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# Adaptive Control of CRE with Proportional Fair Resource Scheduling in LTE HetNets

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**Abstract:** A heterogeneous network (HetNet) in LTE is typically a combination of macrocells and small cells contributing to meeting the increasing demand for network capacity. Cell range extension (CRE) is the process to extend the area under the small cell in order to balance the loads between the macrocell and the small cell. A cell selection offset (CSO) is added to small cells to set the amount of extension appropriately. An adaptive CSO can better address the continuously changing network conditions than a fixed CSO. While deriving schemes for CSO determination, it is rational to incorporate practical resource scheduling methods as well as to focus on the achievement of good balance in loading, which existing research works are lacking. An adaptation technique of CSO, based on the round robin (RR) resource scheduling, is already demonstrated. However, proportional fair (PF) resource scheduling can be a better choice in a practical network, as it incorporates radio link conditions. In this paper, we propose, based on our formulation, a CSO adaptation method, which can minimize the difference in PF scheduling based loading between the macrocell and the small cell. Then we use simulation results for the demonstration of the effectiveness of the proposed method.

**Keywords:** LTE, HetNets, CRE, Load balancing, CSO.

## 1. Introduction

Long term evolution (LTE), and its later version LTE-Advanced are the most efficient technologies among current cellular communication deployments. The heterogeneous networks (HetNets), introduced in LTE-Advanced, can enhance coverage and capacity greatly. A HetNet consists of regular macrocells typically transmitting at a high power level, overlaid with low power small cells such as picocell, femtocell, remote radio head (RRH), and relay node (RN) [1], [2]. In this paper, in addition to the macrocell, the HetNet is considered to have only picocells and femtocells and they both are referred to as small cells. The small cells offload traffic from the macrocell and offer an extension of the reach of coverage [3]. They improve the conditions in coverage holes providing higher data rates at cell edge or in hotspots. The small cells have smaller base stations with lower antenna gain compared to the macrocells and so, their site acquisition can be simpler. However, there are some challenges that need to be addressed in HetNets.

Due to the fact that the eNodeB transmit power of the macrocell is much higher than that of the small cell, a huge crowd of User Equipments (UEs) tend to connect to the macro eNodeB even when the path loss between them and the small cell is lower. This leads to an unbalanced load distribution among the cells. Consequently, the overcrowded macrocell can lack enough resources and its average user throughput can be very low. As a remedy to this problem, 3GPP has introduced the concept of cell range extension (CRE). CRE is the process of expanding the range of the small cells by adding a virtual cell selection offset (CSO) to the small cells in HetNets. This enables a UE to associate with an eNodeB with lower downlink signal to interference plus noise ratio (SINR), which results in more traffic offloading from macrocell to small cell and consequently, the system capacity increases [4]. The use of a fixed CSO value is the simplest implementation. By contrast, self-organizing network (SON) can be used, which can self-update various network parameters [5]-[7]. SON can be utilized effectively to achieve network self-optimization in HetNets scenario and thus, an adaptation of CSO can be used [8]. The adaptive control of CRE is also proposed in [9], [10]. The authors in [11] proposed an adaptive CSO based on resource block utilization ratio (RBUR), which estimates the varying load conditions in each cell. This method uses a threshold value of RURB and an initial

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CSO value. A new CSO is calculated and if its corresponding RURB is higher than the threshold RURB, then the macrocell is considered overloaded and CSO is increased. In [12], the authors also proposed adaptive RURB based CSO, which can improve the overall capacity. Instead of using a common CSO value for all UEs in the cell, the authors of [13] proposed the use of dedicated bias value for each UE. Here, using the Q-learning algorithm, each UE learns its bias value that minimizes the number of UE outages from its past experience independently. However, this procedure requires a long convergence time. The authors in [14] proposed a simple decentralized adaptive cell association (SDACA) method, which has fast convergence time based on individual UE feedback with the assistance of a broadcast from macro eNodeB. The authors in [15] proposed an adaptive control method which improves the cell edge user throughput and maintains the average user throughput at the same time. However, the suggested schemes of most research works do not incorporate any practical resource scheduling methods although the expansion in CRE should depend on how the resources are allocated to individual users in both the macrocell and the small cell in practice. Secondly, many research works suggest an optimum CSO value that maximizes the total throughput in the macrocell and the small cell [12], [16], which evidently, will tend to cause the operation at high SINR. However, this contradicts the basic purpose of CRE, which is to create balance in loading. The balance can ensure satisfactory average user throughput in the macrocell although it acquiesces to allowing some users intentionally to operate at lower SINR.

