Cooperation Based Energy Efficiency Optimization Using Game Theory Framework for Heterogeneous Networks

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***Abstract*—Wireless communications knows a real progress that continues relentless as subscribers consume new products and services using mobile devices having more and more powerful feature sets and performance. Consequently we have both a growth in electromagnetic radiation which can be harmful for human health, and mobiles battery consumption that have to be increasingly greater with such performances. In this paper[1] we propose a new power optimization scheme that aims to reduce the transmit power while guarantying a good capacity for the system, based on a cooperation protocol algorithm and using a game theory based resource allocation scheme.**

Keywords— energy efficiency; green communications; cooperative networks; heterogeneous wireless networks.

I. INTRODUCTION

During the last, decade we have experienced an explosive increase in the use of mobile devices. Technology advances and consumer's demands have transformed mobile terminals, from simple voice call terminals to rich multimedia applications platforms providing various services including: internet access, video teleconferencing, GPS localization, high quality audio and video. This increased complexity of the mobile terminals has two key impacts, first, the growth in electromagnetic radiation, second, the battery lifetime for mobile devices.

In recent years, there has been increasing public concern about the health implication of Electromagnetic (EM) wave exposures due to the mobile phone. Many researches have been done to give a complete picture of health risks that are caused by the use of mobile phones. Also, various public organizations in the world have established safety guidelines like a limit of absorption rate (SAR) of mobile that is stated by International Commission on Non-Ionization Radiation Protection (ICNIRP) [1].

Also the limited battery lifetime has always been bottleneck when it comes to the development of improved portable electronic products. In addition, constraints in the size and weight of mobile phones prohibit the use of heavy and large battery packs as power sources.

Therefore, minimizing the power consumption of wireless platforms becomes a great challenge, for the entire Information and Communication technologies (ICTs), at all system levels.

To deal with these two problems listed above, several researches have been launched. In [2] many examples were proposed using cognitive radio to reduce electromagnetic radiation.

As one of the methods reducing energy consumption in a mobile device, it has been shown in [3] that in an heterogeneous environment 2G and 3G, switching the network in dependency of the service used by the device can improve energy efficiency.

In [4] a protocol "TailEnder" was developed, based on measurement-study of the relative energy consumption characteristics in 3G GSM and WIFI, it minimizes energy usage while meeting delay-tolerance deadlines specified by users.

Another way to make the cellular networks more power efficient is by decreasing the propagation distance between nodes, hence reducing the transmission power. Therefore, cellular network deployment solutions based on smaller cells such as micro, pico and femtocells are very promising in this context. [5].

In this paper, we propose to associate cooperation protocol based on channel gain diversity and game theory power allocation schemes, to achieve a better performance in term of capacity and power consumption in a heterogeneous network.

This paper will be organized as follows, in section II, the system model is presented. In section III we describe our proposed solution, in section IV we compare our cooperative approach with the non-cooperative one by numerical results, and section V concludes this paper.

II. SYSTEM MODEL

We consider the uplink in a heterogeneous network composed of two cells, each cell contains a number N users randomly distributed in a circle of radius R in a two dimensional plane $(Fig.1)$. The first base station (BS) has the coordinate$(0, 0)$and the second one has the coordinate $(x_{BS}, 0)$.

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The key idea of this work is to take advantage of the channel gain diversity in the cooperative system, we will compare the channel gains of all users to the two existent BSs, and then attach each user to the cell with which it has the higher channel gain. We showed in a previous work [6] that using our cooperative approach we can minimize the transmit power without degrading the sum capacity of the system.

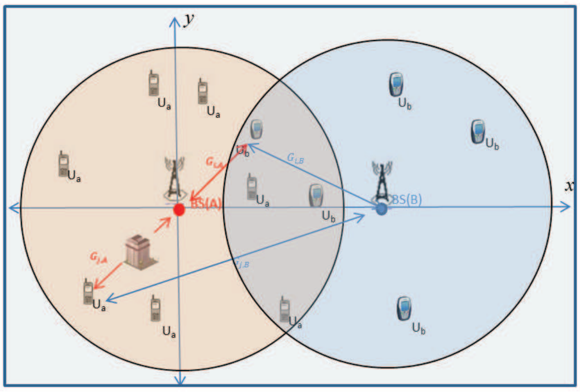

Fig. 1. two collocated cells operating in a heterogeneous environment.

In this work, we propose to add a game theory based resource allocation to our cooperative approach in order to improve the performance in terms of power consumption and capacity.

The channel gains used in this scenario are based on COST-231 Hata model [7] including log-normal shadowing with standard deviation of 10dB, plus fast-fading assumed to be i.i.d (independent and identically distributed) circularly symmetric with distribution $\mathcal{CN}(0,1)$.

