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Sleep mode strategies for dense small cell 5G networks

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***Abstract*—The evolution of the fifth generation (5G) of mobile networks tends towards the prevalence of dense femtocell deployments, which offer improvements in data rate and overall network's capacity. Small cell deployments and particularly femtocells provide an attractive, cheap and flexible solution for the increased traffic demand. However, the resulting dense networks are characterized by challenges, too, such as increased interference and resource allocation. In this paper, we propose ways to address these difficulties by combining hybrid access, sleep mode and a power control mechanism. Simulations show that the above mechanism leads to improved capacity and throughput for subscribers, along with improved energy efficiency, without compromising the non-subscribers performance.**

***Index Terms*—femtocells, hybrid access, power control, sleep mode**

I. Introduction

Considering the demands for higher data rates and increased capacity that the fifth generation of mobile networks (5G) has to meet, urban areas will become overpopulated by cellular base stations, what is called ultra dense networks [1]. A large part of these networks are small cells and particularly femtocells. Femtocells serve a small number of users inside a small coverage area, their deployment is in-expensive and easy and they are characterized by low energy consumption in contrast with other type of small cells like picocells or macrocells. Another unique characteristic of femtocells is that they are mainly privately owned. This allows flexibility in their access policy deployment.

When in Closed Access Mode, the femtocell offers the total share of its resources to users belonging to a trusted group called Closed Subscriber Group (CSG). Subscribers enjoy the services they purchased at their maximum without worrying about external users and that's why is preferable for owners since that none except from them may access their femtocell. Additionally, subscribers also benefit from privacy and security offered through this access policy. Open Access Mode is chosen mostly by companies or public buildings because of their free-access nature. Everyone (femtocell or macrocell user) who is located in a femtocell's coverage area, can connect to the femtocell and enjoy its service. These femtocells extend macro-tier coverage causing less interference than close access mode, and give users the opportunity to choose a femtocell that serves them in the best possible way.

The main drawback of deploying closed access femtocells is that femtocells suffer as well as cause high interference to any nearby user without the right of access to it. On the other hand, in the case of open access, femtocell owners are not willing to share the resources they have paid for. The compromise is given through hybrid access mode which allows the connectivity of non-CSG users to private users, but setting limits to the resources that can be shared while giving preferential treatment to CSG users. With hybrid access femtocells, the level of access can be controlled and the connection can be configured to guarantee a satisfying performance for non-CSG users.

An other challenge that arises with the densification of the networks is energy efficiency. Specifically, the utilization of thousands of devices makes energy consumption a critical point of success for this type of networks [2]. One of the ways to tackle that is sleep mode. Sleep mode in femtocells is a state where it has switched off most of its parts, when they are not needed, thus reducing energy consumption. Upon sensing a user that requires its operation, usually with a sniffer component which remains activated, the femtocells rapidly wakes up to serve the user.

Research has been active addressing these issues. In order to overcome the challenges that arise through increased interference in two tier networks, [3] enforces a power control for femtocells that guarantees a minimum Signal-to-interference-plus-noise ratio (SINR) for macrocell users. Furthermore, [4] and [5] utilize the benefits offered by the operation in hybrid access and present reduced interference and increased throughput of users that adopt it. Hybrid access is also utilized in [6] to solve the resource allocation problem, in order to improve the performance of the femto tier. The authors of [7] show how cooperation strategies between femtocells can enhance the performance of the macro tier regarding outage probability and data throughput.

Sleep mode strategy of [8] also focuses on interference mitigation for macrocell users, achieving better performance along with significant power savings. The latter is the focus of [9] which compares 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.

In this paper, we are developing methods to find base stations that harm the network more than they benefit it. We expand the mechanism in [10] investigating different levels of restrictions. In the mechanism we utilize sleep mode that turns off these femtocells to mitigate interference and improve energy efficiency. The main goal is to find ways to deactivate base stations without jeopardizing the performance of their subscribers. Therefore, we utilize a specific hybrid access policy and enforce three requirements in order to combine its effects with the sleep mode mechanism. Firstly, femtocells in hybrid access will give access to external users only if they belong in the CSG of another member of the same cluster. Secondly, the femtocell where the user came from has to enter sleep mode. The third requirement demands that subscribers' performance is not affected negatively by the deactivation of femtocells.

