Distributed Sleep Mode Power Control in 5G Ultra Dense Networks

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Abstract. The upcoming 5G networks are characterized by ultra dense deployments of small cells. These structures are capable of providing the much desired increase in capacity and data rates. The limited resources though present challenges on how they will be shared among the high number of base stations. Distributed coordination will play a big part in resource allocation. In this paper, we present a power control mechanism for dense femtocell deployments which utilizes sleep mode strategies and spectrum sharing among users. The mechanism exhibits increased throughput for the femtocell subscribers, preserving non-subscribers performance and increasing the network's energy efficiency.

Keywords: Femtocells · Sleep mode · Power control

1 Introduction

There is a consensus that in order to reach the massive targets of next generation mobile networks, a tremendous amount of base stations will be required. Some have even estimated that at some point the access points will surpass the number of users [1]. However, this massive deployment can be problematic in terms of interference and power consumption especially for the macrocells and small cells which usually compete for the available resources, they often adopt restrictive access policies and in contrast with the M2M communications, they have a high power consumption. Thankfully, this is recognized by the community which therefore has made crucial the issue of interference mitigation for better performance and the reduction of energy consumption of new mobile networks both for cutting costs for the operators and ecological sustainability [2].

A combination of the above goals can be seen in base stations' sleep mode. Sleep mode is a major part of energy reduction in the macrocell tier. This is when the macrocell base stations decide to turn into a low power node when traffic demand does not justify their operation (i.e. at night) and can be met

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by the adjacent macro base stations. Due to the massive penetration of small cells, it is evident that these techniques will have to address the small cell tier too. While micro or pico cells are easy to handle, since for the majority they are deployed and controlled by the operator who can determine their operation in a centralized way, femtocells are not.

Due to their ad-hoc deployment and the exclusive access permissions, the macro cell strategies are not that easily transferable in the femto tier. For example, one cannot centrally determine that a private owned femtocell must be deactivated, both because such action is considered invasive and because traffic cannot be easily passed to adjacent femtocells due to the Closed Subscriber Access policy of most femtocells. However, this can be facilitated if we find a way to combine the sleep mode of one femtocell with the interference mitigation for the users of another one.

Sleep mode of femtocells is an active research field. In [3] 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 [4] 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 [5] 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 [6] 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.

In this paper, we extend the mechanism that we introduced in [7] that aims to reduce the number of active femtocells in the area without compromising their subscribers performance. The novelty of the mechanism is that it strives for deactivating a base station even when its subscribers are active by combining sleep mode and hybrid access operation in femtocell clusters and enforcing a restriction policy that guarantees performance gains. In our initial approach we were based only in spectrum sharing waiting for the restrictions to be met. This led to a very small number of cases that met the requirements which resulted in a small number of deactivated femtocells.

Instead in this paper, we introduce power control in order to increase that number by investigating what the power level of the femtocells should be in order to meet the performance restrictions. If such level exists and it is feasible, subscribers of the femtocell that turns to sleep mode are handed over to the neighbour femtocells. On the other hand, subscribers of the femtocell accepts willingly the non-subscriber users since the increased power level of their base station and the reduced interference due to inactivation of the nearby femtocell should cause a boost to their performance. We also expand the mechanism requirement set in order to protect femtocell users that belong to the same cluster but do not participate in the user exchange. Ultimately, the addition of power control leads to fewer concurrently active base stations leading to increased capacity gains for the subscribers and increased energy efficiency.

The structure of the rest of the paper is as follows: The next section presents the model of interference between the base stations in the femto and macro tier and we describe how sleep mode works in femtocells. The third section provides a detailed analysis of our proposed mechanism. In the fourth section, the evaluation of our proposal is taking place, providing extensive results obtained through simulations. Finally, the last section summarizes our conclusions and draws future research steps.

2 System Model

For the evaluation of our method we focus on users' performance gains regarding the impact in data rate for femtocell subscribers and macrocell users. Below we describe the model we used as basis for the formation and evaluation of our proposed scheme presented in the following section and the details of the sleep mode operations.

2.1 Pilot Power

In order to evaluate the performance repercussions of our setup to users data rate, we utilize Long Term Evolution Advanced (LTE-A) architecture, and its Orthogonal frequency-division multiple access (OFDMA) technology. OFDMA is characterized by flexible allocation of available spectrum resources to users, allowing complex spectrum allocation strategies. Since dense small cell deployments will mostly back up the demands of dense populated area, we follow the LTE-A directives for urban environments for the calculation of necessary parameters, such as path loss and gain [8].

