $\delta_{b_i u_j}$ denotes the path loss from BS b_i to UE u_j, g_{b_i} and g_{u_j} denote the BS antenna gain and the UE antenna gain, respectively. Also, the uplink receive power of BS b_i from UE u_j is modeled by

$$P_{r_{b_i,u_j}} = P_{t_{u_j}} \cdot \frac{g_{u_j} g_{b_i}}{\delta_{u_j b_i}}. \tag{5}$$

The downlink SINR of UE u_j served by BS b_i is

$$SINR_{u_j,b_i}^{DL} = \frac{P_{r_{u_j,b_i}}}{\sum_{b_k \in \boldsymbol{B} \setminus \{b_i\}} P_{r_{u_j,b_k}} + \sigma^2} \tag{6}$$

where σ^2 denotes the noise power and $\sum_{b_k \in \boldsymbol{B} \setminus \{b_i\}} P_{r_{u_j,b_k}}$ denotes the receive power from all other BSs, respectively. Then, the achievable downlink rate of UE u_j served by BS b_i can be derived from the modulation and coding scheme (MCS) [10], [11] as $R_{SINR_{u_j,b_i}^{DL}}$.

Similarly, the uplink SINR from UE u_j to BS b_i can be derived in a similar manner as

$$SINR_{b_i,u_j}^{UL} = \frac{P_{r_{b_i,u_j}}}{\sum_{u_k \in \boldsymbol{U} \setminus \{u_j\}} P_{r_{b_i,u_k}} + \sigma^2}, \tag{7}$$

where $\sum_{u_k \in \boldsymbol{U} \setminus \{u_j\}} P_{r_{b_i,u_k}}$ is the receive power from all other UEs. The achievable uplink rate from UE u_j to BS b_i can also be modeled by $R_{SINR_{b_i,u_j}^{UL}}$.

C. Cell Range Expansion with Rate-Based CRE Offset

The following issues are ignored in previous work [4], [6]-[9]: a better setting of CRE offsets and an optimal cell selection method to offload macro BSs' traffic, increasing the pico BSs' utilization, and yet maintaining UEs' downlink and uplink transmission qualities. As mentioned in Sec. I, due to the large transmission power difference between macro and pico BSs, the coverage area of the pico BS and the utilization of the pico BS is limited when CRE is not applied in HetNet. However, PUEs in the expansion region and MUEs near the expansion region may experience unequal downlink and uplink channel qualities. To deal with these problems, we propose a rate-based CRE offset (RBCREO) scheme in heterogeneous networks.

The basic principle of the rate-based CRE offset is to adjust the CRE offset based on the ratio of a UE's uplink to downlink data demands. UEs with a higher uplink traffic demand will be assigned a larger CRE offset, and these UEs will have higher probabilities to associate with pico BSs and benefit from higher uplink rate of pico BSs. UEs with higher downlink traffic demands are allocated a lower CRE offset to have more chance to connect to the macro BS and enjoy a higher downlink rate. The cell selection strategy of RBCREO is described as:

$$C_{u_j} = \arg\max \left(SINR_{u_j,b_i}^{DL} + CREO_{u_j,b_i}\right) \tag{8}$$

$$CREO_{u_j,b_i} = \begin{cases} CREO + f(UL_{u_j}/DL_{u_j}), \text{if } b_i \text{ is a pico BS} \\ 0, \text{if } b_i \text{ is a macro BS} \end{cases}, \tag{9}$$

where C_{u_j} denotes the UE u_j's association to BS. $CREO$ and $CREO_{u_j,b_i}$ represent the system's default CRE offset and the rate-based CRE offset of UE u_j to BS b_i, respectively. $SINR_{u_j,b_i}^{DL}$ is the DL SINR from BS b_i to UE u_j, and $f(UL_{u_j}/DL_{u_j})$ is a strictly increasing function with respect to the ratio of UE u_j's uplink over the downlink traffic demand.

The rate-based CRE offset reserves the system's default CRE offset to expand pico BS's coverage and maintain the basic offloading effect. The UEs with higher uplink traffic demands are assigned a larger offset and can further increase their opportunity to associate with pico BSs, thus obtaining better uplink performance.

