Joint User Association and ABS for Energy-Efficient eICIC in Heterogeneous Cellular Network

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Abstract. In the work, we design a novel EE-eICIC algorithm to deal with determining the amount of almost blank subframes (ABS) and user should associate with pico or macro from energy efficiency perspective. Using a generalized fractional programming theory and the convex programming, we propose an iterative and relaxed-rounding algorithm to deal with the problem. Numerical experiments show that the proposed EE-eICIC method can obtain superior performance comparing with state-of-the-art algorithms in terms of energy efficiency of system.

Keywords: Energy efficiency (EE)
Enhanced inter-cell interference coordination (eICIC) · Load balancing
Heterogeneous cellular network (HetNet)

1 Introduction

The 3GPP standard has proposed the eICIC that macrocell make its downlink transmission silent in specific time frames, namely almost blank subframes (ABSs) [1]. The user associated with small cell can transmit at a higher data rate for ABSs due to much less interference.

The eICIC allocation is related with the user association, i.e., the allocation of ABS and user association rule decide the airtime resources and the allocated user to macro or pico. Most exsit works [2–4] have focused on different dynamic ABS configuration schemes for load balancing between macro cell and small cell with the dynamic variations of load. But these works almost pay more attention to improving the network throughput but neglect the energy efficiency (EE). And only ABS configuration cannot meet the need to reduce cross-tier interference significantly when the number of picocell is large [5]. The work [6] has point out that bias setting for per-tier is not efficient for EE on load balancing. It reveals that the user association for EE is quite different from that for load balancing investigated for system capacity on interference management.

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Interference management together with reducing energy consumption should be considered jointly in HetNets [7]. However, the association of UE is predetermined with SINR in the downlink between macro and pico. Therefore, we propose an energy-efficient joint UE association and ABS scheme for eICIC.

2 System Model

We consider the TDD system in two-tiers HetNets, where the subframe and ABS for eICIC are configured dynamically. For the purpose of signal to interference plus noise ratio (SINR) model, we distinguish downlink association into two categories: pico-associated and macro-associated. Table 1 gives the expression of variables.

Table 1. The expression of variables

Notation	Description
$P_{Rx}(u)$	The received power of user
$P_{BS}(u)$	The received interference from BS (pico or macro)
N_{sf}	The number of ABS-period
N_m	Non-ABS subframes used by pico
A_p	ABS subframes used by pico
x_u	Airtime in non-ABS subframes for user
$y_{u,A(nA)}$	Airtime in ABS (non-ABS) subframes for user
p_u^{BS}	The transmit power of BS (macro or pico)
p_{ref}^{macro}	The broadcast signals power for macro over ABS subframes

The SINR of user associated with pico is

$$SINR_{pico}(u) = \begin{cases} \frac{P_{Rx}(u)}{P_{pico}(u) + N_0} & \text{for ABS} \\ \frac{P_{Rx}(u)}{P_{pico}(u) + P_{macro}(u) + N_0} & \text{for non-ABS} \end{cases} \tag{1}$$

The SINR of user associated with macro is

$$SINR_{macro}(u) = \frac{P_{Rx}(u)}{P_{pico}(u) + P_{macro}(u) + N_0} \text{for non-ABS} \tag{2}$$

So, we obtain the date rate for user from Shannon capacity formulation.

3 Optimization Problem Formulation

Our objective is to maximize the EE of network and still satisfies the basic rate requirements of all the users. Naturally, we jointly optimize these variables

$\psi = \{R_u, P_u, x_u, y_{u,A}, y_{u,nA}, A_p, N_m\}$ to obtain the EE-eICIC algorithm by the following optimization problem (OP1). The problem variables are denoted in Table 1.

$$\max_{\psi} \frac{\sum_u R_u}{\sum_u P_u} \tag{3}$$

$$R_u \leq r_u^{macro} \cdot x_u + r_{u,A}^{pico} \cdot y_{u,A} + r_{u,nA}^{pico} \cdot y_{u,nA} \tag{4}$$

$$P_u \leq p_u^{macro} \cdot x_u + (p_u^{pico} + P_{ref}^{macro}) \cdot y_{u,A} + p_u^{pico} \cdot y_{u,nA} \tag{5}$$

$$x_u \cdot (y_{u,A} + y_{u,nA}) = 0 \tag{6}$$

$$A_p + N_m \leq N_{sf}, \forall p, m \in I_{BS} \tag{7}$$

$$\sum_{u \in U_m} x_u \leq N_m, \forall m \in M \tag{8}$$

$$\sum_{u \in U_p} y_{u,A} \leq A_p, \forall p \in P \tag{9}$$

$$\sum_{u \in U_p} y_{u,A} + y_{u,nA} \leq N_{sf}, \forall p \in P \tag{10}$$

$$x_u \geq 0, y_{u,A} \geq 0, y_{u,nA} \geq 0 \tag{11}$$

$$A_p, N_m \leq N^+, \forall p, m \in I_{BS} \tag{12}$$

where N^+ denotes the positive integers.