For the power levels of each femtocell, we take into account the position of the femtocell inside the macrocell. Since we examine most co-channel transmission between the macro and femto tier, the effective range of the femtocells would be totally different between a femtocell near the edge and near the center of the macrocell due to interference. Thus, we adjust femtocells' power levels towards a constant radius of coverage [9], by taking into account the power received from the closest macrocell at a target femtocell radius r. A maximum power level $Pmax$ is also set:

$$P_f = min\left(P_m + G_\theta - PL_m(d) + PL_f(r), Pmax\right). \tag{1}$$

with $PL_f(r)$ denoting the line of sight path loss at the target cell radius r, P_m the transmit power of the closest macrocell and G_θ the antenna gain. $PL_m(d)$ is the average macrocell path loss at the femtocell distance d (excluding any additional wall losses).

2.2 Sleep Mode

The sleep mode model considered in this paper is based in [3,10]. During this mode, most components of the femtocell switch off, thus contributing to the power savings, apart from the ones needed for connection with the back-haul network and the ones required for sensing when a nearby subscribed user is transmitting in order to set the femtocell to full operational mode when needed. Sensing is done with an additional component-"sniffer" that is able to sense rises in received power on the uplink frequency band. Such rise would indicate a connection established between a user and the macrocell. Setting a threshold on the sensed rise accordingly to reflect the desired coverage radius of the femtocell, the sniffer wakes up the femtocell if the threshold is surpassed and the user is allowed to access it through a handover procedure.

This approach allows multiple components of the femtocell to be switched off such as the radio frequency (RF) transmitter and receiver leading to a reduction in power consumption close to 40%. Drawbacks of this approach include the requirement of a handover from macrocell to femtocell and that it is limited by the fact that underlying macrocell infrastructure must be present. However, this limitation falls within the scope of our paper since we explore dense urban scenarios. Also, the additional signaling due to sleep mode integration and handover requirement is more than compensated by the reduction of femtocell functionalities in sleep mode, resulting in the reduction of overall signalling compared to the same scenarios if femtocells would always operate in full mode [10].

2.3 Throughput Calculation

When the power of the femtocells has been determined (either the pilot or the proposed) we derive the Signal-to-interference-plus-noise ratio (SINR) of each user. The SINR of a user u on each sub-carrier k, served by either macrocell or a femtocell, is given by:

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

where $P_{B,k}$ is the transmit power of user's serving base station B on subcarrier 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 [11]:

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

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 [12]:

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

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, $\beta_{u,k} = 0$.

3 Proposed Scheme

The ad hoc nature of femtocells deployments is a critical factor that depending on the circumstances may lead to a success or a failure. On the one hand, the flexibility they provide and the targeting of very specific local needs is very helpful. On the other hand, the lack of central coordination for their placement may lead to severe problems. The deployment of macrocell layer base stations is carefully planned regarding the location and the spectral usage, in order to gain the maximum of their utilization and avoid large interference issues. If no such planning took place, and base stations happened to be in very close distance and using same frequencies, the interference would be catastrophic and handovers would quite frequently occur.

Unfortunately, in femtocell layer this could be a usual scenario for the upcoming ultra dense networks. The situation gets worse, if we also consider that private owned femtocells operate mostly in closed access mode, making the handover option to other femtocells impossible. The accumulative interference of multiple nearby femtocells for an apartment residents in a building would easily lead to the acquirement of a femtocell by that household, too. It is easy to conclude that with every deployment of a femtocell in a building, the need of the neighbors for their own femtocell increases, thus eventually, every apartment in that building will have a femtocell.

This however represents a disparity, because the number of femtocell base stations will not reflect the actual needs in data rates, capacity or connections but solely the exclusivity of usage between separate apartments. This situation causes mainly three problems. Firstly, the subscribers of a femtocell will suffer by the accumulative interference of all the other nearby femtocells. Secondly, any individual not belonging to any of the femtocells access list, would also suffer tremendously. Thirdly, the energy consumption of the practically redundant base stations should be avoided.

