Sleep Mode Performance Gains In 5G Femtocell Clusters

Christos Bouras*†, Georgios Diles†
*Computer Technology Institute and Press "Diophantus", Patras, Greece
†Computer Engineering and Informatics Dept., University of Patras, Greece
bouras@cti.gr, diles@ceid.upatras.gr

***Abstract*—Femtocells present an efficient, low cost solution to help reach the traffic and data rate targets of 5G mobile networks. However, their ad-hoc nature, the expected great density of deployment and their closed registration policy may result in multi-layered networks with base stations' ranges constantly overlapping and non-registered users struggling from the accumulative interference. In this paper, we propose a mechanism where femtocells operate in clusters, and may decide to turn to sleep mode if capacity demand of its users is met adequately by the remaining awake femtocells. We propose a special version of hybrid access targeting only users of neighboring femtocells, in order to reduce the number of active base stations and thus, to reduce interference. We enforce sleep mode under conditions that ensure the increased throughput of each involved registered user and the increased capacity provided by the entire cluster with the extra benefit of reduced energy.**

***Keywords*—5G, clusters, femtocells, hybrid access, sleep mode**

I. INTRODUCTION

In order to achieve the demand in data rate and traffic in the upcoming 5G mobile systems, networks will contain multiple base stations per area [1]. These dense infrastructures will vary in range of transmission and serving capability. Femtocells, a main part of these ultra dense networks, provide small range services for a small number of users. In contrast to other types of base stations, such as macro cells and picocells which require large maintenance and cause heavy financial burden, femtocells are easy to maintain and deploy making their private ownership possible. However, being private entities also determines their access policy.

Femtocells' access policy varies from open access to closed access with hybrid access in between. In close access, the most logical choice for privately owned femtocells, a list of User Equipments (UEs), known as Closed Subscriber Group (CSG) are served by the femtocell when within its range. In open access instead, the femtocell may serve any user, thus avoiding interference but with the drawback of the exploitation of private resources by outsiders. This approach is usually preferred by company buildings or mobile vendors to increase the provided data rates locally. Hybrid access is a compromise between the previous two. In hybrid access, both macro and femto users (MUE, FUE) are allowed access to femtocells spectrum when inside its coverage area, usually enforcing different policies and limitations between the two types of users and giving priority to the subscribers.

The problem of dense femtocell deployments is that with every new deployment of a closed access femtocell, large interference appears on nearby users who they may find the solution of poor service to a closed access femtocell of their own. This will lead to a great number of femtocells deployed in a small area, where their number will reflect the exclusivity of usage by the users and not their demands on capacity. Thus, in this paper we propose a system where femtocells in these dense deployments may be turned off when their operation causes more interference than benefit to the users and overcoming the exclusivity by allowing a version of hybrid access mode where femtocells may also accept to serve users in the CSG of their neighboring femtocells. However, turning off completely the device would not be practical, since mobile traffic and users topology may change often, thus requiring for a switched off device to instantly reactivate, which is difficult. Instead, a medium state of low power, called sleep mode is preferred where femtocells have turned off only some of their components [2] making easier the transition to full power state when needed.

Sleep mode of femtocells is an active research field. In [2] 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 [3] 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 [4] to improve the enerty 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. On the other hand, sleep mode strategy of [5] focuses on interference mitigation for macrocell users, achieving better performance along with significant power savings.

While the above papers utilize sleep mode, all but the last one have their primary focus on the energy efficiency of the network and not the interference mitigation. The last paper aims to mitigate interference but takes into account only the performance of macrocell users, and not femtocells' registered users. In this paper we propose a sleep mode strategy that can apply to clusters, that aims to reduce interference among femtocell subscribers of nearby femtocells and improve macrocell users' performance. Specifically, we group femtocells in

978-1-4673-8817-7/16/$31.00 ©2016 IEEE

clusters, and we propose a variation of hybrid access between femtocells-members of the cluster. Based on the scheme, an hybrid access femtocell will allow only external users that are in the CSG of another member of the cluster along with the demand that the latter will enter sleep mode. The above condition along with additional constraints that we enforce, leads to gains for every user of the involved femtocells, thus respecting the gains expected by owing a femtocell. Sleep mode also reduces the total interference in the area, benefiting every other user (FUE or MUE) in the area. A final side effect of our strategy is the power savings as a result of sleep mode for some base stations. We conduct simulations to validate our algorithm that show increased data rate for femtocell subscribers and overall cluster capacity. In addition, we measure how the reduction of active base stations leads to reduced interference for macrocell users.

