Energy efficiency in sleep mode for 5G femtocells

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***Abstract*—Energy efficiency is a major requirement for next generation mobile networks both as an end to reduce operational expenses and to increase the systems’ ecological friendliness. Another integral part of 5G networks is the increased density of the deployment of small radius base stations, such as femtocells. Based on the design principle that demands a system to be active and transmitting only when and where it is needed, we evaluate the energy savings harvested when sleep mode techniques are enforced in dense femtocell deployments. We present our novel variations of sleep mode combined with hybrid access strategies and we estimate capacity and energy benefits. Our simulations show significant advantages in performance and energy efficiency.**

Keywords—femtocells, sleep mode, energy efficiency, 5G

I. INTRODUCTION

Expecting small cells to dominate to increase spectral efficiency and address the demand of next generation mobile networks, ultra dense deployments will also be investigated for their energy efficiency. Many approaches on energy efficiency focused on macrocell tier, will be examined for the small cell tier. Sleep mode is one of these techniques. In femtocells, an attractive type of small cell due to its low cost, sleep mode is an intermediate state of low power where they switch off partially [1] providing energy efficiency when they are not utilized and allowing a quick transition to full operation when required. A description of the functional basic principles can be found in [1] where several approaches which differ on which entity is responsible for waking up the femtocell are described and compared on power savings. Different sleep mode mechanisms are also evaluated in [2] in dense small cell networks, concluding that careful selection of the base stations is required. [3] utilizes an opportunistic sleep-wake switching mechanism to achieve energy savings (up to 40%) and load decrease. Clustering is used in [4] establishing hierarchy and defining a femtocell as a leader to be responsible for sensing call needs allowing the rest to sleep.

The primary focus of above papers is energy savings. In this paper we propose a strategy for dense femtocell deployments expanding our work in [5], based on sleep mode that facilitates both energy efficiency and interference mitigation. It also provides capacity incentives to femtocells to sleep even when there are active subscribers, based on user redistribution. We implement this as an extended form of hybrid access mode defining a policy of spectrum management and the terms that dictate which femtocells will sleep. This ensures increased performance for either individual data rates or the entire cluster capacity and power savings. Section II contains the system model, Section III presents the proposed algorithm and Section IV depicts its evaluation. Finally, Section V contains our conclusions.

II. SYSTEM MODEL

The sleep mode model considered in this paper is based on [1] and [6]. Components of the femtocell switch off apart from the ones needed for the back-haul network connection and for sensing user activity in order to wake up the femtocell. Sensing is done through a “sniffer” component that senses rises in received power on the uplink, indicating a user-macrocell connection. Setting a threshold to reflect the desired coverage radius, the sniffer wakes up the femtocell if the threshold is surpassed and a handover takes place. Drawbacks include the requirement of underlying macrocell infrastructure and the handover. However, the former poses no barrier for urban scenarios. Also, the additional signalling due to sleep mode integration and the handover is more than compensated by the reduction of femtocell functionalities in sleep mode [6]. This approach allows components to be switched off as shown in Table I [1], such as parts of the field programmable gate array (FPGA) associated memory and the radio frequency (RF) transmitter. The “sniffer” is estimated to 0.3W consumption. We easily derive the savings between the two operating modes:

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

This means power savings close to 40%. A second approach is based on core network controlled sleep mode [1]. The core network identifies connections and through the mobility management entity in Long Term Evolution Advanced (LTE-A) checks for nearby femtocells that the user has access to and sends a wake up signal. This has the advantage of switching every part of the femtocell apart from the microprocessor and backhaul circuitry, increasing power savings to $\sim$70%.

For the performance metrics, we comply with LTE-A, utilizing the Orthogonal frequency-division multiple access (OFDMA) for flexible spectrum allocation and following the LTE-A directives for urban environment’s parameters such as path loss [7]. For the femtocell’s power, we take into account its position. In co-channel tiers, the effective range of the femtocell depends on the femtocell-macrocell distance due to interference. Thus, we adjust femtocells’ power towards a constant coverage radius [8]:

$$P_f = min(P_m + G - PL_m(d) + PL_f(r), Pmax) \tag{2}$$

where $PL_f(r)$ is the path loss at the target radius r, P_m the power of the closest macrocell and G the antenna gain. $PL_m(d)$ is the macrocell path loss at the femtocell distance d and $Pmax$ the maximum power. We then derive the Signal-to-interference-plus-noise ratio (SINR) of user u on subcarrier k:

$$SINR_{u,k} = \frac{P_{B,k} G_{u,B,k}}{N_0 \Delta f + \sum_{B'} P_{B',k} G_{u,B',k}} \tag{3}$$

