Capacity Improvement via Phantom Cells

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Abstract— **Vastly increasing capacity and coverage demand in communication networks accompanied by energy efficiency challenge is getting attraction in research topics. Phantom cells based heterogeneous networks (HetNets) is a new idea which proposed to fulfil these requirements in the next generation cellular networks. In this paper, the resource allocation problem in an orthogonal frequency-division multiple access (OFDMA) based Macrocell/Phantom cell heterogeneous network is investigated in downlink path. Specifically, a proper algorithm is presented in order to maximize the total throughput of all phantom cell users' equipments with regard to the protected minimum network capacity of the existing macrocell. To fulfil the objective goal, an iterative approach is employed in which OFDM subchannels and power transmitted by base stations are sequentially assigned and optimized at each step for each frequency band. It is showed that the overall joint subchannel and power allocation algorithm converges to local maximum of the original designed problem. Performance improvement of proposed algorithm is confirmed by numerical results.**

Keywords- Carrier Aggregation, Phantom cells, , Optimization Heterogeneous Networks, Resource Allocation, Green communication.

I. INTRODUCTION

With the appearance of new popular wireless devices such as tablets, smart phones and others, there is a significant growth in wireless traffic demand [1]. Clearly the existing wireless cellular structures will not able to support the expected data rate and quality in future.

Long Term Evolution-Advanced (LTE-A) is one of the best standards introduced by 3GPP to meet the huge traffic demand in future [2]. Currently, the researchers working on various aspects of LTE-A such as Massive MIMO, Carrier Aggregation and Heterogeneous Networks to enhance the capacity [3-5].

Based on small cell point of view, Heterogeneous Network (HetNet) is a large number of femtocells distributed alongside a Macro cell by allowing frequency reuse with the Macro cell user's equipments (MUE). By deploying femtocells, much higher spectral efficiency can be achieved within a specific geographical area [6-7]. Moreover, since femto base stations are low power, capacity increasing reached in the green communication fashion.

However, due to using the same bands by MUEs and femto cell user equipments (FUEs), FUEs cause some interference to MUEs transmission. A lot of works have been done on the context of optimum resource allocation in HetNet in order to maximize the total capacity with respect to the co-channel interference between FUEs and MUEs [8-10]. Nevertheless, it seems by operating one frequency band the transmission rates goal could not be reached.

Therefore, in the current study we use additional aspect of LTE-A, i.e. carrier aggregation, to the HetNet in order to increase the total throughput. According to carrier aggregation, various component carriers belong to different bands can be aggregated together so as to increase the transceivers bandwidth and as a result improve the data rate [11]. Small cells in carrier aggregated heterogeneous networks are known as phantom cells in literature [12].

In this paper we investigated scheduling and resource allocation procedures in OFDMA based HetNets in downlink path. It is supposed that MUEs supported by the main carrier frequency and phantom cell users (PUEs) can use additional frequency in order to get the maximum capacity. Accordingly, at the first step, the problem is formulated as an optimization problem for frequency F1. The objective function maximized the total throughput of all PUEs with regard to protected minimum rate of a macrocell in each carrier, independently. By exploring the problem a proper algorithm has been suggested for resource allocation in this step. At the second stage another optimization problem has been formulated for frequency F2 in order to maximize the PUEs' capacity. A suitable method is suggested for the second stage and the entire resource allocation procedure has been evaluated by simulation.

As simulation results verify, our suggested scenario enhanced the total capacity significantly. Moreover, it will be shown that a target rate can be reached expeditiously, with less power consumption which make it suitable from green communication point of view.

The remainder of this paper is organized as follows. In Section II, system model and its related formulation is discussed. In Section III, a proper algorithm for resource allocation is presented. Performance evaluation of the proposed algorithm is verified by numerical experiments in Section IV and finally, Section V concludes the paper.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A two tier network in downlink path, where a macrocell overlaid with M phantom cells is assumed. The macrocell is a conventional cell which supports its user with frequency F1 based on OFDMA structure. Phantom cells are supplied with individual base stations which can be operate in two frequency band (F1 and F2) with lower power and consequently small footprint (Fig.1). In frequency F1 the phantom cells are allowed to use the same subcarriers with macrocell by considering the co-channel interference constraint.