The novelty of the above mechanism is that these requirements allow femtocells to enter sleep mode even when their subscribers are active, since their performance is guaranteed not to be affected in some level. We formulate the mechanism for different scenarios regarding the performance restrictions with the non-affected performance being every user's throughput, the femtocell's provided data rate to all of each users and the femtocell cluster's capacity. Conducted simulations showed that our methods succeeded in terms of reduced interference for femtocell users and increased capacity.

The rest of this paper is structured as follows: Section II describes the system model. Section III presents the proposed scheme of our algorithm and in Section IV we evaluate our proposal through simulations. Finally in Section V we draw our conclusions and offer suggestions for future work.

II. System model

In order to evaluate our model we focus on femtocell base stations' and cluster's performance gains concerning the affect in data rate for all network users. In this section we describe our system fundamentals.

First, we describe our model in evaluating users' data rate. In our model we utilize Long Term Evolution Advanced (LTE-A) architecture, and its Orthogonal Frequency-Division Multiple Access technology (OFDMA) [11]. Dense small cell deployments benefit from OFDMA's flexible allocation of available spectrum resources to users, by allowing complex spectrum allocation strategies. As for the calculation of necessary parameters as path loss, we follow the LTE-A directives [12].

In order to measure the power level needed for each femtocell, we have to deal with the position of femtocells inside the macrocell coverage area. Due to interference, a femtocell near the edge of the macrocell has totally different effective range in comparison with a femtocell which lies in the center of the macrocell. Consequently, we adjust the power level of femtocell by a maximum power level P_{max} and a constant radius of coverage [13] considering the power received from the closest macrocell at the target femtocell radius r. Specifically:

$$P_f = min(P_m + G - PL_m(d) + PL_f(r), P_{max}) \quad (1)$$

From equation 1 , $PL_f(r)$ denotes the line of sight path loss at the target cell radius r, P_m the transmit power of the closest macrocell, $PL_m(d)$ is the average macrocell path loss at the femtocell distance d (excluding any additional wall loss) and G is the antenna gain

Due to the need for a beneficial sleep mode, in this paper we consider the sleep mode described in [14] and [15]. Waking up a slept femtocell consists of two processes. First, after a user-macrocell connection is established, an added component senses a rise in received power on the uplink frequency. This component is called sniffer and will only wake up the femtocell if a predefined threshold is reached. The threshold reflects the desired coverage radius of each femtocell. As the femtocell wakes up, the user has to go through a handover procedure in order to access it.

This model allows selected femtocell components, such as radio frequency transmitter and receiver, to be switched off contributing to energy efficiency. On the other hand, the consumption of the sniffer component $P_{sniffer}$ is added estimated to an average of $0.3W$. This addition, is compensated fully by the total savings which are close to 40%. Drawbacks of this approach are the requirement of a handover from macrocell to femtocell. This means that an underlying macrocell infrastructure must be present. However, since we explore dense urban scenarios, this limitation is not a concern.

As soon as we calculate the femtocells power, we have to determine SINR. The $SINR$ of each user u on each subcarrier k, served by either a macro base station or a femtocell, is given by:

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

Where $P_{B,k}$ is the transmit power of users 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. Also, $P_{B',k}$ and $G_{u,B',k}$ represent the power of every other interfering base station (either femtocell or macrocell) and the gain between them and the user u respectively .

The practical capacity of user u on sub-carrier k is given by [16]:

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

where α is defined by $alpha = -1.5/ln(5BER)$. The overall throughput of a serving base station is calculated as shown below:

$$T_B = \sum_u \sum_k \beta_{u,k} C_{u,k} \quad (4)$$

where we set $\beta_{u,k} = 1$ when the sub-carrier k is assigned to user u and $\beta_{u,k} = 0$ otherwise [17].

III. Proposed scheme

The problems we have to deal with in this case are due to the growing number of households that own their own femtocell, creating an ultra dense network in the femtocell tier. Explaining the above, a simple user who does not have his/her own femtocell, is experiencing interference due to a femtocell installed near his/her location.

For example, a user located in a block of flats is burdened with interference from femtocells installed by users in neighbouring flats. The situation gets worse, considering that the majority of private femtocells operate in closed access policy, which excludes the case of handover on another femtocell. By the time that interference on a user reaches high levels, the possibility for the user in the future to obtain his own femtocell in order to meet his own needs, is highly increased. Ultimately, we are likely to end up with a situation where every household will own a private femtocell.

Due to the dense structure of femtocells there are some important drawbacks. Initially, as mentioned before, the interference between femtocells will be significant as well as the interference that will be displayed to a user who does not belong to the list of femtocells subscribers. Last but not least, the number of operating femtocells will be massive, making the energy consumption of the network a critical problem, which needs to be addressed by an effective way. In the next paragraphs we explain how we address these drawbacks. We combine two operating modes, sleep mode and hybrid access mode.