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

II. SYSTEM MODEL

In order to compare the performance of involved entities for our setup, we need to determine the context of our metrics. We are mainly based on Long Term Evolution Advanced (LTE-A) architecture, and utilize its Orthogonal frequency-division multiple access (OFDMA) approach on allocating resources. This provides us with the means to distribute spectrum resources in the form of resource blocks to a user and determine our spectrum strategy. After the allocation of resources we estimate users' throughput. In our paper we focus on urban dense environments cause these scenarios support the prediction of ultra dense small cell deployments and is one of use cases with high demand that new technologies will have to tackle. Thus, following the LTE-A directives for an urban environment, we calculate path loss with [6]:

$$PL_{MUE} = 15.3 + 37.6 log_{10} R + L_{ow} \tag{1}$$

which provides the path loss of a macro user, with L_{ow} denoting the penetration loss of a wall, for a case of an indoor user. Similarly, for a femtocell user, path loss is estimated by:

$$PL_{FUE} = 38.46 + 20 log_{10} R + L_{ow} \tag{2}$$

Values of 7 and 15 dB are a good estimation of the penetration loss for internal and external walls, respectively, and will be used throughout the simulation process [7]. Internal wall penetration loss is considered when evaluating the interference a femtocell user receives from a femtocell that belongs to the same cluster as explained in later sections.

We then determine the channel gain G, through the following expression:

$$G = 10^{-PL/10} \tag{3}$$

Next, we determine the power transmission of each femtocell. Since macrocell's radius is large, the range of femtocells near the cell center and those close to macrocell edge would be very different if all femtocells transmitted with the same power. Our goal is to achieve a constant radius of coverage. Thus, each femtocell sets its power to a value that on average is equal to the power received from the closest macrocell at a target femtocell radius r, subject to a maximum power of $Pmax$. Therefore, we calculate transmit power through [8]:

$$P_f = min(P_m + G - PL_m(d) + PL_f(r), Pmax) \tag{4}$$

where $PL_f(r)$ is the line of sight path loss at the target cell radius r and P_m is the transmit power of the macrocell in which the femtocell is located and G is the antenna gain. $PL_m(d)$ denotes the average macrocell path loss at the femtocell distance d (excluding any additional wall losses).

When gain and power transmission are determined, we estimate the Signal-to-interference-plus-noise ratio (SINR) of the user. For the case of a macro-user m on sub-carrier k, and as mentioned in [9], SINR is provided by the following equation:

$$SINR_{m,k} = \frac{P_{M,k} G_{m,M,k}}{N_0 \Delta f + \sum\limits_{M'} P_{M',k} G_{m,M',k} + \sum\limits_{F} P_{F,k} G_{m,F,k}} \tag{5}$$

with $P_{X,k}$ the transmit power of serving base station X on subcarrier k, where X can be the macrocell M, a neighbouring macrocell M' or a femtocell F. $G_{x,X,k}$ is the channel gain between user x and serving cell X on sub-carrier k, where x can be a femto or a macro-user and X as described above. N_0 is white noise power spectral density, and Δf sub-carrier spacing. The expression of a femto-user can be similarly derived by taking into account the interference caused by the macrocells and adjacent femtocells of the topology.

The practical capacity of macro-user m on sub-carrier k is given by [9]:

$$C_{m,k} = \Delta f \cdot log_2(1 + \alpha SINR_{m,k}) \tag{6}$$

where α is defined by $\alpha = -1.5/ln(5BER)$. The overall throughput of serving macrocell M can then be expressed as [10]:

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \tag{7}$$

where, $\beta_{m,k}$ notifies the sub-carrier assignment for macro users. When $\beta_{m,k} = 1$, the sub-carrier k is assigned to macro user m. Otherwise, $\beta_{m,k} = 0$. Similar expression can be derived for femto-users, related to the practical capacity and the overall throughput [10].

III. PROPOSED SCHEME

In this section, we present the proposed algorithm in detail. The main concept behind the algorithm is to find a way to avoid the unnecessary operation of a large number of femtocells when the same result in performance (or better) can be achieved through the smart utilization of a smaller number of base stations. It is the private-owned nature of the femtocell that leads to a reasonable preference for exclusive use by its owners. However, this may lead to a overwhelming and unnecessary tendency for femtocell deployment having an opposite result from the one that it was initially intended. While in macrocell coverage the deployment of the base stations in an area follows the data rate and coverage needs for the users existing in that area, the deployment for femtocell base stations and its coverage and data rate capabilities are limited by its exclusive utilization. For example, if a certain area where 10 users lived would be adequately served by 3 femtocells, this number could be unnecessary higher if these 10 users were actually 5 couples living in separate apartments, thus each requiring its own femtocell.