III. Problem Formulation

In the previous section, UEs can adaptively associate with BSs by RBCREO according to their downlink and uplink data demand ratio. With RBCREO, more UEs can be offloaded from a macro BS to a pico BS, and thus more precious resource of the macro BS could be preserved. However, the loading status and the resource condition of BSs are not regarded as the association factors in conventional SINR-based association strategies. To better use the resource of the macro cell and to offload more traffic to the pico cell, we formulate an optimization problem which combines UEs' associations with rate-based CRE offset and a radio resource allocation of BSs for better traffic offloading.

A. Mathematical Model Formulation

Our problem is described as follows. Given the location of macro BS, pico BSs, and UEs, the relative downlink and uplink SINR $SINR_{u_j,b_i}^{DL}$ and $SINR_{b_i,u_j}^{UL}$, and the achievable DL and UL rate $R_{SINR_{u_j,b_i}^{DL}}$ and $R_{SINR_{b_i,u_j}^{UL}}$ from each BS to each UE, to satisfy the downlink traffic demand DL_{u_j} and uplink traffic demand UL_{u_j} of each UE u_j, we attempt to find the UEs' associations and minimize the resource blocks allocated by macro BS by offloading traffic from macro to pico BSs. The traffic offloading for the rate-based CREO (TORCREO) problem is formulated with the following objective:

$$min\left(\alpha \cdot \sum_{u_j \in \boldsymbol{U}} v_{u_j}^{b_0} + (1-\alpha) \cdot \sum_{u_j \in \boldsymbol{U}} w_{u_j}^{b_0}\right) \tag{10}$$

subject to:

$$\sum_{b_i \in \boldsymbol{B}} C_{u_j}^{b_i} = 1, \forall u_j \in \boldsymbol{U} \tag{11}$$

$$\sum_{b_i \in \boldsymbol{B}} R_{SINR_{u_j,b_i}^{DL}} \cdot v_{u_j}^{b_i} \geq DL_{u_j}, \forall u_j \in \boldsymbol{U} \tag{12}$$

$$\sum_{b_i \in \boldsymbol{B}} R_{SINR^{UL}_{b_i,u_j}} \cdot w^{b_i}_{u_j} \geq UL_{u_j}, \forall u_j \in \boldsymbol{U} \quad (13)$$

$$\sum_{u_j \in \boldsymbol{U}} v^{b_i}_{u_j} \leq V_{b_i}, \forall b_i \in \boldsymbol{B} \quad (14)$$

$$\sum_{u_j \in \boldsymbol{U}} w^{b_i}_{u_j} \leq W_{b_i}, \forall b_i \in \boldsymbol{B} \quad (15)$$

$$V_{b_i} \cdot C^{b_i}_{u_j} \geq v^{b_i}_{u_j}, \forall u_j \in \boldsymbol{U}, \forall b_i \in \boldsymbol{B} \quad (16)$$

$$W_{b_i} \cdot C^{b_i}_{u_j} \geq w^{b_i}_{u_j}, \forall u_j \in \boldsymbol{U}, \forall b_i \in \boldsymbol{B} \quad (17)$$

$$\sum_{b_i \in \boldsymbol{B}} SINR^{DL}_{u_j,b_i} \cdot C^{b_i}_{u_j} + CREO_{u_j,b_i} \geq SINR^{DL}_{u_j,b_0}, \forall u_j \in \boldsymbol{U} \quad (18)$$

$$C^{b_i}_{u_j} \in \{0, 1\}, \forall u_j \in \boldsymbol{U}, \forall b_i \in \boldsymbol{B} \quad (19)$$

$$v^{b_i}_{u_j} \geq 0, integer, \forall u_j \in \boldsymbol{U}, \forall b_i \in \boldsymbol{B} \quad (20)$$

$$w^{b_i}_{u_j} \geq 0, integer, \forall u_j \in \boldsymbol{U}, \forall b_i \in \boldsymbol{B} \quad (21)$$

The TORCREO problem jointly considers the associations of UEs and resource allocation of BSs. $C^{b_i}_{u_j}$ in (19) is a binary decision variable which indicates the association of UE u_j to BS b_i. In (20) and (21), the decision variables $v^{b_i}_{u_j}$ and $w^{b_i}_{u_j}$ are the allocated downlink and uplink RBs from BS b_i to UE u_j, respectively. The objective function in (10) states that the macro BS offloads as much traffic as possible while consuming the least resource. α, the downlink importance ratio, is a constant in the range (0,1) to weigh the importance between downlink and uplink resources. (11) limits a UE to associate with only one BS. Both (12) and (13) guarantee the downlink and uplink traffic demands of each UE. The downlink and uplink resource capacities of BSs are restricted in (14) and (15). In (16) and (17), each UE is enforced to associate with the BS which allocates RBs to the UE in downlink and uplink. (18) enforces each UE to associate with the BS candidates which can satisfy the UE's RBCREO.