The basic path loss for the COST-231 Hata model (in dB) in an urban area at a distance d is defined as :

$$\begin{aligned} PL &= 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_b) \\ &-A_M + (44.9 - 6.55\log_{10}(h_b)\log_{10}(d) + C_M \end{aligned} \tag{1}$$

Where f_c is the carrier frequency and h_b is the base station (BS) antenna height.

C_M is 0 for medium sized cities and suburban and is equal to 3dB for metropolitan areas.

A_M is defined as :

$$A_M = 3.20(log_{10}(11.75h_m))^2 - 4.97 \tag{2}$$

where h_m is the mobile antenna height. The shadowing variations of the path loss can be calculated from the log-normal distribution:

$$g\left(\frac{x}{\sigma}\right) = \frac{1}{\sigma\sqrt{2\pi}} exp(\frac{-x^2}{2\sigma^2}) \tag{3}$$

Where σ is the standard deviation.

III. Proposed Solution

In this section, we propose a utility function that meets the objective to maximize the per-user capacity, while mitigating the interference between all users. Specifically, we define a payoff function that represents the SINR constraint, and a price function that specifies the interference constraint. The utility function is defined as:

utility function = payoff function + price function.

To guarantee a minimum level of interference between users, we will consider in each cell separately, an iterative algorithm that at each iteration consider one user as victim and allocate the powers to the other transmitters in such a way that the interference level is minimized to the victim user. In the next step, another user from the list of the users attached to the cell of interest, is considered, and the same algorithm is used. At the end of the iterations and after considering all users, the final power allocation will be the minimum among all values found during the iterative process.

The expression of the victim user instantaneous capacity is given by:

$$C_k = \log_2(1 + \text{SINR}_k) \tag{4}$$

with

$$\text{SINR}_k = \frac{P_{k,A}|h_{k,A}|^2}{\sum\limits_{\substack{m=1 \\ m\neq k}}^{L} P_{m,A}|h_{m,A}|^2 + \sigma^2} \tag{5}$$

where:

- A: is the BS of cell A.
- $P_{k,A}$: is the transmit power from the victim user to BS A.
- $h_{k,A}$: is the channel gain between the victim user and BS A.
- $P_{m,A}$: is the transmit power from the m^{th} user to the BS A.
- $h_{m,A}$: is the channel gain between the m^{th} user and the BS A.
- σ^2: is the thermic noise.
- L: is the number of users in cell A after cooperation.

The expression of the instantaneous capacity of the mth interfering user to the victim user is given by :

$$C_{m,k} = \log_2(1 + \text{SINR}_{m,k}) \quad k \neq m \tag{6}$$

where

$$\text{SINR}_{m,k} = \frac{P_{m,A}|h_{m,A}|^2}{\sum\limits_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2 + P_{k,A}|h_{k,A}|^2 + \sigma^2} \quad k \neq m \tag{7}$$

All users need to recognize their communication environment and adapt the parameters of their communication scheme in order to maximize the per-user capacity.

We assume that the coherence time is sufficiently large so that the channel stays constant over each scheduling period length. We also assume that users know the channel state information (CSI) of their own links, but have no information on the channel conditions of other users.
The interference power experienced to the m^{th} user is given by :

$$\text{Intf}_{m,k} = \sum_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2 + P_{k,A}|h_{k,A}|^2 + \sigma^2 \tag{8}$$

Combining (7) and (8), we define the $\text{SINR}_{m,k}$ as a function of $\text{Intf}_{m,k}$:

$$\text{SINR}_{m,k} = \frac{P_{m,A}|h_{m,A}|^2}{\text{Intf}_{m,k}} \tag{9}$$

and

$$P_{m,A} = \frac{\text{SINR}_{m,k}\text{Intf}_{m,k}}{|h_{m,A}|^2} \tag{10}$$

The protection for user k is guaranteed if the sum of all transmitters powers is not larger than the interference constraint P_{T_k}. The interference constraint is given by:

$$\sum_{m=1}^{L-1} P_{m,A}|h_{m,A}|^2 \leq P_{T_k} \tag{11}$$

In other words, the outage probability of the victim user capacity needs to be below the fixed threshold $P_{out_{max}}$ [8].
In the proposed framework, the outage probability can be expressed as [9]:

$$P_{out_k} \equiv Prob\{C_k \leq R_k\} \leq P_{out_{max}},\ \forall\ k = 1, ..., L \tag{12}$$

where R_k is the transmitted data rate by user k and $P_{out_{max}}$ is the maximum outage probability defined as quality of service for each user. The information about the outage failure can be fed back from the user k to the other transmitters through collaboration and exchange of the CSI.