We address the above by proposing a scheme that combines two operating modes of the femtocell: The hybrid access mode and the sleep mode. Sleep mode as explained in Sect. 2, is a mode used in base stations where most but not all of their functionalities have been turned off. On one hand this provides energy efficiency when full operation is not required, and on the other hand the transition to full operating state is rapid. A waking signal is usually used in order for the femtocell to return to full operation, either from the user, from the network or from the femtocell itself [3,4] with every approach resulting in different advantages and disadvantages in energy efficiency and in functional requirements. In sleep mode we consider zero interference towards non-subscribed users and no serving of subscribed ones.

Hybrid access mode is an operation state for a femtocell where it adapts an intermediate policy regarding which users it will admit. While closed access restricts access to users enlisted to its Closed Subscriber Group (CSG) of the femtocell, and open access allows everyone in its range, hybrid access presents a golden mean. While it preserves its main portion of resources for its CSG users, it may allow external users in their range as well, usually under custom policy restrictions. The main problem for the adoption of hybrid or open access is that owners of private femtocells are justifiably reluctant to offer their resources to external users. Hybrid access admission policies usually tackle this problem through pricing schemes where the owners are compensated for their resources' provision. The same is true for the owners of the femtocell that goes to sleep mode. In most papers, sleep mode is activated only when the traffic demands of their users is zero because otherwise they will experience performance disruptions. Instead, in our case, we follow a different approach that uses a combination of hybrid access and sleep mode to provide incentives of energy savings and data rate gains. Femtocells with active users may turn to sleep, while their users' reallocation is possible through the hybrid access of their neighboring femtocells. This exchange allows the users to willfully adopt these modes, since policy restrictions require performance improvement. As a result fewer base station will be active, while user experience stays the same or improves.

Thus, the mechanism first investigates if a femtocell is eligible to turn to sleep mode, by examining clusters of femtocells and test if a reallocation to a neighboring femtocell is possible. Incentives for the femtocell to turn to sleep mode or to hybrid access are provided through requirements. First, each user belonging to the candidate for sleep mode femtocell has to at least regain its performance when reallocated to another femtocell. This is expressed by:

$$THR_{New} \geq THR_{Old}. \tag{5}$$

The user will of course try to connect to an active femtocell, which will be serving his own subscribers at the time. That means it will probably get a portion of spectrum resources of what it enjoyed by its own femtocell. A part of this reduction is compensated by the reduced interference in the area since a close by femtocell will turn to sleep. The rest might require an increment in the power levels of the new base station in order to reach the user's prior performance. Searching for the required power increment, according to Sect. 2, based on the previous equation we have:

$$P_{Inc} \geq \frac{R * \left(\Delta f + \sum_{B'} P_{B'} G_{u,B'} \right) - P_{Old} * G_{u,N}}{G_{u,N}}. \tag{6}$$

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

$$R = \frac{(1 + aSINR_{Old})^{(N_2+1)/N_1} - 1}{a}. \quad (7)$$

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.

A similar incentive is required for the users of a femtocell candidate to adopt hybrid access. Thus hybrid access is adopted only for users that come from a neighboring sleeping femtocell. In addition, the gains of it turned to sleep mode due to less interference must compensate the reduced spectrum utilization due to hybrid access. Again, added to the reduction of interference due to the sleeping neighbour, a power increment may be required to compensate for the reduction of further spectrum resources:

$$P_{Inc} \geq \frac{R * \left(\Delta f + \sum_{B'} P_{B'} G_{u,B'}\right) - P_{Old} * G_{u,N}}{G_{u,N}}. \quad (8)$$

where $\Delta f + \sum_{B'} P_{B'} G_{u,B'}$ 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:

$$R = \frac{(1 + aSINR_{Old})^{(N_2+1)/N_2} - 1}{a}. \quad (9)$$

Estimating the required power level that will meet both of the demands, a final check is taking place for the rest of the femtocells of the same cluster that do not participate in that particular user exchange. The check makes sure that no subscriber of these femtocells experiences decrease in his/her throughput. This is possible when these users benefit by the deactivation of the slept femtocell at least as strongly as they are affected by the increase on their neighbour's power transmission. If this check returns successful the deactivation and the user exchange is finalized.

4 Performance Evaluation

4.1 Simulation Parameters

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 (Table 1) have been based on 3GPP directives from LTE-A and the LTE simulator in [13]. 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.