- Targeting energy efficiency, we utilize sleep mode which deactivates most of a base stations components. Components switch off apart from the required ones for the back-haul network connection and sensing user activity that will allow it to wake up if required. This intermediate state combines energy efficiency with functionality, since the change from sleep mode to a fully functional state is much faster compared to a completely shut off base station. Also, femtocells that operate in sleep mode cause no interference to non-subscribers and do not serve their subscribers.
- Hybrid access mode allows a certain number of outage-experiencing users to access a limited amount of femtocell's resources without compromising the service quality of femtocell's subscribers. Hybrid access mode has the provision to choose and add the guest network users along with the registered users. Interfering users are readily selected and served by hybrid access femtocells, thereby minimizing the threat for co-channel and adjacent channel interferences.

  The main target for a femtocell which operates under hybrid access mode is to serve and fulfil the needs of the users that are enlisted in the CSG. Therefore, they preserve their main resources for their subscribers and keep a portion for non-subscribers. As the number of users that are served by a femtocell grows, subscribers may fear that their performance will degrade. Hybrid access admission policies usually tackle this problem through pricing schemes where the owners are compensated for their resources' provision.

In this mechanism, we combine sleep mode and hybrid access mode as we aiming for data rate gains. Every femtocell has a chance to turn to sleep mode if the users that it serves can be reallocated to a neighbouring femtocell through the hybrid access mode. Below we present incentives for femtocells to adopt sleep mode or hybrid access through 3 versions, each one of different severity:

A) Every user belonging to the slept femtocell, has to increase or at least reach his previous performance level when reallocated. This approach is fully developed and evaluated in [18].

B) The second scenario requires the overall data rate offered by these femtocells to increase. This way, we increase the possibility of the constraints to be met, and the number of slept femtocells.

First, we examine if a femtocell is eligible to turn to sleep mode by checking if a reallocation of it's users in a neighbouring femtocell is possible and efficiently better. We set the requirements in order to achieve higher performance for the total of users that are served by the femtocell. This can be expressed by :

$$\prod_{i}^{2} \frac{(1 + aSINR_{i,New})^{1/n}}{(1 + aSINR_{i,Old})^{1/N}} \geq 1 \tag{5}$$

Where N represents the number of users served by the femtocell before the reallocation and n represents users after the reallocation respectively. When these requirements are met, users belonging to the current femtocell will try to connect to a neighbor femtocell.

Since a neighbor femtocell acquires a new user, it has to redistribute its resources to the new total number of users that it serves. That means that all users served by this femtocell will face a slight degradation in their performance. To counterbalance this, we refer to performance enhancements. First, users come up against significantly less interference due to the neighbor slept femtocell and when this isn't enough, we provide a power enhancement that will compensate any further loss of performance. Reevaluated power level is computed below:

$$Power_f = \frac{-F_1 - F_2 + \sqrt{F_1^2 - 2F_1F_2 + 4F_1F_2S + F_2^2}}{2F_1F_2} \tag{6}$$

Where F_1 and F_2 are set as:

$$F_1 = \frac{aG_1}{\Delta f * \sum P_1' G_1'}, F_2 = \frac{aG_2}{\Delta f * \sum P_2' G_2'} \tag{7}$$

Where G_1 and G_2 represent the channel gain for both users of the femtocell, P_1 and P_2 is the transmit power of user's serving base station, Δf the sub-carrier spacing. Also P_1', P_2' and G_1' and G_2' denote respectively the power of every other interfering base station (either femtocell or macrocell) for both users and channel gain.

Finally S is set by:

$$S = [\prod_{i}^{2} 1 + aSINR_{i,old}]^{\frac{N_2+1}{N_1}} \tag{8}$$

Where N_2 represents the number of users served by the new femtocell and N_1 the users served by the original femtocell respectively.

After evaluating the required power level, we check that none femtocell belonging to the same cluster and do not participate in the user exchange faces performance reduction. If this check is successful the deactivation and the user exchange is finalized.

C) The third scenario requires the total capacity provided by the femtocells belonging to a cluster to be greater or atleast equal. While this scenario increases the probability of slept femtocells, the individual subscribers' performance may get degraded.