IV. POWER ALLOCATION ALGORITHM

In this section we define the parameters of the utility function specified above. The payoff function is expressed as the capacity for each user, given by the equation (6).

The price function represents the interference constraint as a function of the outage probability constraint defined for each victim user k.
The margin of $P_{T_k} - \sum_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2$ is the maximum interference level that user m can generate to user k (11).

If we divide $P_{m,A}|h_{m,A}|^2$ by $P_{T_k} - \sum_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2$, we will find the interference level expression to be guaranteed for each user k:

$$\text{L}_{\text{Intf}m,k} = \frac{P_{m,A}|h_{m,A}|^2}{P_{T_k} - \sum\limits_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2} \tag{13}$$

which is a normalized value. As long as this ratio $\in [0, 1]$, the protection for each user is met. We compute now P_{T_k} as a function of the outage probability.

To proceed further with the analysis and for the sake of emphasis, we introduce the average channel gain estimate G based on the following decomposition

$$h_{k,A} \equiv G_k * h'_{k,k} \tag{14}$$

where $h'_{k,k}$ is the random component of channel gain and represents the *normalized* channel impulse response tap.

Following the equations derived in the case of the protection of a primary user in a cognitive radio context detailed in [10], the corresponding interference constraint for each user k is:

$$P_{T_k} = \frac{P_{k,A}G_k^2}{1-2^{R_k}} \ln\left(1 - P_{out_k}\right) \tag{15}$$

The utility function will be expressed as following:

$$U_{m,k} = C_{m,k} - \left(\frac{P_{m,A}|h_{m,A}|^2}{P_{T_k} - \sum\limits_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2} \right)^{a_m} \tag{16}$$

The parameter a_m is adjustable to have a comparable values, i.e. the payoff function value and the price function value. We choose $a_m \leq 0$. It could be easily obtained that the price function decreases as the ratio $L_{Intf_{m,k}}$ increases. This fact is caused by the negative property of a_m.
To maximize the utility function we derive $U_{m,k}$ with respect to the $SINR_{m,k}$ which is equivalent to the transmitted power [10]. We replace the capacity by expression given by (6) and use (10) to obtain the following equation:

$$\begin{aligned} U_{m,k} \;=\; & \log_2\left(1 + \text{SINR}_{m,k}\right) - \left(\frac{|h_{m,A}|^2}{P_{T_k} - \sum\limits_{\substack{l=1 \\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2} \right)^{a_m} \\ & \times \left(\frac{\text{SINR}_{m,k}\text{Intf}_{m,k}}{|h_{m,A}|^2} \right)^{a_m} \end{aligned} \tag{17}$$

$$\frac{\partial\, U_{m,k}}{\partial\ \text{SINR}_{m,k}} = \frac{1}{(1+\text{SINR}_{m,k})\ln 2} - \left(\frac{|h_{m,A}|^2}{P_{T_k} - \sum\limits_{\substack{l=1\\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2}\right)^{a_m}$$

$$\times\, a_m \left(\frac{\text{SINR}_{m,k}\text{Intf}_{m,k}}{|h_{m,A}|^2}\right)^{a_m-1} \frac{\text{Intf}_{m,k}}{|h_{m,A}|^2} \qquad (18)$$

We can express the solution of (18) as:

$$(1+\text{SINR}_{m,k})\,\text{SINR}_{m,k}^{a_m-1} = \frac{1}{a_m\beta_m \ln 2} \qquad (19)$$

Where:

$$\beta_m = \left(\frac{|h_{m,A}|^2}{P_{T_k} - \sum\limits_{\substack{l=1\\ l\neq m}}^{L-1} P_{l,A}|h_{l,A}|^2}\right)^{a_m} \left(\frac{\text{Intf}_{m,k}}{|h_{m,A}|^2}\right)^{a_m} \qquad (20)$$

finally we obtain:

$$\text{SINR}_{m,k} = f^{-1}\left(\frac{1}{a_m\beta_m \ln 2}\right) \qquad (21)$$

Where:

$$f(\text{SINR}_{m,k}) = (1+\text{SINR}_{m,k})\,\text{SINR}_{m,k}^{a_m-1}$$

Replacing $SINR_{m,k}$ in (10) we find the transmitted power $P_{m,A}$. The same power allocation is used to define the transmitted power for users in cell B.

The existence and uniqueness of the NASH equilibrium for the proposed game are confirmed in [10].