TABLE I. FEMTOCELL COMPONENTS CONSUMPTION

Hardware component	Consumption (Watts)
Microprocessor-associated memory	1.7 (0.5*)
FPGA-associated memory	2.0 (0.5*)
Other circuitry	2.0
RF transmitter and receiver	1.5*
RF power amplifier	2.0*

*Parts that are switched off during sleep mode

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. We then calculate the user's capacity on that subcarrier [9]:

$$C_{u,k} = \Delta f \cdot log_2(1 + \alpha SINR_{u,k}) \tag{4}$$

where α is defined by $\alpha = -1.5/ln(5BER)$. Setting $\beta_{u,k} = 1$ when the sub-carrier k is assigned to user u and $\beta_{u,k} = 0$ otherwise, we evaluate the overall throughput of serving base station based on the subcarrier allocation, by [10]:

$$T_B = \sum_u \sum_k \beta_{u,k} C_{u,k} \tag{5}$$

III. PROPOSED SCHEME

Although the ad hoc nature of femtocells efficiently targets local needs, the lack of central coordination causes problems. The situation gets worst, considering private femtocells operate mostly in closed access. The accumulative interference of multiple femtocells for residents in a building would easily lead to the acquirement of a femtocell by that household, too. As a result the number of femtocells will not reflect the actual needs but the exclusivity of usage. However, after a certain number in deployed femtocells, the accumulative interference might surpass any gains of having them. Secondly, every non-subscriber in any femtocell will suffer. Thirdly, the energy consumption of the redundant base stations should be avoided.

We address the above by proposing a scheme that combines the sleep and the hybrid access mode. During the sleep mode and its two approaches explained in Section II, we consider zero interference. Hybrid access is an intermediate policy between the closed access that restricts access to users enlisted to the femtocell's Closed Subscriber Group (CSG), and the open access that allows everyone. In hybrid access the femtocell preserves resources for its CSG users, but allows external users as well. Incentives are required for owners to share resources, usually through pricing compensating schemes. The same is true for the sleep mode. While in most papers, sleep mode is activated when no users are active, we provide incentives based on energy savings and data rate gains. Specifically, femtocells with active users may sleep, if their users' reallocation is possible through the hybrid access of their neighbors, while guaranteeing performance improvement. As a result less femtocells are active and user experience improves. Thus, the mechanism investigates if a femtocell is eligible to sleep, examining its cluster and test if a reallocation to a neighboring femtocell is possible. Incentives for the femtocell to turn to sleep or to hybrid access are provided through 3 approaches on requirements, of different severity:

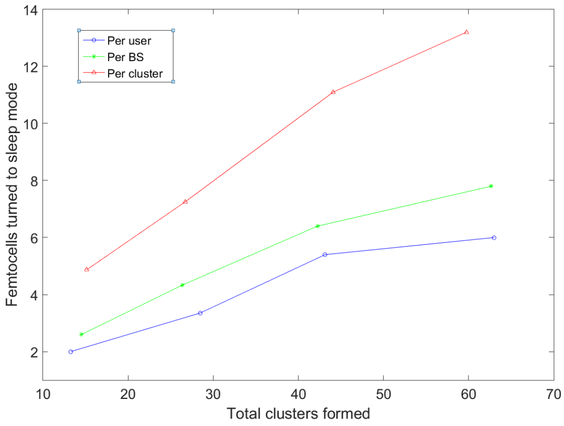

Fig. 1. Number of femtocells turned to sleep mode vs deployment density.

A) Each active user belonging to the slept femtocell has to at least retain its performance when reallocated, which yields:

$$SINR_{New} \geq ((1 + aSINR_{Old})^{(N_2+1)/N_1} - 1)/a \tag{6}$$

where $SINR_{New}$ and $SINR_{Old}$ are the SINR that the user would experience if served by the neighbour or the original femtocell, respectively. N_2 and N_1 are the number of users served by the neighbour and by the origin femtocell, respectively. The last equation is quite possible if $N_2 \sim N_1$ and considering that there is one less source of interference in $SINR_{New}$ (the close-by femtocell in sleep mode). A similar incentive is required for hybrid access: 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:

$$SINR_{New} \geq ((1 + aSINR_{Old})^{(N_2+1)/N_2} - 1)/a \tag{7}$$

B) The second scenario looses the constraints requiring the total of data rates offered by these femtocells to increase. This increases the possibility of the constraints to be met, and the number of slept femtocells.

C) The third scenario requires the total capacity of the cluster to increase, increasing the probability of slept femtocells but individual subscribers may get degraded.