While each deployment would benefit its individual users, there is a point in base station density that when it is exceeded, the accumulative interference of the rest femtocells might make the utilization of femtocells have a negative effect. An extreme example for this problem to be clear would be when a user owing a femtocell would experience so much interference from the neighboring femtocells that he/she would have better data rate if no-one (neither the user nor the neighbors) owned a femtocell. The goal of our algorithm is to find the balance between femtocell gains and problems (capacity boost and interference respectively) in dense deployments, respecting the hesitation that naturally comes to users sharing resources of something privately owned. We do this by introducing a sleep mode strategy so that active base stations better reflect the actual service needs and by proposing a conservative version of hybrid access mode for better utilization of available resources.

First we define the cluster upon the algorithm may apply. We consider femtocell candidates for going to sleep mode (i.e. not transmitting mode) or hybrid access mode when it is part of a cluster, which means it is in a distance of 20 m or less from another femtocell that belongs to this cluster. This limitation is derived from the fact that, as we explain later, there must be an adequate level of interference between two femtocells for the algorithm to make sense and beyond this distance of 20 m, this seems unlikely and the algorithm would only add to unnecessary computational burden and message exchange.

Next we explain what we mean by a femtocell's sleep and hybrid access mode. Sleep mode is a femtocell's power state that is in a way between the normal operating state and the switched off one. The main characteristics of this state as it is used by many studies before ([2], [3]) is that it is a low-power state where some components of the femtocell have switched off or working in low level. At this state, the femtocell is unable to serve a user, and it may require a form of waking signal to return to normal operation. This signal may come from the user, from the network or from the femtocell itself with each approach yielding to different energy requirements. The important characteristic used by this paper is that we consider that a femtocell in this state does not serve any user and its transmissions do not cause interference to any user in their range.

Hybrid access on the other hand is when a femtocell admits any user in its range and not solely the ones registered in its CSG list. This access mode is faced with suspicion and reluctance by the femtocell owners which often require a profit in exchange, usually through a pricing mechanism from the network vendor, i.e. [11]. Instead, in this paper, we propose a more conservative mode of hybrid access that will help us form a reward mechanism providing performance incentives through the coordination with the neighboring femtocells. Specifically, with hybrid access we will refer to the case where a femtocell extends its CSG list of admitted users to include users that are part of the CSG of a femtocell belonging to the same cluster with the femtocell in question. Thus, only a subgroup of possible users may get admitted compared to the standard hybrid access, and as we explain below, this only takes place under strict conditions.

Working in the cluster, the algorithm checks each base station whether it would be beneficial to go to sleep mode. When a femtocell goes to sleep mode, its active users must be reallocated. The rest of the femtocells in the cluster are examined beginning with the one to the closer distance and so on, as candidates to enter hybrid access mode and admit them. We limit the search within 20 m from the user to avoid excessive computations. Since we refer to independent private-owned femtocells, all users involved must experience an advantage for them to accept such a change. Thus, one constraint that must be met is that the subscribers of the femtocell-candidate for sleep mode must have at least the same data rate when served by a neighbor with what it had initially. This can be expressed as follows:

$$THR_{New} \geq THR_{Old} \tag{8}$$

which based on the system model of section II, leads to:

$$SINR_{New} \geq \frac{(1 + aSINR_{Old})^{(N_2+1)/N_1} - 1}{a} \tag{9}$$

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 is the number of users served by the neighbour and N_1 is the number of users served by the origin femtocell. It is obvious that the last equation is quite possible if $N_2 \sim N_1$ and considering that in the calculation of $SINR_{New}$ there is one less source of interference (the close-by femtocell in sleep mode).