Table 1. Simulation parameters

Parameter	Value
Macrocells	9
Macrocell radius	250 m
Femtocells	250–550
Subscribers per femtocell	1–3
Macrocell users	140
Bandwidth	20 MHz
Carrier frequency	2 GHz
BS transmit power	46 dBm
FBS max transmit power	18 dBm

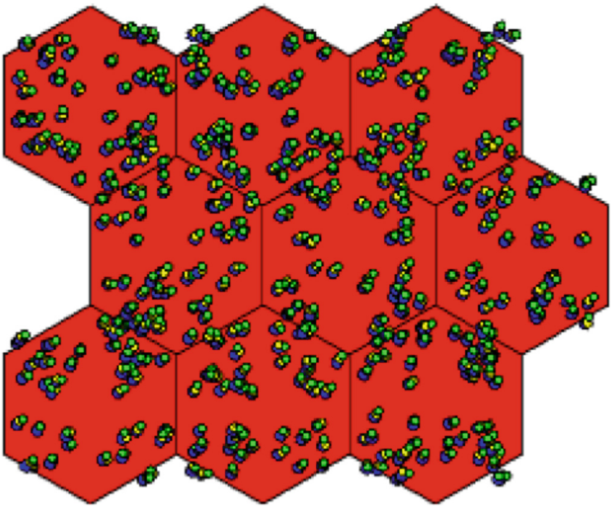

Fig. 1. Instance of the network

4.2 Simulation Results

Figure 2 shows the number of slept femtocells for different densities when the simple form is adopted and when it is enhanced with power control. Simple form represents our initial approach where no power increase was allowed in order to meet the performance requirements. The results are somewhat expected, since initially the restriction for better performance for every user with one less base station is quite strict making the possibility for a slept femtocell thin (i.e. 5 femtocells turned to sleep mode when 50 clusters were formed). Power control causes a dramatic increase in slept femtocells quadrupling the number to 20. Even if we neglect the capacity gains that we present later, and consider the worst case where users' data rate did not experience either an increase or a decrease, the energy gains of the mechanism as a result of the deactivated femtocells are substantial.

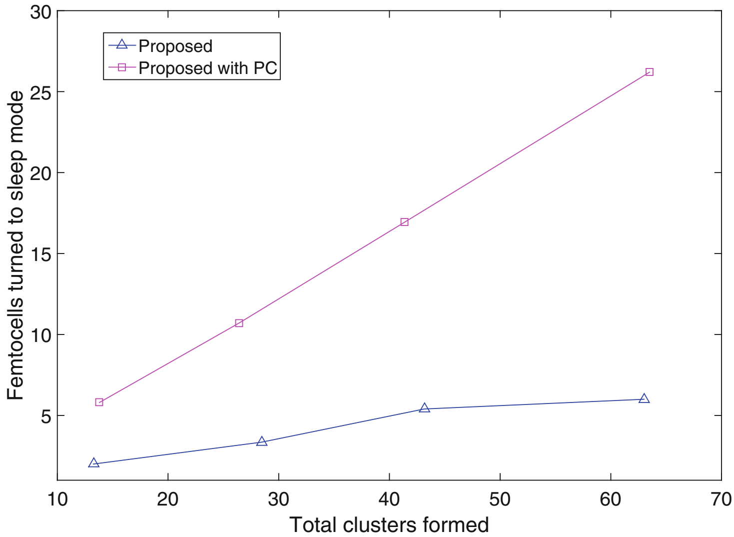

Fig. 2. Number of femtocells turned to sleep mode depending on the femtocell deployment density

However, the worst case regarding the users' throughput does not happen. Since the mechanism requires every user involved in the slept or hybrid femtocell experience the same performance, if the exchange is feasible, it adopts to the user who is in more danger to experience deterioration. That provides a margin of improvement for the users who were not in the danger zone, i.e. users who would not face decrease in their data rate even with the initial power transmission levels. This improvement can be clearly seen in Fig. 3 which displays the CDF of the throughput exhibited by subscribers of femtocells that are part of a cluster (independently of having eventually a slept femtocell in its members or not). The mechanism in its simple form showcases an improvement compared to the initial state where every femtocell is activated and operates in CSG, whereas the power control version increases the performance substantially.