IV. PERFORMANCE EVALUATION

We simulated a network of 9 macrocells with 250m radius transmitting at 46dBm. We randomly deployed multiple femtocells and users. Each femtocell had up to three active subscribers. Simulations were conducted for several femtocell densities (250, 350, 450 and 550). Simulation was based on 3GPP directives and the LTE simulator in [11]. Bandwidth was 20MHz and carrier frequency 2GHz. Cumulative distribution functions (CDF) depict the average of 20 simulations.

Increase in femtocells density increases the number of formed clusters and slept femtocells. Fig. 1 shows a 10% probability for a cluster to have a femtocell in sleep mode,

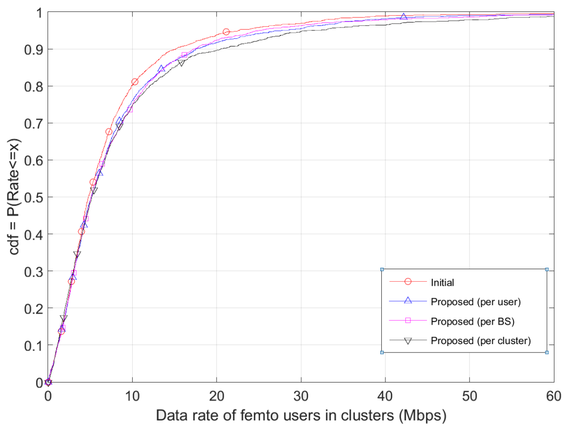

Fig. 2. Data rate of all users subscribed to cluster femtocells.

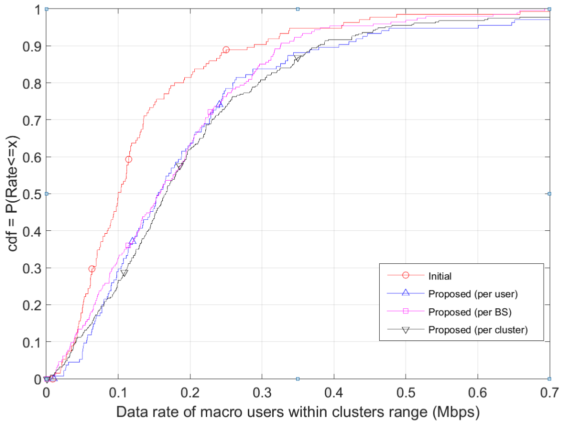

Fig. 3. Data rate of macrocell users that are within femtocell clusters.

for the strictest case requiring improvement for every user and 25% for the relaxed case that requires improvement in the cluster capacity. As we see below, this has a significant impact in energy efficiency and the users' throughput. Figure 2 depicts the CDF of the throughput of subscribers to every femtocell that belongs in a cluster. The increase in performance is evident due to the improvement requirement in terms of either individual, FBS or cluster capacity and the reduction in overall interference caused by the FBSs that turned to sleep mode. The latter affects non-subscribers' throughput too, the improvement of which is seen in Fig. 3.

Finally, we calculate the savings for both the sleep mode versions described in Section II, the one that leads to 40% power savings per femtocell and the one that leads to 70%. As seen in Figure 4 the cluster based optimization yields the most benefits. Each cluster contained on average about 2.5 femtocells and the probability for a slept femtocell in a cluster was 10% and 25% for the strictest and the loosest requirements, leading to 3% and 6% energy savings in all clusters, respectively for the first version of sleep mode (40% savings per femtocell). For the second version (70% savings), energy savings reach 5% and 9% . The energy savings per cluster when it contains a slept femtocell, are on average 15% and 25% for the different versions. Adding the capacity gains, the incentives for the femtocell owner(s) are significant.

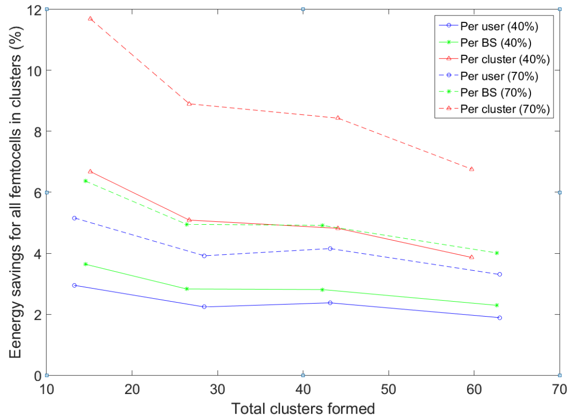

Fig. 4. Energy savings (%) for all femtocells belonging in clusters.

V. CONCLUSIONS

We proposed a mechanism that overcomes the femtocell's density caused by their exclusivity, providing energy efficiency and performance incentives to adapt sleep mode or hybrid access policies. Simulations showed energy and throughput gains due to user reallocation and reduction of active femtocells.

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