Incentives are required for the femtocells asked to operate in hybrid mode, too. Thus, a second constraint that must be met is that users of a femtocell candidate to enter hybrid access mode must also retain or improve the performance levels experienced in CSG mode. This basically means that the effect the femtocell going to sleep has to the candidate for hybrid access femtocell through interference must be greater from the effect of less spectrum utilization due to extra user admission. This may also be expressed with Eq. 9, with the only difference being $N_2 = N_1$ as seen below:

$$SINR_{New} \geq \frac{(1 + aSINR_{Old})^{(N_2+1)/N_2} - 1}{a} \tag{10}$$

In order to increase the probability of the above we allow only one extra user admission by each neighboring femtocells. This means that a femtocell candidate for sleep with 3 users, must reallocate its users to 3 neighboring femtocells. For the same reason (increasing the probability the algorithm requirements are met) and to achieve the maximum benefit, the initially check for a sleep candidate femtocell starts from the

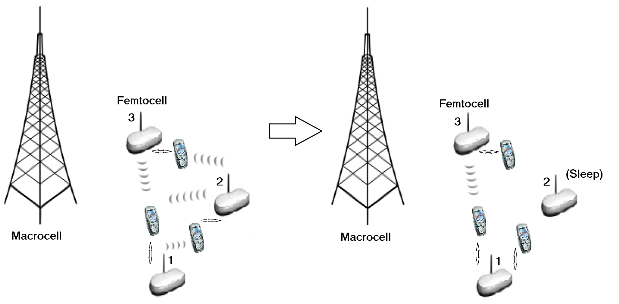

Fig. 1. An illustration of the mechanism. Femtocell 1 protects its user from femtocell's 2 interference by admitting its user and making it go to sleep. Both users benefit from this exchange. The user of femtocell 3 and nearby macrocell users also benefit from the reduction of interference.

femtocell that its users experience the largest interference per subscriber, then the second one and so on. There is increased chance the largest interference to be a result of close by (maybe multiple) femtocells. Thus, a greater chance for a neighbour to be found to compensate for user reallocation and greater chance for the reduction of interference to surpass the extra user for the hybrid femtocell. Fig. 1 illustrates an example while algorithm 1 summarizes the proposed scheme.

Algorithm 1 Proposed scheme

```
Define the members of each cluster
if femtocell i ∈ cluster and distance $u - i < 20m$ then
    femtocell u ∈ cluster
end if
for each cluster do
    Go through the femtocells in cluster to find candidates for sleep mode starting from the one with the greatest received interference per user, then the second one and so on
    for each femtocell ∈ cluster do
        Go through the other femtocells in cluster starting from the closest to find candidates for hybrid mode to reallocate sleeping femtocell users
        for each femtocell ∈ same cluster do
            Constraint 1: Reallocated users retain or improve performance $SINR_{New} \geq \frac{(1+aSINR_{Old})^{(N_2+1)/N_1}-1}{a}$
            Constraint 2: Users of hybrid mode femtocell retain or improve performance $SINR_{New} \geq \frac{(1+aSINR_{Old})^{(N_2+1)/N_2}-1}{a}$
            if Constraint 1 & 2 stand then
                Appointed femtocells go to sleep and hybrid mode
                break;
            end if
        end for
    end for
end for
exit
```

Femtocells communication

A distributed mechanism such as the one described above, faces the challenge of coordination/communication among the femtocells. Signalling among femtocells for interference is necessary, as explained in [12]. To accommodate this, LTE-A has included in its specifications the support for direct femtocell to femtocell communication through X2 protocol[13][14], making coordination for implementing interference mitigation mechanisms possible. Still, however, the disadvantages of signalling overhead and the limitations of computational capabilities of femtocells remain.

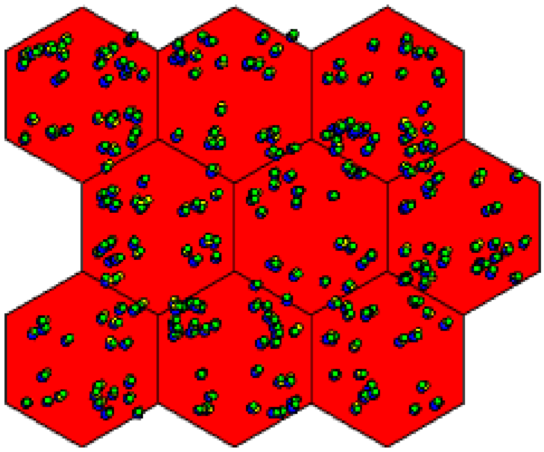

Fig. 2. Instance of the network.

IV. PERFORMANCE EVALUATION

In this section, we provide information on the simulation framework and the parameters of the network model. Afterwards, we present the experimental results obtained.