Let us denote the total number of subcarriers in the shared frequency band (F1) with N_1 and the number of subcarriers which used by phantom cells in frequency F2 with N_2. All cell base stations' are shown by set $A = \{0,\ 1, 2, \dots, M\}$ where index 0 is related to the macro cell and the others are phantom cells' index. Suppose that each cell has different number of users which are indicated by K_m where $m \in A$. The capacity of k-th user on the i-th sub-carrier can be obtained by

$$r_{m,k}^{i} = ln\left(1 + \frac{h_{m,k}^{i}\, p_{m,k}^{i}}{\sum_{j \in M \setminus \{m\}} h_{j,k}^{i}\, p_{j,k}^{i} + N_0}\right) \qquad (1)$$

Where $h_{m,k}^{i}$ is the channel gain between the mth transmitter and kth user's receiver on the ith sub-carrier. $p_{m,k}^{i}$ denotes the kth user's transmit power of mth cell on the ith sub-carrier and N_0 is the additive white Gaussian noise variance.

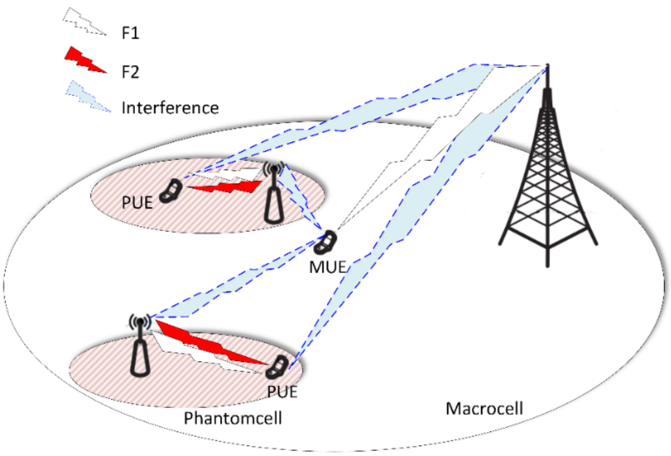

Figure 1. Exemplary HetNet deployment, which solid lines and dashed lines represent communication links and co-channel interference, respectively. Also phantomcells interfere each other UEs.

As mentioned before in order to get the proper resource allocation we should explore and formulate the problem for each carrier frequency individually. At the first step sub-carrier and power allocation should been done in such a way that the total capacity of phantom cells maximized while the macro cell users achieved their minimum required rates. To do so, we should solve the following optimization problem on frequency F1.

$$\begin{aligned}
&maximize && \sum_{m=1}^{M} \sum_{k=1}^{K_m} \sum_{i=1}^{N_1} \alpha_{m,k}^{i} \cdot r_{m,k}^{i} \\
&subject\ to && \sum_{k=1}^{K_0} \sum_{i=1}^{N_1} \alpha_{0,k}^{i} \cdot r_{0,k}^{i} \geq R_{\ min} \\
& && \sum_{k=1}^{K_m} \alpha_{m,k}^{i} \leq 1 \quad \forall\, m, i \\
& && and \quad \alpha_{m,k}^{i} \in \{0,1\} \qquad \mathbf{P1} \\
& && \sum_{i=1}^{N_1} P_m^{i} \leq P_m^{TH} \quad \forall\, m \in A \\
& && 0 \leq P_m^{i} \leq P_m^{i,MAX} \quad \forall\, m, i
\end{aligned}$$

In the above equation the second constraint is related to OFDMA nature of the supposed structure which indicates that each sub-carrier assigned to only one user in each cell. The next two constraints are related to the base stations' total power and spectral mask, respectively.

After finding a proper algorithm for resource allocation based on the equation **P1**, at the second step we should solve the following optimization problem for frequency F2. Note that after resource allocation based on **P1**, the macro cell users get their minimum required rates and since there is not any interference between F1 and F2, problem **P2** formulated to maximize only PUEs' rates.

$$\begin{aligned}
&maximize && \sum_{m=1}^{M} \sum_{k=1}^{K_m} \sum_{i=1}^{N_2} \alpha_{m,k}^{i} \cdot r_{m,k}^{i} \\
&subject\ to && \sum_{k=1}^{K_m} \alpha_{m,k}^{i} \leq 1 \quad \forall\, m, i \\
& && and \quad \alpha_{m,k}^{i}\{0,1\} \qquad \mathbf{P2} \\
& && \sum_{i=1}^{N_1} P_m^{i} \leq P_m^{TH} \quad m \in \{1,2, \dots, M\} \\
& && 0 \leq P_m^{i} \leq P_m^{i,MAX} \quad \forall\, m, i
\end{aligned}$$

Noticeably, the above problem is same as the problem **P1** except the first constraint which was related to the protected minimum capacity of the macrocell network.

