Energy Savings in Power Control for 5G Dense Femtocells

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Abstract. The dramatic increase in traffic observed in the recent years in mobile networks is not expected to slow down. Increasing the number of deployed base stations of different range and capabilities creating ultra dense networks is one of the solutions that will be adapted in order to cover the demand. Energy efficiency schemes are needed in order to keep the energy impact of such an approach limited. In this paper we focus on densely deployed femtocells (clusters) evaluating the power savings resulted from a power controlled sleep mode mechanism. The mechanism tries to reduce the number of operating closed access femtocells, by providing performance incentives to the clusters subscribers to coordinate reducing energy consumption without compromising their throughput. Simulations investigate the different levels of power savings depending on the chosen configuration and the deployment density.

1 Introduction

Femtocells are low range base stations that will play a major part in the upcoming fifth generation of mobile networks. They combine flexibility covering local demands without the need for large macrocell deployments and the low cost in their deployment and maintenance. Since they are mostly intended for private ownership and usage, the cost is removed from the network operator to the owners increasing their appeal. This also entails the large number deployed since it can lead to a femtocell per household in the future. This is not unrealistic in urban scenarios considering the expected number of access point in the future [8].

It is easy to see the downsides of such scenarios. The large number of private owned base stations of uncoordinated deployment, closely located with antagonistic utilization of resources may lead to severe interference. Their large number also reveals the increased energy consumption. Both interference mitigation and energy consumption have been appointed as major challenges in the upcoming networks. When the number of femtocells is small, their low range and low consumption compared to macrocells make these issues seem insignificant. However in the scale of the expected dense deployment, these issues become prevalent.

L. Barolli et al. (eds.), *Advances on Broad-Band Wireless Computing, Communication and Applications*, Lecture Notes on Data Engineering and Communications Technologies 12,
https://doi.org/10.1007/978-3-319-69811-3_27

One way to address both these challenges is to adopt different operating modes for femtocells. Two main alternative modes towards this goal are sleep and hybrid access mode. Both these modes have been examined and adjusted for utilization at the femtocell layer, trying to respect the layer's specific characteristics, such as private ownership and the lack of central control.

In [7] the authors propose energy-efficient algorithms that lead small cell base stations to sleep mode in a bid to reduce cellular networks power consumption. Three different strategies for algorithm control are discussed, relying on small cell driven, core network driven, and user equipment driven approaches each leading to different energy savings. The authors in [2] also compare different sleep mode mechanisms in dense small cell networks to conclude that sleep mode can lead to significant energy efficiency especially with the careful selection of the base stations.

A cluster-based approach is incorporated in [13] to improve the energy efficiency of small cell networks. Specifically, the clusters use an opportunistic base station sleep-wake switching mechanism to strike a balance between delay and energy consumption with gains that reach 40% in energy consumption and 23% in load. The work in [12] on the other hand, utilizes sleep mode strategy but focuses on mitigating interference for macrocell users. The evaluation showed that the strategy achieved better performance along with significant power savings.

There is significant work on the topic of hybrid access, too. In [6], a power control algorithm is proposed that can provide Quality of Service (QoS) support in minimum signal-to-interference-plus-noise ratios (SINRs) for all users while exploiting differentiated channel conditions. The algorithm uses non-cooperative game theory and applies it to a hybrid access scheme through a distributed load-award association for macro users, which enables flexible user association to BSs of either tier. The authors in [9] propose a mechanism in resource partitioning that takes into account the pre-experienced SINR value of the non-CSG users, to determine the upper and lower bound of spectrum regions that may be allocated to these users.

In contrast with the above, we adopt a power control mechanism that incorporates both modes. Specifically, we extend our work in [1] and evaluate the energy savings of our proposed scheme. Specifically, the scheme tries to reduce the number of operating femtocells, by turning some of them in power mode, when it estimates that their users' need can be met by the operation of neighbouring femtocells who willingly turn to hybrid access mode. Therefore, a negotiation takes place between neighbouring femtocells, where the mitigation of interference due to the deactivation of a number of femtocells in a cluster becomes an incentive for performance gains to their neighbors making them willing to accept the unregistered users of these slept femtocells. Our proposed mechanism has been examined regarding the capacity gains in [1]. In this paper we investigate which are the power savings that result from the deactivation (power mode) of a large number of femtocells. We simulate the application of the mechanism for several femtocell deployment densities and we show that it has some substantial benefits in energy consumption.