A. Simulation parameters

The simulator's network configuration consists of 9 macrocells with 250m radius each. The macro base station is considered to be located at the center of each site, transmitting with a predefined power value of 46dBm. We randomly deployed 250 femtocells with their users in a random distance within 18m from the base station. The number of subscribers for every femtocell was also chosen randomly, with each having 1 up to 3 users. 100 macrocell users were also deployed. Fig. 2 shows an instance of the topology of the network and Table 1 provides an overview of the network and technology parameters used in the simulation. Parameter values were based on LTE-A technology and the LTE simulator in [16].

B. Performance results

The simulation was conducted 20 times in order to provide reliable measurements, and the figures below represent the accumulative results. Fig. 3 depicts the empirical cdf of the SINR experienced by femtocell users belonging to the clusters. It is obvious that there is a significant improvement in the SINR when our proposed scheme is enforced, compared to the initial CSG operation of the femtocells. A part of this improvement comes from the users who belong to femtocells that participated in the user exchange, that is the femtocells that turned to sleep mode and their neighbors that admitted their users. Based on the constraints described in the previous

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Macrocells	9
Macrocell radius	$500\ m$
Femtocells	250
Femtocell subscribers	$1-3\,(per femtocell)$
Macrocell users	100
Bandwidth	$20\ MHz$
Carrier frequency	$2\ GHz$
BS transmit power	$46\ dBm$
FBS max transmit power	$21\ dBm$
Subcarrier spacing	$15\ kHz$
White noise power density	$-174\ dBm/Hz$

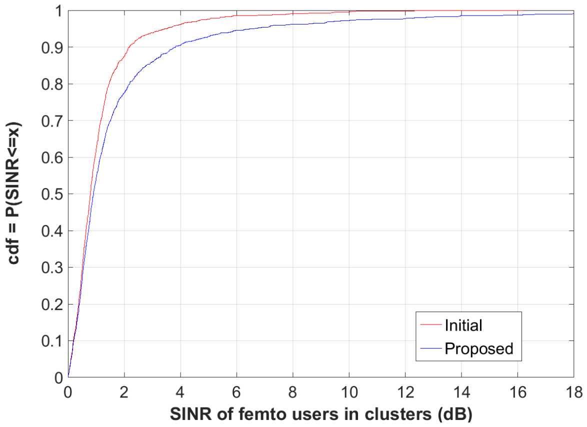

Fig. 3. SINR of all users subscribed to femtocells that are members of clusters.

section, the increase in their SINR due to less interference from the sleeping base stations must be large enough to more than compensate for the reduced spectrum per user due to utilization of less base stations. The other part of the total increase comes from the rest femtocells belonging to the cluster where a base station has turned to sleep mode, since the total interference in the area has reduced.

The algorithm aims ultimately to increase subscribers' data rate, with the combination of sleep mode and cluster-based hybrid access, adapting the number of active base stations to the actual needs of the topology. Fig. 4 depicts the improvement on the data rate of all femtocell subscribers that belong to the clusters. Similar with the SINR, the improvement comes both from the smarter reallocation of users, and the overall interference reduction in the area from deactivating femtocells. While the figure showcases the accumulative performance of the users, none of the users individually experiences reduction in his/her achieved data rate because of the strict constraints enforced.

The reduction of the overall interference in a cluster area when one or more femtocells go to sleep mode, is also important for the users served by the macrocell. These users are greatly affected by the increased density of deployed base stations since they experience the accumulated interference. Since the proposed scheme does not affect the power levels of the rest femtocells when one of them enters sleep mode, it is obvious that when in a cluster area, macro users will greatly benefit when a nearby femtocell gets deactivated. Fig. 5 illustrates this positive effect in these users' data rate.

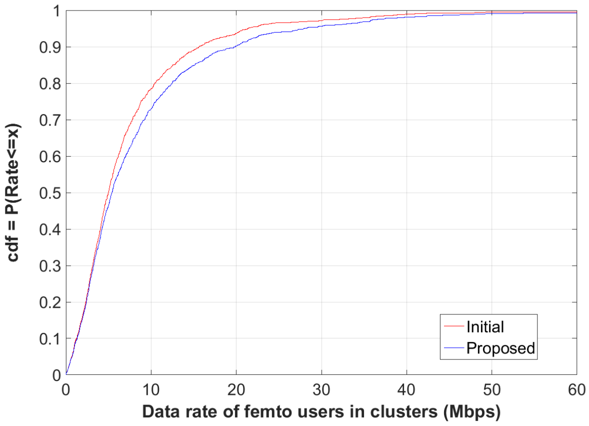

Fig. 4. Data rate of all users subscribed to femtocells that are members of clusters.