B. Problem Complexity Analysis

Theorem 1. The TORCREO problem is NP-hard.

Proof: To analyze the problem complexity of TORCREO, we first consider a special case of the original problem, which takes into account only UEs' downlink traffic demand and BSs' downlink resource limit. Thus, the problem becomes:

$$P^1: min \sum_{u_j \in \boldsymbol{U}} v^{b_0}_{u_j} \quad (22)$$

subject to the following constraints:

(11), (12), (14), (16), (18), (19), and (20).

Since each UE can only be associated with a BS and this BS has to satisfy the UE's traffic demand, if the association $C^{b_i}_{u_j}$ between UE u_j and BS b_i can be determined, the number of downlink RBs $v^{b_i}_{u_j}$ allocated from BS b_i to UE u_j is also obtained. Consider Problem P^1 and set the decision variable $v^{b_i}_{u_j}$ as a given parameter. Then, Problem P^2 can be reformulated as follows:

$$P^2: min \sum_{u_j \in \boldsymbol{U}} v^{b_0}_{u_j} \cdot C^{b_0}_{u_j} \quad (23)$$

subject to constraints (11), (18), and (19), and the modification of (14) by

$$\sum_{u_j \in \boldsymbol{U}} v^{b_i}_{u_j} \cdot C^{b_i}_{u_j} \leq V_{b_i}, \forall b_i \in \boldsymbol{B} \quad (24)$$

We further consider a special case of P^2, denoted by P^3, where all UEs associated with the macro BS consume the same constant number of RBs which is denoted by v^{b_0}. Problem P^3 can be formulated as minimizing the total number of UEs being associated with the macro BS:

$$P^3: min\, v^{b_0} \cdot \sum_{u_j \in \boldsymbol{U}} C^{b_0}_{u_j} \quad (25)$$

subject to (11), (18), (19), and (24).

Since the total number of UEs in the system is fixed, to minimize the total number of UEs which are associated with the macro BS is equivalent to maximizing the total number of UEs which are associated with the pico BSs. Problem P^3 can be reformulated as:

$$P^4: max \sum_{u_j \in \boldsymbol{U}, b_k \in \boldsymbol{B} \setminus \{b_0\}} C^{b_k}_{u_j} \quad (26)$$

subject to (11), (18), (19), and (24).

Clearly, the special case of the TORCREO problem, P^4, can be reduced from the maximizing the number of pieces packed problem [12], which is an NP-complete problem. The problem which maximizes the number of pieces packed is described as follows. Given a set of *n* fixed capacity bins $\{\beta_1, \beta_2, \ldots, \beta_n\}$ and a set of different size items $\{\mu_1, \mu_2, \ldots, \mu_m\}$, the objective is to maximize the number of items packed into these bins such that no bin capacity is exceeded. If we can solve the special case of the TORCREO problem (i.e., P^4) in polynomial time, we can also solve this bin packing problem in polynomial time, which means maximizing the number of pieces packed problem can be reduced to P^4. Since P^4 is a special case of the TORCREO problem, any algorithm that can solve the TORCREO problem in polynomial time can also solve P^4 in polynomial time. Therefore, we can deduce that the special case of the TORCREO problem can be reduced in polynomial time from maximizing the number of pieces packed problem. Since the latter is NP-complete, we conclude that the TORCREO problem is NP-hard. ■

Heuristic Algorithm: Pico First Association (PFA)