The rest of the paper is structured as follows. The next section describes the interference and power model that we considered when evaluating the interference and energy characteristics in femtocells different operating modes. Section 3 provides an in depth description of the proposed mechanism. Section 4 is an extensive look of the simulating results where the mechanism is evaluated. Finally, we draw our conclusions and suggest our next steps in Sect. 5.

2 System Model

In this section we describe the sleep mode model we used to evaluate the energy savings for each slept femtocell. We also describe a well interference model we used in order to estimate the capacity restrictions described in Sect. 3.

2.1 Power Savings Model

In order to evaluate the energy savings each time a femtocell partially deactivates we utilize the sleep mode model described in [4,7]. According to this approach, when deemed necessary, the femtocell deactivates parts that are not utilized such as parts of the microprocessor and field programmable gate array (FPGA) associated memory, the radio frequency (RF) transmitter and receiver, and the power amplifier. Depending whether the responsibility of waking up the femtocell comes from the femtocell itself or the from the network, there are differences in some additional operating parts. In the former case, a sniffer part is required to maintain operation in sleep mode in order to identify signals that could designate the need to restore the full functionality of the femtocell. This signals could be large rises in the received power in the uplink, which could represent connections between nearby users and the macro Base Station. In the latter case (network controlled waking), this feature is not necessary since the network centrally has a good knowledge of itself and decides if a specific femtocell should be awake based on the network needs and topology.

Each approach has its advantages and disadvantages. The first is fully distributed and does not require any central coordination. On the downside it requires more parts to remain active, the capability for the user to connect to a macro Bs and the subsequent handover. We utilized Table 1 to evaluate the energy savings for this case, which yields to:

$$P_{savings} = P_{micro} + P_{FPGA} + P_{receiver} + P_{transmitter} + P_{amplifier} - P_{sniffer} = 4.2W \tag{1}$$

The above reduction corresponds to a reduction of 40% in the femtocells consumption. The second approach is able to deactivate more parts such as the operations responsible for the backhaul connectivity while it does not require any sniffing hardware since these functions are controlled by the central network. In this case the savings can reach 70%. The downside of this approach is the involvement of network resources to coordinate the needs centrally, such as through the mobility management entity (MME) in Long Term Evolution (LTE), that can check for a nearby femtocell that the user has access to connect.

Table 1. Femtocell components consumption

Hardware component	Energy consumption (Watts)
Microprocessor-associated memory	1.7 (0.5^a)
FPGA-associated memory	2.0 (0.5^a)
Other circuitry	2.0
RF transmitter	1.0^a
RF receiver	0.5^a
RF power amplifier	2.0^a

[a] Parts that are switched off during sleep mode.

In this paper we utilize both these scenarios to evaluate our mechanism regarding possible energy savings. We also take into account the variation in the femtocells' power transmission. That is, we consider the increase in power levels that our algorithm occasionally determines, and deduct it from the energy savings.

2.2 Interference Model

In the proposed mechanism that we describe in the next section, we allow sleep and hybrid access mode in femtocells given that the subscribers' data rates are guaranteed and that interference mitigation benefits coming from the sleep mode outweighs the reduction of the base stations. In order to evaluate this, we use a well-known interference model to measure the effect between users and nearby BS. We evaluate the Signal-to-interference-plus-noise ratio (SINR) of a user u on each sub-carrier k, served by either macrocell or a femtocell, is given by:

$$SINR_{u,k} = \frac{P_{B,k}G_{u,B,k}}{N_0\Delta f + \sum\limits_{B'} P_{B',k}G_{u,B',k}} \tag{2}$$

where $P_{B,k}$ is the transmit power of user's serving base station B on sub-carrier k, and $G_{u,B,k}$ is the channel gain between user u and its serving cell B on sub-carrier k. Similarly, $P_{B',k}$ and $G_{u,B',k}$ denote respectively the power of every other interfering base station (either femtocell or macrocell) and the gain between them and the user u. N_0 is the white noise power spectral density, and Δf the sub-carrier spacing.