The authors in [16] proposed an adaptive algorithm to update the CSO value based on round robin (RR) resource scheduling. However, while RR considers only fairness among users, proportional fair (PF) considers both fairness and individual radio link quality of the users in resource scheduling. Since, it is the radio link quality that dictates how effectively the users can utilize the radio resources, PF is more popular than RR. Therefore, in this paper, using our formulation, we propose an adaptive algorithm to update the CSO value based on PF resource scheduling. In the proposed scheme, the CSO will be considered optimum when it minimizes the difference between the PF based average user throughput of the macrocell and the small cell.

The remainder of this paper is organized as follows. A system model and the problem formulation are developed in Section II. The proposed scheme for adaptive control of CRE is explained in Section III. In Section IV, simulation results are presented to demonstrate the effectiveness of the proposed scheme. Finally, the whole paper is concluded in Section V.

## 2. System Model and Problem Formulation

A formulation is made in this section, which will help establish the proposed scheme in the following section. Here, we consider an LTE HetNet scenario with a small cell overlaid with a macrocell in the system model. For the purpose of formulation, we first derive resource allocation quantities, which can apply to either small cell or macrocell. LTE uses resource block (RB) as the basic unit for the allocation of resources to the UE. Each RB consists of 12 adjacent subcarriers and six or seven symbols [1]. A pair of RBs taking up one transmission time interval (TTI) is referred to as a scheduling block (SB) in this paper. We assume that both RBs in an SB are mapped onto the same frequencies.

The active users in the cell are identified as **K** ={1,2,…, *k*,.., K} where K is the total number of active users with data ready for transfer. For simplicity, it is assumed that a user can establish only one logical channel mapped to an EPS bearer. The possible MCS levels are **J** = {1,2, …, *j*,.. , J} where J is the total number of MCS supported and J is 29 for both downlink and uplink in LTE specifications. The SBs available in a TTI are identified as **N** ={1,2,…,*i*,…….., N} where N is the total number of SBs and it depends on the available bandwidth in the cell. For simplicity, the reduction in data rate due to packet losses and retransmissions is ignored, which in practice, depends on the SINR of the individual SBs. Thus, the estimated data rate corresponding to an SB for user *k* who can potentially use MCS *j* is given by

$$r_{j,k}=C_{j,k}\log_2\left(M_{j,k}\right)\frac{S_{sb}\text{-}ND_{sb}}{T_sN_{sb}} \quad (1)$$

Here, $C_{j,k}$ is the code rate and $M_{j,k}$ is the modulation for MCS j used by the user k in a TTI. $S_{sb}$ is the total number of resource elements in an SB. $ND_{sb}$ is the number of resource elements used in an SB for purposes other than data. $T_s$ is the symbol period and $N_{sb}$ is the number of symbols in a subframe. $T_sN_{sb}$ is always 1 ms, which is the length of a subframe.

$b_{j,k}$ is set to 1 to indicate that MCS j is used for user k where $b_{j,k} \in \{0,1\}$. Since all SBs allocated to a user in a TTI must use the same MCS [1],

$$\sum_{j=1}^{J} b_{j,k}=1, \quad \forall k \quad (2)$$

$\rho_{i,k}$ is set to 1 to indicate that $i^{th}$ SB is allocated to user k where $\rho_{i,k} \in \{0,1\}$. Since an SB can be allocated to only one user,

$$\sum_{k=1}^{K} \rho_{i,k}=1, \quad \forall i \quad (3)$$

The overall data rate for user k is given by

$$R_k=\sum_{i=1}^{N} \rho_{i,k} \sum_{j=1}^{J} b_{j,k}\, r_{j,k} \quad (4)$$

Assuming that the user *k* is allocated $\psi_k$ number of SBs

$$\sum_{i=1}^{N} \rho_{i,k} = \psi_k \quad (5)$$

The estimated data rate for user k is given by

$$R_k=\psi_k \sum_{j=1}^{J} b_{j,k}\ r_{j,k} \quad (6)$$

Here, $\psi_k$ depends on the resource allocation method. Here, proportional fair (PF) scheduling is selected as the resource allocation method. The PF scheduler uses a PF metric for each user. The PF metric for user k at t numbered TTI is computed by