III. EXTRACTING PROPER ALGORITHM

The problem **P1** is a mixed integer nonlinear problem which is not feasible in general. However, by some realistic assumptions and changes, an appropriate algorithm can be extracted to solve it. To this end, we first assume that there is not any phantom cell and determine feasibility of the problem by allocating optimal resource to macro cell.

Clearly, if the maximum achievable throughput by the macro cell is less than R_{min}, the problem is infeasible and it has not any solution.

Let us assume that the MUEs can achieve their minimum rate requirement and the problem is feasible. It has been shown that ignoring the phantom cells, maximum throughput of the macro cell can be achieved via the following procedure:

- Optimal sub-carrier assignment for MUEs done as:

$$k_i^* = argmax\ h_{0,k}^i \qquad k \in \{1,2,\dots,K_0\}\ and\ i \in N_1 \tag{2}$$

- By user assignment according to the above equation, the optimal power of each sub-carrier can be computed by the cap limited Water-filling algorithm as:

$$p_0^{(i)*} = \left[\frac{1}{\Psi} - \frac{N_0}{h_{0,k^*}^i}\right]_0^{P_0^{i,MAX}} \tag{3}$$

In which,

$$[x]_0^\beta = \begin{cases} \beta & if \quad x \geq \beta \\ x & if \quad 0 < x < \beta \\ 0 & if \quad x \leq 0 \end{cases} \tag{4}$$

And Ψ is Lagrangian multiplier with the value:

$$\Psi = \sum_{i=1}^{N_1} p_0^{(i)*} = P_0^{TH} \tag{5}$$

After MUEs resource allocation according to the above method, if the computed total throughput is equal to the $R_{\ min}$ then there is not additional capacity for phantom cells and the problem's solution is finished. Otherwise, if $R^* > R_{\ min}$ then we should find an algorithm for phantom cell users in order to use the remaining capacity in the best manner.

To do this, we use fmincon interior point algorithm in MATLAB to find the best user and power assignment among all phantom cells, simultaneously [14].

As mentioned before, the problem **P2** is similar to **P1** in general except to one constraint. Consequently, in order to solve it, ignoring the first part of the above method which is related to the macrocell, we can solve it by using fmincon algorithm directly. Different steps of the proposed resource allocation procedures are summarized in algorithm 1 and 2 to tackle **P1** and **P2**, respectively.

Note that, since these algorithms are used to determine the scheduling procedure in two different frequency, therefore, they can be computed simultaneously. Also it is important to note that by using these algorithms, even there was not any resource for the phantom cell users in frequency F1, we sure that they can gain some throughput related to the F2 usage.

Algorithm 1 procedure for solving **P1**

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    - Compute Macrocell subcarriers' power assignment ($p_0^{(i)*}$), according to the equations
      (2) and (3) without regard to Phantom cells interference.

IF $\sum_{k=1}^{K_0}\sum_{i=1}^{N_1} \alpha_{0,k}^i . r_{0,k}^i < R_{\ min}$
    the problem has not any solution

Else IF $\sum_{k=1}^{K_0}\sum_{i=1}^{N_1} \alpha_{0,k}^i . r_{0,k}^i = R_{\ min}$

  The best solution is

  $p_0^{(i)*} = \left[\frac{1}{\Psi} - \frac{N_0}{h_{0,k^*}^i}\right]_0^{P_0^{i,MAX}}$      $for\ \ i \in N_1$

  $P_m^i = 0$      $for \quad m \in \{1,2,\dots.,M\}$
Else
repeat to satisfy problem conditions

    - Sort PUEs experiencing best channels and assign subchannels $\alpha_{m,k}^i$ in each cell
      separately. $m \in \{1,2,\dots.,M\}$

    - Allocate optimal power $P_m^i$ for selected PUEs by an interior-point method.