Following the same process as before, we can assume that we need to fulfil an equation of requirements in order to select a femtocell which is eligible to turn to sleep mode. This equation must represent that the total performance of subscribers served by femtocells which belong to the current cluster, is not degraded after the reallocation. This can be expressed by

$$\prod_{1}^{s} \frac{(1 + aSINR_{i,New})^{1/n}}{(1 + aSINR_{i,Old})^{1/N}} \geq 1 \tag{9}$$

Where s represents the number of subscribers that lie in the coverage area of femtocells which belong in the current cluster.

Similarly to the previous scenario, some users may face performance degradation as well as reducted interference after the reallocation, since a close by femtocell now operates in sleep mode. Also, we calculate again a power increment like before in order to fulfil subscribers' needs.

IV. Performance Evaluation

In this section, we first describe the simulation environment we used based on the system model described in Section II. Then, we present our findings regarding the proposed scheme and analyse the results.

A. Simulation parameters

Our simulator network contains 9 macrocells with their base station at the center of the cell transmitting at 46dBm. The radius of each macrocell is 250m. Multiple femtocells are deployed along with their subscribers (Fig. 1). Each femtocell could have up to three transmitting subscribers simultaneously. The transmit power of femtocells is calculated based on the system model in Section II and its maximum permitted value is set to 18Bbm. A number of macrocells users were also deployed randomly in the area. Table I contains some of the simulation parameters. The values for the network parameters were taken from 3GPP directives for LTE-A and the LTE simulator in [19].

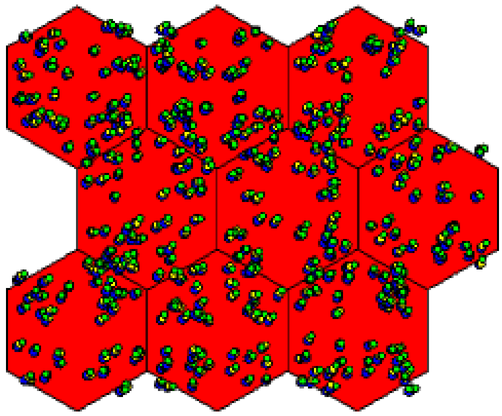

Fig. 1. An instance of the simulated network

TABLE I
Simulation Parameters

Parameter	Value			
Macrocells	9			
Macrocell radius	250 m			
Femtocells	250	350	450	550
Femtocell subscribers	$1-3\,(per femtocell)$			
Bandwidth	20 MHz			
Carrier frequency	2 GHz			
BS transmit power	46 dBm			
FBS max transmit power	18 dBm			

B. Performance results

Figure 2 shows the number of slept femtocells between the three scenarios described above and for different densities of femtocell deployment. It is evident that as the density of femtocells increases, the number of formed clusters also increases. We can also observe that the number of slept femtocells during the second scenario, whose limitations relate to the overall performance of femtocell, are higher than the original scenario.

This increase is mainly due to the looser restrictions of this approach. In this approach, a femtocell will go to a sleeping state only if the overall throughput of the femtocell is greater or equal than before, after the users exchange. The augmented number of deactivated femtocells also comes from the power increment that occurs when the previous requirements are not fulfilled, since we manage to equalize femtocell's throughput with our power control mechanism.

Compared to the first power control scenario where our simulations showed an average of 26 femtocell in sleep mode when 60 groups were formed, we achieved about 2-3 more slept femtocells in this version. The same logic applies for the third scenario, too. The looser requirements for the third case, which are about total cluster's performance lead to an additional increase in the number of slept femtocells. Specifically