$$PF_k(t)= \frac{R_k(t)}{\overline{R_k}(t)} \quad (7)$$

where $R_k(t)$ is the estimated data rate calculated for t numbered TTI using (6) but $\overline{R_k}(t)$ is calculated from the previous actual data rates. $\overline{R_k}(t)$ is given by

$$\overline{R_k}(t)=\left(1-\frac{1}{T_{PF}}\right)\overline{R_k}(t-1)+\frac{1}{T_{PF}}R_k(t-1) \quad (8)$$

where $T_{PF}$ is the window size of the average throughput.

There are a few different ways to determine $\psi_k$ using the PF metric. We suggest that the number of SBs, to be allocated to different users, increases proportionately with his PF metric, as indicated by

$$PF_1: PF_2:...: PF_k:...:PF_K= \psi_1:\psi_2.....\psi_k..:\psi_K \quad (9)$$

$\psi_k(t)$ can be computed as

$$\psi_k(t)=\left\lfloor\frac{PF_k(t)}{\sum_{k=1}^{K} PF_k(t)}\right\rfloor \quad (10)$$

Once the computed $\psi_k(t)$ is used as the number of SBs allocated to user k, his estimated data rate given by (6) can be close to his actual data rate and so, we ignore their differences. Thus, the average user throughput is given by

$$R_{Ave}=\frac{1}{K}\sum_{k=1}^{K} R_k = \frac{1}{K}\sum_{k=1}^{K} \psi_k \sum_{j=1}^{J} b_{j,k}\ r_{j,k} \quad (11)$$

The average user throughput for the macrocell and the small cell, denoted as $R_{Ave}^{m}$ and $R_{Ave}^{s}$, respectively, can be determined according to (11). The purpose of CRE is to balance the loads and we consider the achievement of the balance as making the average user throughput in the macrocell and in the small cell equal. Therefore, the CRE needs to be properly set with a view to minimizing δ, where δ can be expressed as

$$\delta= R_{Ave}^{m}-R_{Ave}^{s} \quad (12)$$

## 3. PROPOSED SCHEME

In this section, we propose a method for frequent updating of CSO, based on the formulation of Section 2. In the proposed scheme, CSO continuously adapts to the changes in both user distribution and radio link quality and this adaptation attempts to balance the load. For this purpose, based on PF scheduling, which incorporates radio link conditions, CSO is frequently adjusted to a value that attempts for the best possible balance in load between the macrocell and the small cell, i.e. attempts to minimize δ. We assume that the total number of currently active users in the macrocell and the small cell, $K_T$ has a fixed value. Representing the number of active users in the macrocell and in the small cell as $K_m$ and $K_s$, respectively,

$$K_T=K_m+K_s \quad (13)$$

The active users in the small cell are identified as $\mathbf{K_s}$ $=\{1,2,....,K_s\}$. So, the number of the active users in the macrocell is $K_T$-$K_s$. For the best possible balance in load, a proper value needs to be set for $K_s$, which can be determined as

$$K_s^{*}=\underset{K_s \in Z}{\arg\min}\ \delta \quad (14)$$

The UE is served by the cell from which the downlink received power, represented as reference signal received power (RSRP), becomes maximum. So, a UE is served by q cell, which meets the condition

$$\underset{q}{\arg\max}\ RSRP\left(P_q G_q^k\right)+CSO_q$$

where $P_q$ and $CSO_q$ are the transmit power and the CSO of q cell, respectively, and $G_q^k$ represents the channel gain of user k from q cell. Considering the channel gain dominantly affected by Rayleigh fading H, log-normal shadowing $X_\alpha$, and path losses $PL_k$, the channel gain of a user k can be shown as [16]

$$G_q^k=10^{(-PL_k+X_\alpha)/10}.|H_k|^2 \quad (15)$$

Path loss, $PL_k$ of small cells and macrocells can be calculated according to formulas shown in Table 1 [17]. Ignoring the impact of hysteresis margin, a user k is served by the small cell if it satisfies

$$RSRP\left(P_s G_s^k\right)+CSO_s > RSRP\left(P_m G_m^k\right)+CSO_m \quad (16)$$