The (4) and (5) state the rate and power consumption for a user is limited the airtimes obtained from macro or pico. The (6) denotes association constraint, which user only associates with either macro or pico, but not both. The (7) ensures that the ABS subframes used by pico in I_{BS}, where I_{BS}, $BS \in \{macrocell, picocell\}$ denotes that the set of basestation interfered with each other. The (8) states that airtime used by user from macro is less than the total ABS N_m. The (9) states airtime allocated to the UE from a pico is less than the total available ABS subframes A_p. The (10) states airtime allocated to the UE from a pico is less than the period of ABS N_{sf}.

Since the OP1 is a mixed integer programming problem, the solution to OP1 is generally NP-hard [8]. We solve it in a suboptimal way. The structure of (3) is exploited to reformulate with generalized fractional programming [9]. The optimization problem (OP2) can be solved in Algorithm 1 for a given η (e.g., η_k at iteration k) is

$$\begin{array}{ll} \max_{\psi} & (R_u - \eta P_u) \\ \text{s.t.} & (4) - (12) \end{array} \tag{13}$$

But it is hard to solve (13) for a given η. Even with in a single pico and a single interfering macro, the OP2 problem is also NP-hard [1].

Algorithm 1. Iterative Algorithm for EE-eICIC

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Set the error tolerance $\varepsilon > 0$ and the maximum iteration number $K_{max}$
while Stop == 0 and $k \le K_{max}$ do
    Solve the problem OP2 for a given $\eta_{EE}^{k}$
    if $|\eta_{EE}^{k}| = |(R_u^k - \eta_{EE}^{k} P_u^k)| < \varepsilon$ then
        Stop = 1;
        return the optimal EE-eICIC configuration policy $\boldsymbol{\psi}^{opt}$ and maximal $\eta_{EE}^{opt}$
    else
        set $\eta_{EE} = \frac{R_u}{P_u}$ and $k = k + 1$, Stop = 0.
    end if
end while
```

4 Algorithm for Nonlinear Program

In the section, we introduce two stages algorithm in polynomial time to deal with the OP2. The description is as follows in detail.

4.1 Solution for the Relaxed Problem OP3

Firstly, we solve the relaxed problem OP3 from OP2. The OP3 is computed by ignoring the constraints (6) and relaxing the (12) on N_m and A_p into positive real numbers. The OP3 can be denoted as:

$$\begin{aligned} &\max\nolimits_{\boldsymbol{\psi}} \quad R_u - \eta P_u \\ &\text{s.t.} \quad (4) - (5)\ and\,(7) - (11) \\ &\qquad\quad A_p, N_m \in R^{+}, \forall p, m \in I_{BS} \end{aligned} \tag{14}$$

where R^{+} denotes the positive real numbers. The relaxed OP3 is a convex programming, so we introduce the CVX tools [10] to solve the OP3, which is defined as Algorithm 2. Algorithm 2: CVX with (14).

4.2 Interger Rounding the Result of Algorithm 2

To get the feasible solution of N_m and A_p for OP2, we adopt the rounding method:

$$Rnd(x) = \begin{cases} floor(x) & x < \frac{N_{sf}}{2} \\ ceil(x) & x \ge \frac{N_{sf}}{2} \end{cases} \tag{15}$$

where floor is round down and ceil is round up. The rounding and EE-association scheme are shown in Algorithm 3.

5 Numerical Results

For the purpose of this study, Tx power of macros and pico are set to 36 dBm and 30 dBm, and the broadcast signals power from macro in ABS is set to 23 dBm.

Algorithm 3. The rounding and association Algorithm

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1: EE-ABS Rounding: To make $N_m^*$ and $A_p^*$ integer values. $N_m^* = Rnd(N_m^{'})$ and $A_p^* = Rnd(A_p^{'})$ ,where $N_m^{'}$ and $A_p^{'}$ are results of Algorithm 2.
2: UE EE-Association for Downlink:
       $R_u^{macro} = r_u^{macro} \cdot \widetilde{x}_u, P_u^{macro} = p_u^{macro} \cdot \widetilde{x}_u$    (16)
       $R_u^{pico} = r_{u,A}^{pico} \cdot \widetilde{y}_{u,A} + r_{u,nA}^{pico} \cdot \widetilde{y}_{u,nA}, P_u^{pico} = (p_u^{pico} + P_{ref}^{macro}) \cdot \widetilde{y}_{u,A} + p_u^{pico} \cdot \widetilde{y}_{u,nA}$    (17)
   where $\widetilde{x}_u$, $\widetilde{y}_{u,A}$, $\widetilde{y}_{u,nA}$ is output of Algorithm 2. Computing $\eta_u^{pico} = \frac{R_u^{pico}}{P_u^{pico}}$, $\eta_u^{macro} = \frac{R_u^{macro}}{P_u^{macro}}$. If $\eta_u^{macro} > \eta_u^{pico}$, user can connect with macro, or with pico.
3: Energy-Efficient Computation:
   For each user, calculate the time scale of frame
       $\widehat{x}_u = \frac{\widetilde{x}_u \cdot N_m^*}{X_m}, \widehat{y}_{u,A} = \frac{\widetilde{y}_{u,A} \cdot A_p^*}{Y_{p,A}}, \widehat{y}_{u,nA} = \frac{\widetilde{y}_{u,nA} \cdot (N_{sf} - A_p^*)}{Y_{p,nA}}$    (18)
   Finally, the rate and power consumption of user are computed in macrocell or picocell. For $u \in U_m^*$, $R_u{}^* = r_u^{macro} \cdot \widehat{x}_u, P_u^* = p_u^{macro} \cdot \widehat{x}_u$. For $u \in U_p^*$, $R_u{}^* = r_{u,A}^{pico} \cdot \widehat{y}_{u,A} + r_{u,nA}^{pico} \cdot \widehat{y}_{u,nA}, P_u^* = (p_u^{pico} + P_{ref}^{macro}) \cdot \widehat{y}_{u,A} + p_u^{pico} \cdot \widehat{y}_{u,nA}$. So the EE of user: $\eta_u^* = \frac{R_u^*}{P_u^*}$.
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For comparison, three methods we use are as follows: (1) Max sum rate with eICIC (MaxSUMRate) [11], (2) Max log rate with eICIC (MaxSUMlogRate) [1], (3) Proposed method Max EE with eICIC (MaxEE).

In Fig. 1, we plot the convergence evolution of the overall convergence rate of EE-eICIC Algorithm under the system of one macrocell, two picocells and thirty users. It is observed that it converges typically in ten steps.

Figure 2 shows the effect of the number of users on energy efficiency of system, with the number of macro is 1 and the number pico is 2. In Fig. 3, it is shown that MaxEE achieves significant energy efficiency gain over MaxSUMlogRate and MaxSUMRate. The proposed scheme MaxEE is improve the energy efficiency gain average by 21.4% and 43.6%, compared to MaxSUMRate and

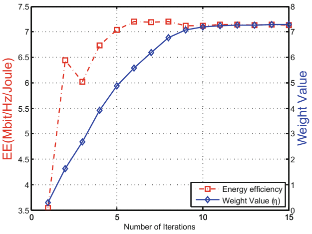

Fig. 1. Convergence of EE-eICIC algorithm

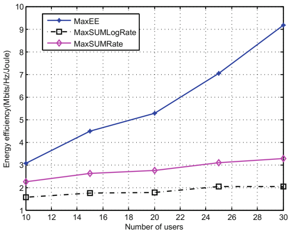

Fig. 2. Energy efficiency vs. users

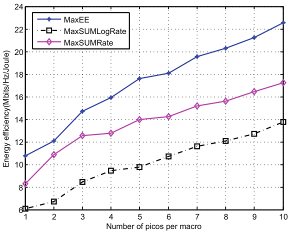

Fig. 3. Energy efficiency vs. picos

MaxSUMlogRate respectively. We can see that the eICIC need to be design from energy efficiency perspective.

In Fig. 3, we can see that the proposed MaxEE obtains the best EE performance, which has the EE gain by about 23.44% and 64.71% over the MaxSUMRate and MaxSUMlogRate on average. Moreover, the EE gain increases with the number of picos, which mean that the small cell is energy efficiency for HetNets.

6 Conclusion

In the work, we have formulated a novel framework for EE-eICIC in HetNet. To deal with this mixed-integer fractional programming problem, an iterative algorithm is proposed firstly by using fractional programming theory. And then we solve the problem through simplifying the UEs association and ABS allocation in a two-step relaxed-round algorithm to reduce the computational complexity. Our numerical results show that the energy efficiency of joint UEs association and ABS allocation can obtain a significant gain on energy efficiency of system.

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