Input: the BSs set $\boldsymbol{B}=\{b_0,b_1,\dots,b_n\}$, the UEs set $\boldsymbol{U}=\{u_1,u_2,\dots,u_m\}$, the DL and UL resource capacity V_{b_i} and W_{b_i} , the DL SINR $SINR^{DL}_{u_j,b_i}$ and the achievable DL rate $R_{SINR^{DL}_{u_j,b_i}}$, the UL SINR $SINR^{UL}_{b_i,u_j}$ and the achievable UL rate $R_{SINR^{UL}_{b_i,u_j}}$, the DL and UL traffic demand DL_{u_j} and UL_{u_j}, and the corresponding rate-based CRE offset $CREO_{u_j,b_i}$

sort all $u_j \in \boldsymbol{U}$ by UL_{u_j}/DL_{u_j} in descending order to *A[]*;

for all u_j from *A[0]* to *A[m-1]* **do**

$C^{b_i}_{u_j}$=0;

sort all $b_i \in \boldsymbol{B}\backslash\{b_0\}$ by $SINR^{UL}_{b_i,u_j}$ in descending order to $B_p[]$;

for all b_i from $B_p[0]$ to $B_p[n-1]$ **do**

if ($\sum_{b_i\in \boldsymbol{B}} C^{b_i}_{u_j} \neq 1$ && $SINR^{DL}_{u_j,b_i}+CREO_{u_j,b_i} \geq SINR^{DL}_{u_j,b_0}$) **then**

allocate $v^{b_i}_{u_j}$ and $w^{b_i}_{u_j}$ until $R_{SINR^{DL}_{u_j,b_i}} * v^{b_i}_{u_j} \geq DL_{u_j}$ && $R_{SINR^{UL}_{b_i,u_j}} * w^{b_i}_{u_j} \geq UL_{u_j}$;

V_{b_i}-=$v^{b_i}_{u_j}$, W_{b_i}-=$w^{b_i}_{u_j}$, $C^{b_i}_{u_j}$=1;

end if

end for

if $\sum_{b_i\in \boldsymbol{B}} C^{b_i}_{u_j} \neq 1$ **then**

allocate $v^{b_0}_{u_j}$ and $w^{b_0}_{u_j}$ until $R_{SINR^{DL}_{u_j,b_0}} * v^{b_0}_{u_j} \geq DL_{u_j}$ && $R_{SINR^{UL}_{b_0,u_j}} * w^{b_0}_{u_j} \geq UL_{u_j}$;

V_{b_0}-=$v^{b_0}_{u_j}$, W_{b_0}-=$w^{b_0}_{u_j}$, $C^{b_0}_{u_j}$=1;

end if

end for

Fig. 2. The proposed PFA algorithm.

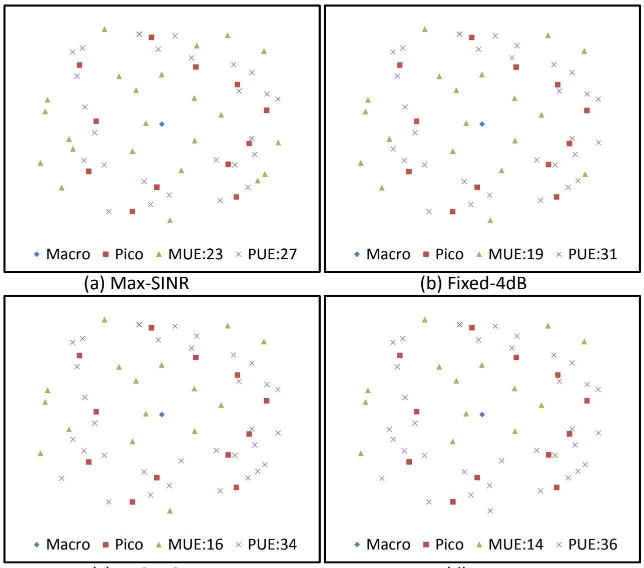
IV. Heuristic Cell Selection Algorithms with Rate-Beased CRE Offset

In this section, we propose a near optimal solution called Pico First Association (PFA), which is a heuristic algorithm combining the UEs' associations and resource blocks allocation of BSs according to the rate-based CRE offset. The PFA algorithm is shown in Fig. 2. The downlink and uplink channel conditions between each UE and each BS, and the downlink and uplink traffic demand of each UE are first reported to the macro BS. In PFA, UEs are sorted by the ratio of uplink to downlink traffic demands, and then associated with the BSs in the following procedure until all UEs are served. The UE attempts to associate with the pico BSs in the decreasing order of the uplink SINR. If the pico BS fits the UE's rate-based CREO and has sufficient resources to serve the UE's traffic demand, the UE is associated with this pico BS. Otherwise, the UE tries to associate with another pico BS in the decreasing order of the uplink SINR. The UE is associated with the macro BS if all pico BSs cannot satisfy its traffic demand or its RBCREO. The PFA algorithm stops after each UE finds its association to BSs.