Assuming $CSO_m$=0

$$CSO_s > RSRP\left(P_m G_m^k\right)-RSRP\left(P_s G_s^k\right) \Leftrightarrow k\in \mathbf{K_s} \quad (17)$$

A proper value of $CSO_s$ needs to be set using (17) such that $K_s = K_s^*$ where $K_s^*$ is given by (14). The joint optimization problem based on (14) and (17) is complex. It cannot be solved by first determining $K_s^*$ using (14) and then determining $CSO_s$ using (17). This is because $G_q^k$ is different for different users and there is no prior information on which users may switch from the macrocell to the small cell with a certain increase in $CSO_s$. Therefore, we suggest an iterative procedure to reach a solution for an optimum $CSO_s$. The network will find out the optimum CSO by varying CSO values iteratively until it converges and makes $K_s$ closest to $K_s^*$. Any suitable iterative root-finding method, for example, Newton's method, can be chosen to find out the optimum CSO. Both RSRP and CSO values are actually integers and so, a quick convergence can be expected. The use of the optimum CSO can allow $R_{Ave}^m$ and $R_{Ave}^s$ to take on the closest possible values. The optimum CSO values need to be determined and applied continuously at short regular intervals for proper adaptation with the changing conditions. The use of proportional fairness for resource scheduling makes the computation more practical and realistic.

In practice, multiple small cells can be overlaid with a macrocell. In this case, the above analysis may be considered separately between each of the small cells and the macrocell and then every small cell employs the proposed method on a stand-alone basis. However, the analysis will be more effective if it includes all the small cells under the macrocell jointly, albeit with a lot more computational load.

## 4. SIMULATION

The proposed method was simulated using parameter values shown in Table 1. The HetNet consists of a macrocell and a small cell and they have equal channel bandwidth. The users were assumed to be uniformly distributed within the HetNet. Rayleigh model was used to represent the fading environment. The PF metric was computed using equations (1)−(10). Then the average data rates in the macrocell and the small cell were computed using equation (11). The PF metric gradually decreases in a cell with the distance of users from the eNodeB and this is shown for macrocell in Fig. 1. The data rate of a user is affected by both path loss and PF metric depending on its distance from the eNodeB and this is also shown for macrocell in Fig. 2.

**TABLE I. SIMULATION ASSUMPTIONS**

| Parameter | Value |
|---|---|
| Transmit power of macrocell | 43 dBm |
| Transmit power of small cell | 30 dBm |
| Distance between eNBs of macrocell and small cell | 8 km |
| User speed (Pedestrian speed) | 10 km/hr or 2.78 m/sec |
| Macro path loss model | 128.1 + 37.6 $\log_{10}$ R (dB) [R in km] |
| Pico path loss model | 140.7 + 36.7 $\log_{10}$ R (dB) [R in km] |
| Fading environment | Rayleigh model |
| Channel bandwidth | 10 MHz |
| Carrier frequency | 2 GHz |
| No. of RBs | 100 |
| Total no. of users in the HetNet | 40 |
| User distribution | Random |
| Scheduling algorithm | Proportional fairness |