From the SINR we then calculate the capacity of the user u on that subcarrier k by [5]:

$$C_{u,k} = \Delta f \times log_2(1 + \alpha SINR_{u,k}) \tag{3}$$

where α is defined by $\alpha = -1.5/ln(5BER)$. Based on the spectrum allocation and the subcarriers utilized by the user, we evaluate the overall throughput of serving base station by [11]:

$$T_B = \sum_u \sum_k \beta_{u,k} C_{u,k} \tag{4}$$

where, $\beta_{u,k}$ notifies the sub-carrier assignment for the users. When $\beta_{u,k} = 1$, the sub-carrier k is assigned to user u. Otherwise, $\beta_{u,k} = 0$.

Before our proposed power control takes over, we calculate the pilot power considering the macrocell effect on the effective range of the femtocell. Therefore, we adopt the pilot power in [3] that ensures a constant radius of coverage.

3 Proposed Power Control

While the utilization of femtocells is definitely beneficial, we briefly discussed some challenges in the introduction. Specifically, the interference that results from multiple base stations without any deployment planning. This problem intensifies in the femtocell tier, considering that in contrast with the macro tier, the base stations do not cooperate and its base station's subscribers are entitled to the resources of only one BS. The subscribers ownership business model that femtocells usually adopt, increases their number, since they depend on the number of separate households and not on the data rate demands of these households' users.

We propose a coordination scheme where the femtocells cooperate in order to reduce the number of active BSs through the redistribution of their users. Given the need of incentives for the femtocells' owners to adopt it, we provide capacity gains and energy savings, through sleep mode and hybrid access.

Specifically, when a cluster of femtocells is formed (i.e. multiple femtocells in a small area), the mechanism tries to identify for femtocells that can be turn to sleep mode without affecting negatively any of the cluster femtocells' subscribers. One novelty of our mechanism is that it may choose to deactivate a femtocells even if their subscribers have active connections with the femtocell. The mechanism searches for neighboring femto BS and reallocates the users to them (up to one user per neighboring femtocell).

The above requires two requirements in order to overcome the reluctance of the femtocells' owner to adopt either sleep mode and reallocation, or hybrid access mode where they share their resources with non-subscribers. For both cases, we guarantee the data rate of the subscribers. With the now deactivated femtocell, however, the same number of users must achieve the same data rates with less available resources. For that reason, we utilize power control. First, for the users that are allocated to a neighboring femtocell, we estimate if any power control is needed. On one hand they might need to share the resources, however their new femtocell has one less source of interference, that is the neighboring recently deactivated femtocell. This makes the algorithm a simple reallocation algorithm that exploits the unplanned, hence often bad deployment of the femtocells. If however, this is not the case, an increase in power levels might be needed from the femtocell that now serves an extra user. To compensate for the subscribers of the slept femtocell, according to the model in Sect. 2, this required increase is:

$$P_{Inc} \geq \frac{R \times \left(\Delta f + \sum\limits_{B'} P_{B'} G_{u,B'}\right) - P_{Old} \times G_{u,N}}{G_{u,N}} \ . \qquad (5)$$

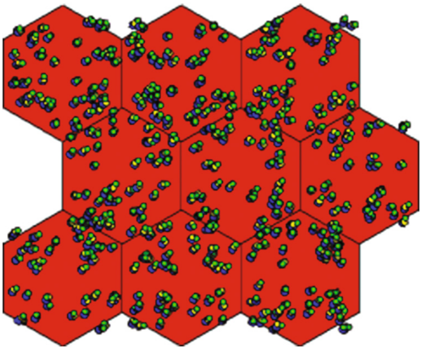

Fig. 1. An instance of the network

where $\Delta f + \sum\limits_{B'} P_{B'} G_{u,B'}$ denotes the interference in the user when connected to the new femtocell, $G_{u,N}$ his/her gain relative to the base station the user might migrate, P_{Old} the power of that station and R is:

$$R = \frac{(1 + aSINR_{Old})^{(N_2+1)/N_1} - 1}{a} \ . \tag{6}$$

where $SINR_{Old}$ is the SINR that the user would experience if served by the original femtocell. $N2$ is the number of users served by the neighbour and $N1$ is the number of users served by the origin femtocell. Power increment is also subject to a maximum allowed power transmission of the femtocell.