The UEs in PFA are sorted to associate with the BSs with a complexity of $O(m\log m)$. Each UE then tries to find associations with pico BSs at most n times or is finally associated with the macro BS, with $O(n\log n+n+1)$. Since the number of pico BSs is much smaller than the number of UEs, it follows that the total time complexity of the PFA algorithm is $O(m\log m + m(n\log n+n+1)) = O(mn\log n)$.

Table I. Simulation Parameters

Cell Layout	3 sectors/site with 4 picos/sector
Cell Radius	500m
Carrier Frequency	2.0GHz
Bandwidth	10MHz+10MHz
Path Loss	Macro: $128.1+37.6\log_{10}(R)$ dB (R in km) Pico: $140.7 + 36.7\log_{10}(R)$ dB (R in km) UE:$15.3+37.6\log_{10}(R)$ dB (R in m)
TX Power	Macro: 46dBm (~40W) Pico: 30dBm (~1W) UE:23dBm (~200mW)
Antenna Gain	Macro: 14dBi Pico: 5dBi UE: 0dBi
Thermal Noise	-174dBm/Hz
Subframe Duration	1ms
Number of RBs	50,000
MCS	15 Types: QPSK/16QAM/64QAM [10], [11]
Number of UEs	50
Traffic Demand of UEs	DL: 64Kbps~2Mbps (average 1Mbps) UL:64Kbps~1Mbps (average 500Kbps)



(a) Max-SINR (b) Fixed-4dB

(c) RBCREO (d) PFA

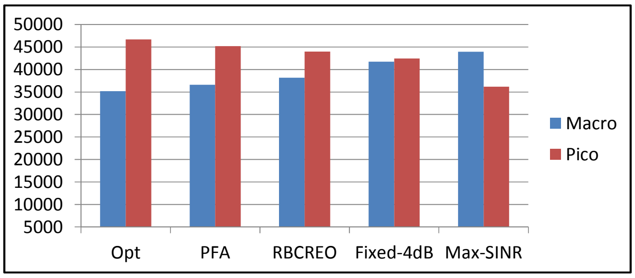
Fig. 3. Simulation results: UEs' associations.

V. Performance Evaluation

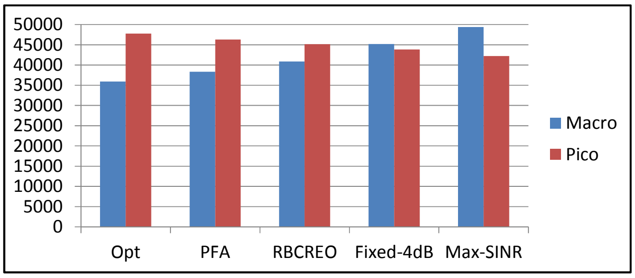
In this section, we compare the offloading performance of traditional Max-DL-SINR association, Fixed-4dB-CREO, rate-based CREO (RBCREO), the PFA algorithm, and the optimization solution (Opt) which gives the solution to the TORCREO problem with a brute force manner.

A. Simulation Setup

In our simulation, Fixed-dB-CREO with a 4dB offset is selected as the baseline. We choose 4dB+$2\log_{10}(UL_{u_j}/DL_{u_j})$ as the function of RBCREO to compare with Fixed-4dB-CREO.



(a) Allocated DL RBs



(b) Allocated UL RBs

Fig. 4. Simulation results: allocation of resource blocks.

We set the downlink importance ratio α in TORCREO to be 0.5 to balance both downlink and uplink importance and to measure the performance of TORCERO under such a setting. The rest of the simulation parameters are set according to the 3GPP recommendations for outdoor heterogeneous systems [13] and listed in Table I.