until convergence of $P_m^i$
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Algorithm 2 procedure for solving **P2**

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repeat to satisfy problem conditions
    - Sort UEs experiencing best channels and assign subchannels $\alpha_{m,k}^i$ in each cell
      separately. $m \in \{1,2,\dots.,M\}$

    - Allocate optimal power $P_m^i$ for selected UEs by an interior-point method.

until convergence of $P_m^i$ and
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IV. NUMERICAL EXPERIMENTS RESULTS

Consider OFDMA downlink of a mixed architecture Macrocell/Phantomcell network deployment where four phantomcells placed uniformly around a circle with radii equal to 50m and a macrocell which its BS is located at the center of circle. Numerical results are obtained from an 80 averaging Monte Carlo simulation. The network scenario in our numerical examples is shown in Fig. 2.

Macrocell has a radii of 500m and Phantomcells have a radii of 50m. K_m=10 MUEs and K_P = 5 PUEs are located in each cell with uniform distribution in angle and Gaussian distribution in distance. OFDMA downlink consists of $N_1 = N_2 = 8$ subchannels for frequency F_1 and F_2 with bandwidth of 180KHz. Macrocell BS has p_0 = 47dBm and each phantomcell BS has p_m = 23dBm, $m \in A\{0\}$ total power and $P^{MAX} = P^{TH}/N$. AWGN spectral power density is -174dBm/Hz. Channel model is $h^i_{m,k} = \chi . d^{-\beta}_{m,k}$ where χ has Rayleigh distribution and $\beta = 3$ is path loss exponent.

In figure 3 we compare power convergence of macrocell for two R_{min} as well as phantomcell's power convergence in F1. In addition, power consumption of phantomcell in F2 is demonstrated in this figure. It can be seen that macrocell and phantomcell's consumed power settle after few tens of iterations. Phantomcell power consumption at R_{min} = 15bps/Hz in F1 is higher than the one in F2. Explanation is that phantomcell in F1 has to consume more power in the presence of macrocell interfence than in the situation where there is no such interference, that is to say F2.

In figure 4 we show throughput convergence of macrocell. In figure 5 throughput convergence of phantomcell in F1 for R_{min} = 45bps/Hz and F2 is presented. Figures 3, 4 and 5 show that power and throughput convergence is fast enough to make this algorithm a suitable candidate for a resource allocation strategy in a real network implementation.

Figure 6 concludes the trade-off between macrocell R_{min} and average phantomcell throughput per user. Phantomcell throughput is reduced by increasing macrocell R_{min} due to need of more power in macrocell, consequently more interference for phantomcell. Notice that phantom cell higher throughput in F2 is obtained by lower power consumption compared to F1 (Figure 6). The total aggregated throughput makes it clear that this macrocell/phantomcell deployment is benefical and an aproach to comeover the capacity demand in wireless comunications.

V. CONCLUSIONS

In this paper, we studied an efficient algorithm in terms of green communications to carry out the resource allocation problem of downlink path of a two-tier heterogeneous network. Optimization objective is to maximize phantomcell throughput by means of carrier aggregation method while overlooking co-channel interference to protect macrocell minimum required throughput. By extracting the proper algorithm for system model and formulated problem, the goal is fulfilled. The effectiveness of proposed algorithm which is shown by numerical experiments, makes our research a competitive algorithm for implementing in a practical cellular communication scenario.