V. COMPARISON AND SIMULATION RESULTS

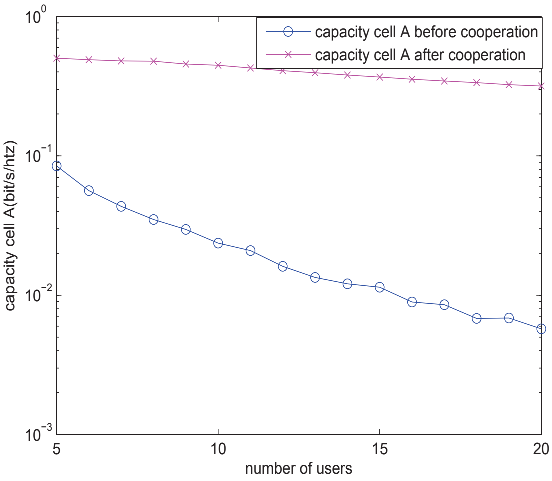

Fig. 2. Capacity Cell A

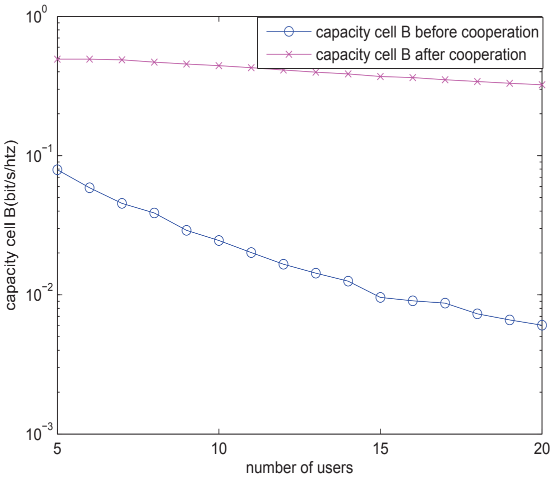

Fig. 3. Capacity Cell B

For the validation of the theoretical ideas presented above, we resort to realistic network simulations with two cells of a radius $R = 100m$ and a level of overlap $x = \frac{R}{4}$ between the cells. Channel gains are based on the COST-231 pathloss model as mentioned before. The transmit power and the capacity are evaluated by Monte Carlo simulations with $1e^4$ iterations.

Figures (2) and (3) respectively represent the capacity of cell A and B, the curves show that after our cooperative approach and power allocation scheme the capacity of each cell greatly increases. Figures (4) and (5) show that the mean transmit power per user in each cell is significantly lower.

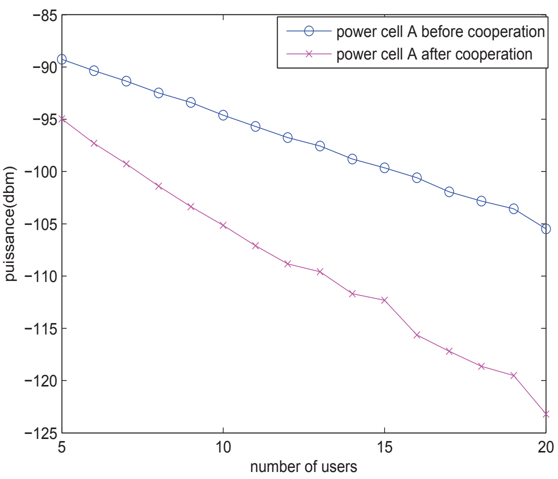

Fig. 4. Power Cell A

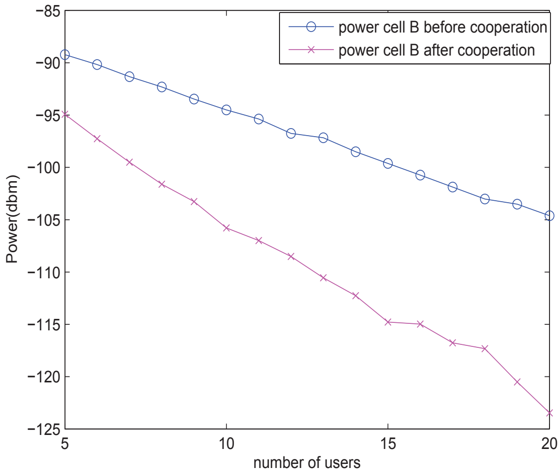

Fig. 5. Power Cell B

VI. CONCLUSION

In this paper we investigated the benefit of improving energy efficiency for heterogeneous cellular networks. We proposed a new cooperative scheme associated to a game theory based power allocation scheme in order to minimize the transmit power at the mobile terminal side the one hand and enhance the capacity of the system the other hand.

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