Since these scenarios are characterized heavily by their tendency in trade-offs, there are also users who are going to be influenced negatively. Figure 4 depicts

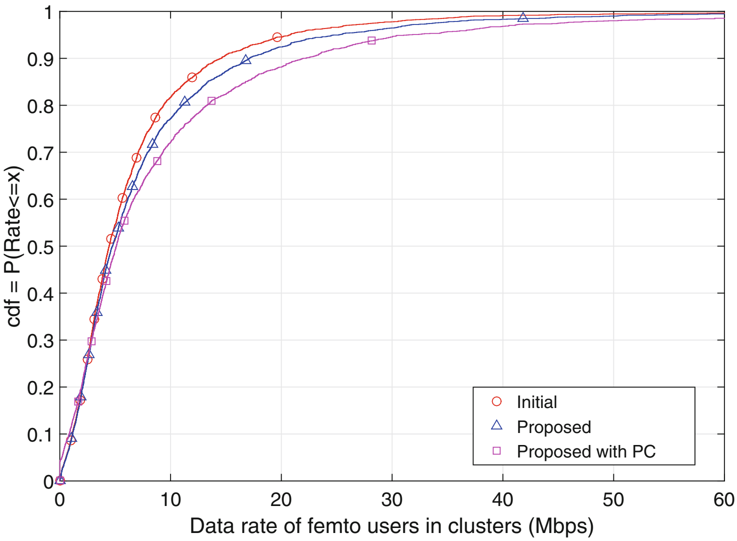

Fig. 3. CDF of the data rate of femto users that are subscribers to femtocells that are members of clusters.

the CDF of the macrocell users that were found in the range of one (or more) femtocell that belong in a cluster. The simple strategy mainly resulted in the deactivation of femtocells within a cluster. Remaining operating stations did not increase their power levels, at least not due to the mechanism requirements. This had a beneficial effect on this type of users who saw the overall interference in the

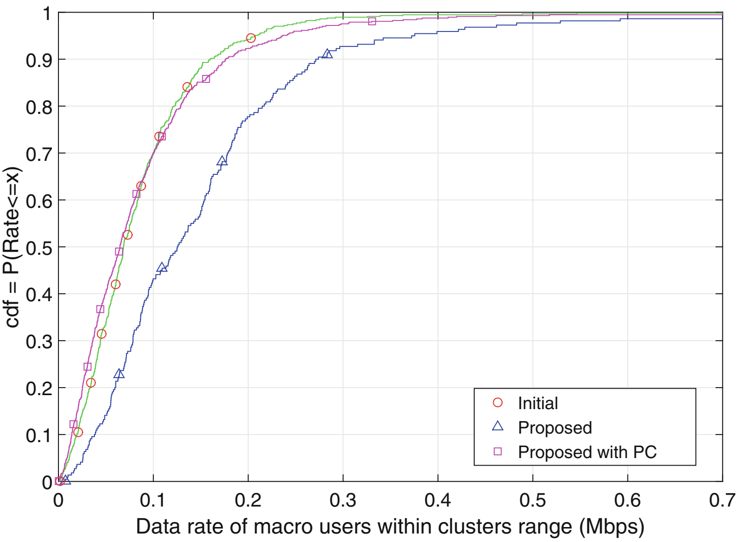

Fig. 4. CDF of the data rate of macro users that are affected by femtocells that are members of clusters

area to mitigate. Unfortunately, in the power control version, any mitigation due to femtocell deactivation is balanced by an equal increase due to power transmission increase. Therefore, the macro users' throughput is significantly behind the simple sleep strategy version. It is worth to note however, that compared to the initial state macro users mostly retain their performance without experiencing any downfall.

5 Conclusions and Future Work

In this paper we investigated performance gains for our proposed sleep mode and hybrid access mechanism extending its benefits by introducing a power control strategy. The mechanism tries to overcome the base station density caused by the exclusivity of femtocell resources, providing performance incentives to their users in order to turn their femtocell into sleep mode or adapt hybrid access policies.

We managed to increase substantially the number of femtocells turned to sleep mode by simply allowing the increase in power transmission in the hybrid access femtocells that admit neighbour femtocell's users. Balance is enforced by seeking the maximum increase in power control that retains the performance of the subscribers involved in the user exchange and at the same time avoiding negative influence to the close-by subscribers of the same cluster's femtocells. As a result the overall capacity provided by the femtocells to their subscribers is increased substantially without compromising any individual subscribed user. The increased energy efficiency of the enhanced approach is also noted. On the downside, macrocell users lose the benefit they enjoyed by the deactivation of some nearby femtocells due to the increase in power transmission of the remaining operating stations. However, compared to their initial state, no substantial decrease is observed.

Future extensions of this work could include the estimation of energy efficiency and performance gains of the algorithm, adding user mobility, and examining different traffic models.

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