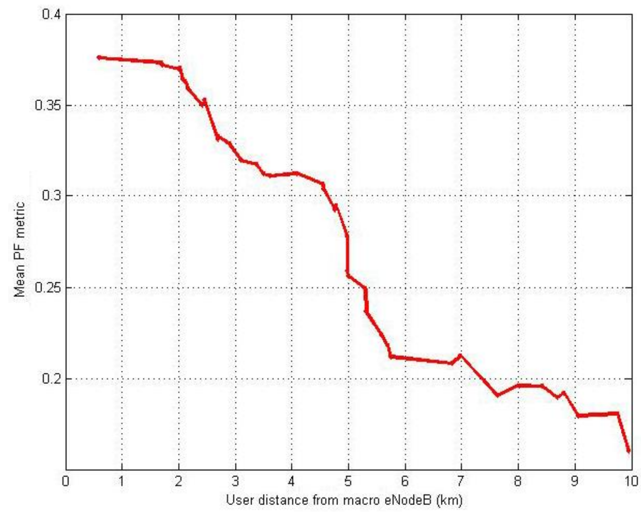


**Figure 1. Variation of mean PF metric with user distance from macro eNSodeB.**

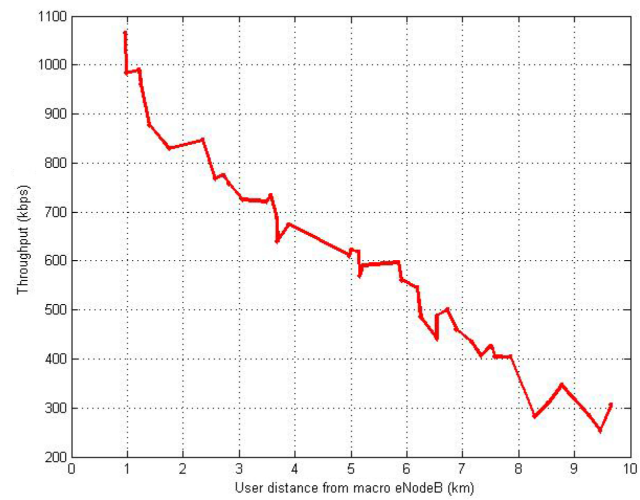


**Figure 2. Variation of throughput with user distance from macro eNodeB.**

The average data rates were computed iteratively for a wide range of CSO values. The CSO value that yielded the minimum difference between the average data rates of the macrocell and the small cell, was selected as the optimum one. For simplicity, no numerical methods were used here for quick convergence.

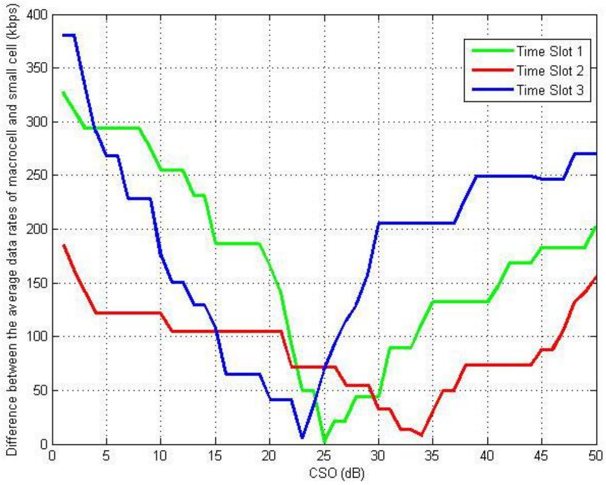


**Figure 3. Selection of optimum CSO values in three different time slots.**

Fig. 3 shows how the difference between the average data rates of the macrocell and the small cell varied with CSO values. The results are shown for three different time slots and the optimum CSO values were found to be 23 dB, 25 dB, and 34 dB. For these CSO values, the difference between the average data rates of the macrocell and the small cell drops to only 10 kbps or smaller. The optimum CSO distributes the number of users in the macrocell and the small cell according to (13), (14) and (17) and this distribution of users can be considered as the best possible balance. The differences in the three results stem from the randomness of user locations and the use of Rayleigh fading model. In the proposed scheme, the optimum CSO needs to be computed and applied at regular time intervals. The length of this time interval should depend on the scenario.

## 5. Conclusion

It is important to ensure that no cells in LTE HetNets get overcrowded. The CRE is a useful feature to offload macrocell and utilize the small cell properly. But the amount of virtual expansion in CRE should be continuously adapted using CSO values such that it maximizes the balance in load. Proportional fair (PF) resource scheduling is popular for practical networks as it provides pretty high cell throughput while maintaining fairness among users to some good extent. In this paper, the proposed scheme uses PF and formulates for optimum CSO values that can provide the best load balance between the macrocell and the small cell. The simulation uses the Rayleigh fading model and considers a simple HetNet with one small cell overlaid by a macrocell. Simulation results demonstrate that the difference between the average data rates of the macrocell and the small cell drops to negligibly small values for optimum CSO values and thus, a good balance in PF scheduling based loading is achieved.

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