For the users of the femtocell that adopts hybrid access to accommodate the subscriber of the slept femtocell, the required increase is:

$$P_{Inc} \geq \frac{R \times \left(\Delta f + \sum\limits_{B'} P_{B'} G_{u,B'}\right) - P_{Old} \times G_{u,N}}{G_{u,N}} \ . \tag{7}$$

where $\Delta f + \sum\limits_{B'} P_{B'} G_{u,B'}$ denotes the interference of the subscriber, $G_{u,N}$ his/her gain as before, P_{Old} the power of the femtocell and R this time:

$$R = \frac{(1 + aSINR_{Old})^{(N_2+1)/N_2} - 1}{a} \ . \tag{8}$$

We want every subscriber of the femtocell to at least maintain their data rate, whether they participate in the above reallocation or not. Therefore, if we identify the power levels (and they are feasible) from above, we check their impact to the rest of the femtocells' subscribers. Usually the interference mitigation from the deactivation of the slept femtocell surpasses the impact from any increase in power levels. If that is the case, the mechanism enforces turns the femtocell off and enforces any new power levels.

4 Performance Evaluation

In this section we present the simulator variables and show the evaluation results.

4.1 Simulation Variables

In our simulations, we considered a network of 9 macrocells with the base station located at the center of each cell and transmitting at 46 dBm. The cells' radius was 250 m. In this area we randomly deployed multiple femtocells and their subscribers. Each femtocell could have up to three transmitting subscribers at the same time. Macrocell users were also randomly deployed. Parameters values have been based on 3GPP directives from LTE-A and the LTE simulator in [10]. Results depicting cumulative distribution function (CDF) show the average obtained by 20 repeated simulations. An instance of the simulation topology is shown in Fig. 1.

4.2 Simulation Results

Figure 2 shows the significant increase in the number of deactivated femtocells in our mechanism. For comparison reasons we present the cases when the redistribution of users required power boost for the femtocells and the case where the redistribution relied simple to a better reallocation of users without any power control allowed.