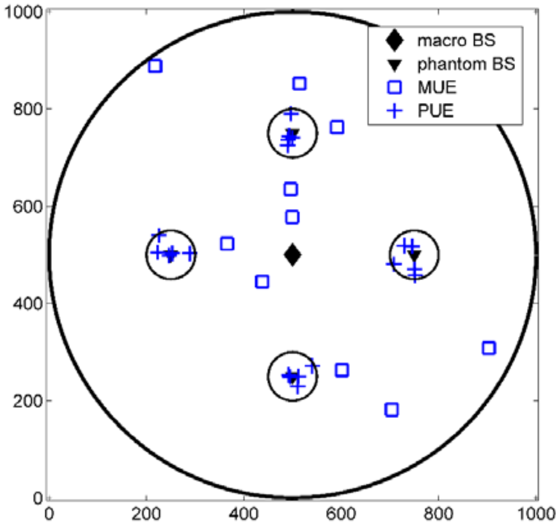

Figure 2. Numerical example of user placement in the network geometry model

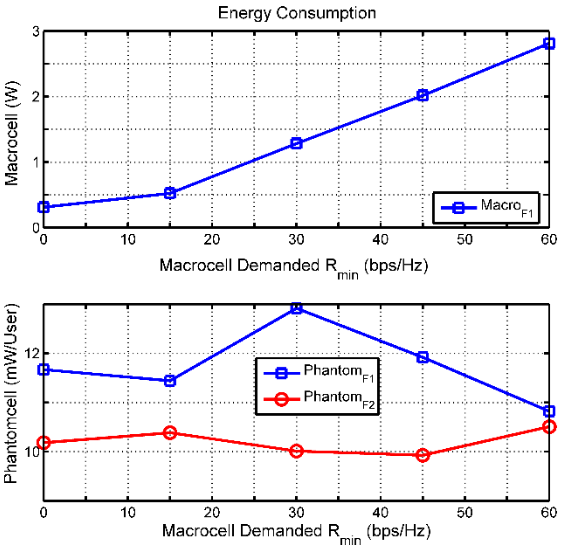

Figure 3. Convergence of power consumption in macrocell and phantomcell for F1 and F2; Solid lines demonstrate power consumption of phantomcell and dashed lines are for macrocell.

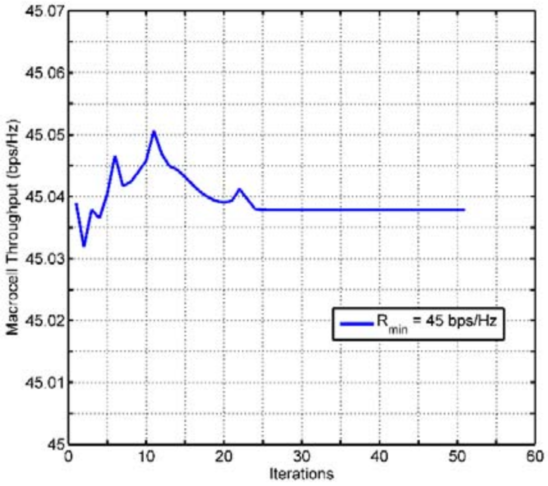

Figure 4. Convergence of throughput in macrocell for R_{min}=45bps/Hz

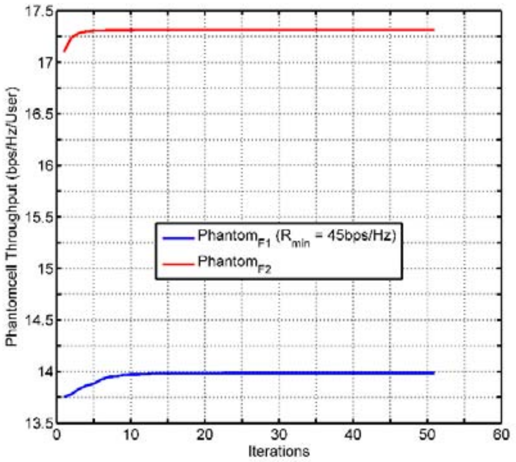

Figure 5. Convergence of throughput in phantomcell for F1 (R_{min}=45bps/Hz) and F2.

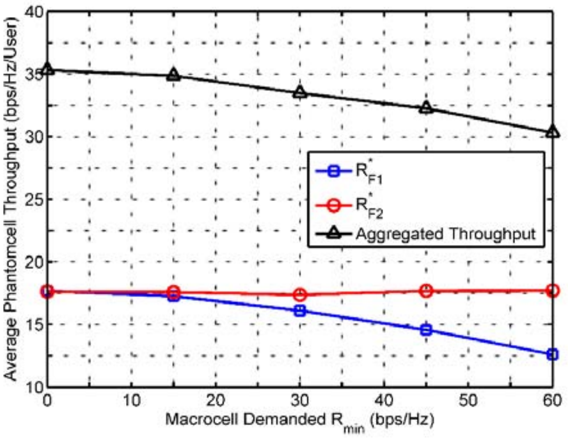

Figure 6. Achieved balance between average phantomcell throughput and macrocell demanded R_{min}

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