B. Simulation Results

Fig. 3 shows the UEs' associations with BSs for different association strategies. The Fixed-4dB-CREO association has more opportunity for MUEs to become PUEs than the traditional Max-DL-SINR strategy. RBCREO can adaptively change UEs' CREO by their traffic demand and switch more MUEs to become PUEs than Fixed-4dB-CREO. By gathering the loading status and the resource condition of BSs, the heuristic PFA algorithm can further offload more UEs to the pico cell, thus decreasing the load of the macro BS.

In Fig. 4, we compare the resource allocation of different association strategies. Clearly, many DL and UL RBs are consumed by the macro BS with the Max-DL-SINR strategy and the utilization of pico BSs is not high. The rate-based CREO obviously offloads more traffic from the macro cell to the pico cell, and saves more DL and UL resource of the macro BS than both Max-DL-SINR and Fixed-4dB-CREO. As mentioned above, by accounting for the traffic load information and the resource condition of BSs, our PFA algorithm can reduce much more loading of the macro BS, and redirect traffic to the pico BSs thus mitigating the under-utilization problem of pico BSs based on the load information of BSs. It is also shown that our heuristic PFA algorithm can be very closed to the optimal solution to TORCREO.

VI. Conclusion

In this work, we propose a scheme with a rate-based CRE offset which associates UEs with appropriate BSs according to their traffic demands. To lighten the load of the macro BS and increase the utilization of pico BSs, we formulate our problem to a mixed binary integer programming problem. The problem is proved to be NP-hard. We then propose a heuristic algorithm to solve this problem. The simulation results show that our heuristic is indeed effective for HetNet.

Acknowledgements

This work was supported in part by the Excellent Research Projects of National Taiwan University, under Grant Number AE00-00-04, and in part by National Science Council (NSC), Taiwan, under Grant Number NSC102- 2221-E-002-014-MY2.

References

[1] "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017," white paper, Cisco, Feb. 2013.

[2] "Small Cells – What's the Big Idea?," white paper, Small Cell Forum, Feb. 2012.

[3] A. Damnjanovic, J. Montojo, Y. Wei, T. Ji, T. Luo, M. Vajapeyam, T. Yoo, O. Song, and D. Malladi, "A Survey on 3GPP Heterogeneous Networks," *IEEE Wirel. Commun.*, vol. 18, no. 3, pp. 10 –21, Jun. 2011.

[4] D. Lopez-Perez, X. Chu, and I. Guvenc, "On the Expanded Region of Picocells in Heterogeneous Networks," *IEEE J. Sel. Top. Signal Process.*, vol. 6, no. 3, pp. 281 –294, Jun. 2012.

[5] Qualcomm Incorporated, "Importance of Serving Cell Selection in Heterogeneous Networks," 3GPP, R1-010701, Jan. 2010.

[6] R. Madan, J. Borran, A. Sampath, N. Bhushan, A. Khandekar, and T. Ji, "Cell Association and Interference Coordination in Heterogeneous LTE-A Cellular Networks," *IEEE J. Sel. Areas Commun.*, vol. 28, no. 9, pp. 1479 –1489, Dec. 2010.

[7] I. Guvenc, "Capacity and Fairness Analysis of Heterogeneous Networks with Range Expansion and Interference Coordination," *IEEE Commun. Lett.*, vol. 15, no. 10, pp. 1084 –1087, Oct. 2011.

[8] K. Okino, T. Nakayama, C. Yamazaki, H. Sato, and Y. Kusano, "Pico Cell Range Expansion with Interference Mitigation toward LTE-Advanced Heterogeneous Networks," in *IEEE ICC* 2011.

[9] K. Kikuchi and H. Otsuka, "Proposal of adaptive control CRE in heterogeneous networks," in *IEEE PIMRC* 2012.

[10] D. Lopez-Perez and X. Chu, "Inter-Cell Interference Coordination for Expanded Region Picocells in Heterogeneous Networks," in *ICCCN* 2011.

[11] S. Sesia, I. Toufik, and M. Baker, *LTE, The UMTS Long Term Evolution: From Theory to Practice*. Wiley, 2009.

[12] E. G. C. Jr, J. Y.-T. Leung, and D. W. Ting, "Bin packing: Maximizing the number of pieces packed," *Acta Inform.*, vol. 9, no. 3, pp. 263–271, Sep. 1978.

[13] 3GPP, "Further Advancements for E-UTRA Physical Layer Aspects." TS 36.814 v9.0.0.