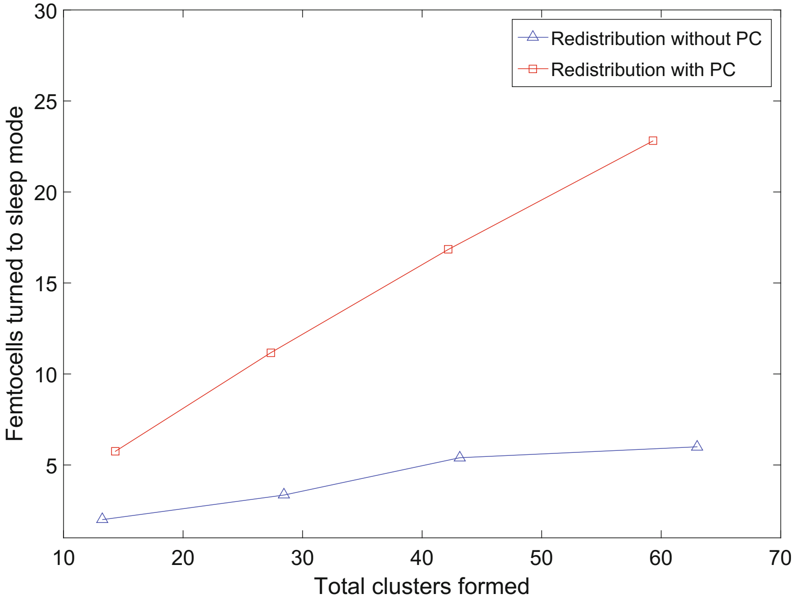

Fig. 2. Number of femtocells turned to sleep mode vs deployment density

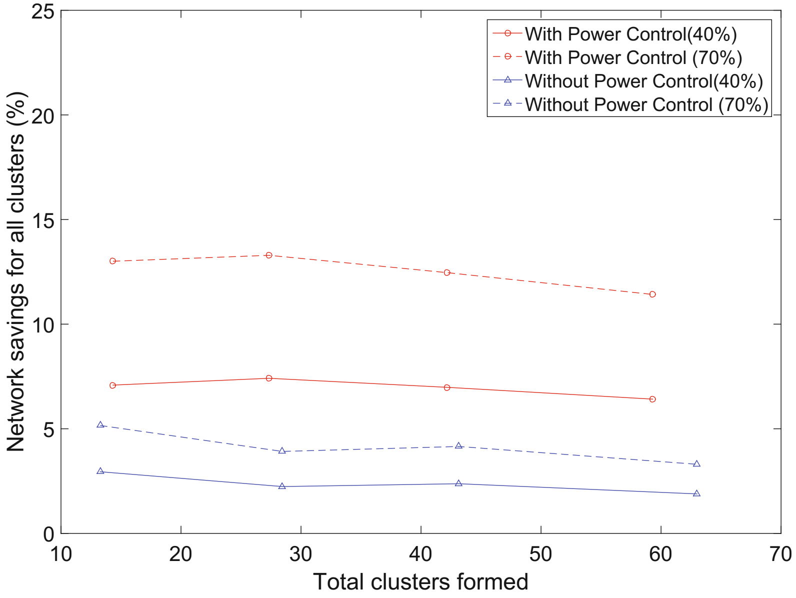

Fig. 3. Energy savings (%) for all femtocells belonging in clusters

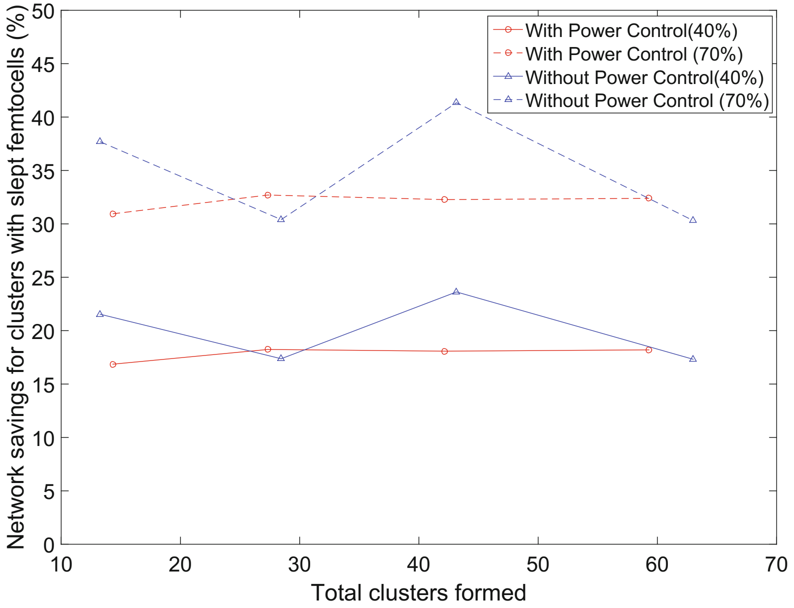

Fig. 4. Energy savings (%) for femtocells belonging in clusters that contain at least one slept femtocell

Figure 3 presents how the previous figure translates to energy savings. The number of femtocells that get deactivated are significant, and so are the resulting energy savings. We present those as a percentage, which means they depict the reduction in consumption. As we expected the power control allows femtocells to utilize their resources much better, causing many of them to be redundant and switch off, leading to an average of 7% in energy reduction for the femtocell controlled sleep mode model presented in Sect. 2. For the network controlled model, the reduction reaches 12%, a significant number considering that we measure the consumption of the entire femtocell tier with femtocells in clusters.

Finally, we normalize the results in Fig. 4, presenting the energy per cluster. The simulation shows that power control increases the chance a cluster to contain one slept femtocell and does not increase the number of slept femtocells in a cluster if that already contains it. Therefore, we can see in the figure that the reduction in energy consumption is quite similar in cases with and without the power control. In both cases, however, and in both types of controlled sleep mode, we consider the savings significant.

5 Conclusions and Future Work

In this work we tried to evaluate possible energy savings as a result of our proposed mechanism. The mechanism utilizes sleep and hybrid access modes and along with power control, covers the demands in data rates reducing the number of operating femtocells. The result of the mechanism is increased energy savings without any negative effect in the network's capacity or the individual data rates of the femtocells' subscribers.

The mechanism achieves a better utilization of resources and shows the margin of improvement that can be reached when we utilize distributed coordination among the otherwise ad-hoc femtocells networks. It also depicts how performance improvement can be a critical incentive when the vendor goals must involve private owned infrastructure and resources. On the downside, signaling and calculation capacity requirements increase.

Future possible extensions can be the combination of the performance incentive with pricing incentives from the vendor. This will increase the tolerance of the owners to either accept sleep mode and/or hybrid mode for their property, lowering the strict performance restrictions. This may lead to an increased number of slept femtocells and as a result increase energy efficiency.

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