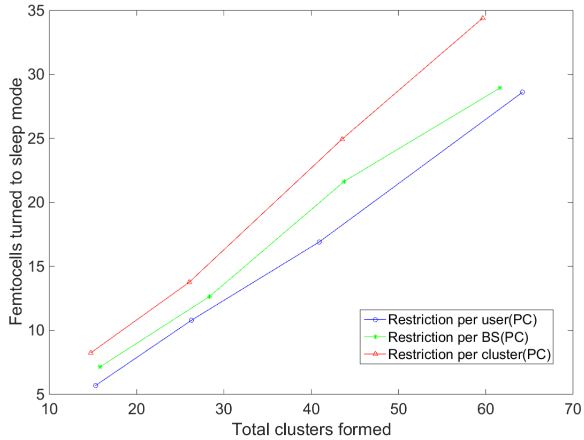

Fig. 2. Number of femtocells turned to sleep mode

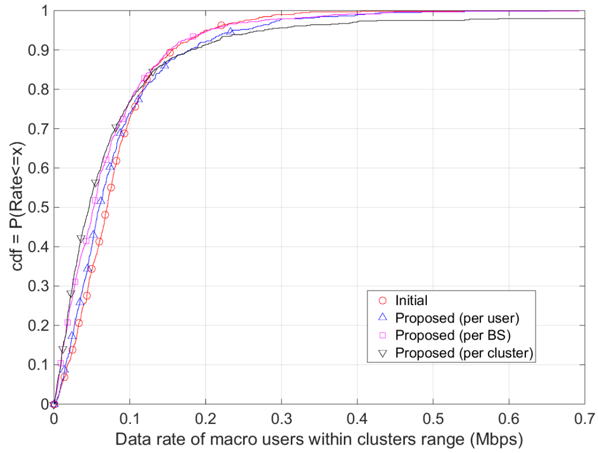

Fig. 4. Data rate of macro users in clusters (Mbps)

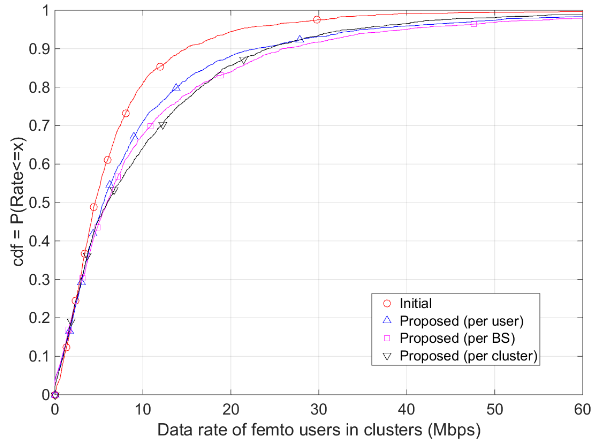

Fig. 3. Data rate of femto users in clusters (Mbps)

the number increased by 23% approximately compared to the first scenario.

Figure 3 depicts the data rate for femtocell subscribers that belong to a femtocell that was part of the cluster. The improvement of the overall provided capacity comes both from the smart reallocation of users exploiting the power control and the interference mitigation in the area from slept femtocells. The figure showcases the accumulative performance of femtocells, meaning that while we experience an increase in the overall capacity for scenarios B and C, only the first scenario ensures that none of subscribers experiences reduction in their data rate individually. It becomes evident that scenarios B and C aim to serve conditions where the accumulative capacity and the energy efficiency are the most prevalent priorities for the network.

Finally, we investigate the effect of our mechanism to the macrocell users (non-subscribers to any nearby femtocell). These type of users suffer immensely from interference. Because of the dense nature of our network, a macro user which is located inside a cluster, is influenced by the accumulative interference from all nearby femtocells, which means that their performance can be severely degraded.

Figure 4 depicts the CDF of the macrocell users' data rate that were found in the range of femtocells that belong in a cluster. These users are affected by the mechanism in two antithetical ways. The first is the mitigation of interference by the reduced number of operating femtocells. The second is the increase of interference due to the possible increase in the power transmission of remaining femtocells.

As we can see in the figure, these factors balance each other out. Any reduction of interference due to the deactivation of femtocell is offset by the increase resulting from the increase in power. As a result, macro users overall wont experience any major performance difference compared to the original operating conditions.

V. Conclusions and Future Work

This paper aimed at developing new and enhanced methods in order to increase the number of slept femtocells and improve the capacity of small cell networks. We exploited hybrid access and sleep mode and created two versions of our power control method. In both versions the challenge was to urge subscribers of femtocells to accept non-subscribed users from neighboring femtocells to access their femtocell or to accept their femtocell turning in sleep mode by accessing neighbouring femtocells themselves.

Based on our mechanism, a femtocell will turn to sleep mode only if its deactivation will benefit enough the performance of close by femtocells' subscribers, by mitigating interference. Therefore, the reallocation of users will be completed only if the performance of all involved users will benefit collectively in comparison with the original topology. By guaranteeing that their performance wont be affected negatively (instead, they might experience an increase in their femtocells' collective capacity), we managed to mitigate the subscribers' reluctance to accept deactivating a large number of femtocells.

Simulations indicate that subscribers from both the femtocell that turned into sleep mode and the femtocell that accepted users from a neighbouring cell will benefit collectively from increased data rate and less interference, increasing the overall capacity. Besides that, there is a significant number of slept femtocells in the network, contributing in energy efficiency of our network. Finally, the macrocell users who are located in the range of the cluster's femtocells are not affected negatively by the mechanism.

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