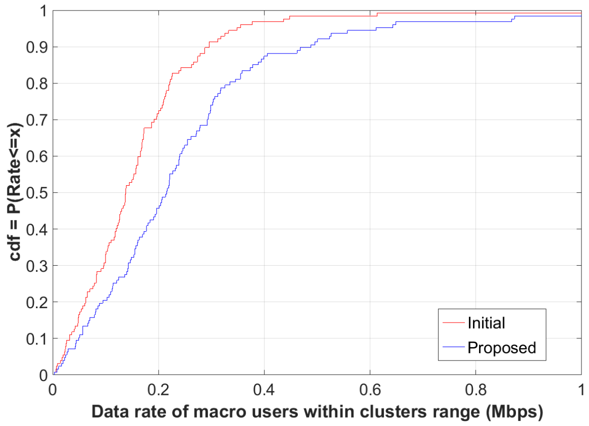

Fig. 5. Data rate of macrocell users that are within areas where a femtocell cluster has formed.

In every simulation, the deployment was randomly different which caused the formation of the clusters and the applicability of the mechanism to change. For the parameters discribed above, the average number of clusters formed was close to 14 ranging from 7 to 21. The average number of femtocells transitioning to sleep mode was close to 3 (ranging from none to 9) and the probability every cluster to have one femtocell in sleep mode was around 20%.

Finally, we must mention the gains in energy efficiency of the proposed scheme. While our main target introducing the scheme was the improvement of the data rate when the density of exclusive base stations results to more interference than performance gain, it is obvious from the works mentioned in the first section that femtocell sleep mode strategies yield to significant power savings. Thus, along with the performance boost, our setup has also the important side effect of better energy efficiency.

V. CONCLUSIONS AND FUTURE WORK

In this paper we introduced a scheme targeting dense deployments of femtocells. The scheme proposes a combination of sleep and hybrid access mode causing a boost in the subscribers' data rate by reducing the number of active base stations. More specifically, a femtocell-member of such a cluster operating in closed access mode, may decide to extend its list of admitted users to include users of another femtocell-member of the same cluster. A necessary condition is the latter femtocell to turn to sleep mode, causing enough interference reduction to the former femtocell subscribers in order to compensate for the admission of extra users. The users that change their serving base station must be also guaranteed at least the same level of performance that they experienced when served by their primary femtocell.

Conducted simulations showed that our proposed scheme increases the data rate of all individual subscribers involved in the exchange, those belonging to the femtocell in sleep mode and those belonging to the one in hybrid access mode. Due to the deactivation of some base stations, the subscribers of the rest femtocells also experience better data rate caused by the reduced interference in the area, increasing the overall capacity provided by the femtocell cluster, something that also benefits the data rate of any close-by macrocell user. In addition, an important side effect of the reduced number of active base stations is the improvement in energy efficiency.

Possible future enhancements of this work may be the estimation of the proposed algorithm's benefits in energy efficiency. Another possible enhancement would be the loosing of constraints for the scheme to be enforced and compare the results. For example, instead of the requirement of each user individually improving his/her data rate, the mechanism could be activated when gains are noticeable in the total capacity of the femtocells involved, or in the entirety of the cluster.

REFERENCES

[1] A. Osseiran, F. Boccardi, V. Braun, K. Kusume, P. Marsch, M. Maternia, O. Queseth, M. Schellmann, H. Schotten, H. Taoka, H. Tullberg, M. Uusitalo, B. Timus, and M. Fallgren, "Scenarios for 5G mobile and wireless communications: the vision of the METIS project," *Communications Magazine, IEEE*, vol. 52, no. 5, pp. 26–35, May 2014.

[2] I. Ashraf, F. Boccardi, and L. Ho, "Sleep mode techniques for small cell deployments," *IEEE Communications Magazine*, vol. 49, no. 8, pp. 72–79, August 2011.

[3] E. Mugume and D. K. C. So, "Sleep mode mechanisms in dense small cell networks," in *2015 IEEE International Conference on Communications (ICC)*, June 2015, pp. 192–197.

[4] S. Samarakoon, M. Bennis, W. Saad, and M. Latva-aho, "Dynamic clustering and sleep mode strategies for small cell networks," in *2014 11th International Symposium on Wireless Communications Systems (ISWCS)*, Aug 2014, pp. 934–938.

[5] S. Ali, M. Ismail, and R. Nordin, "Femtocell sleep mode activation based interference mitigation in two-tier networks," *Procedia Technology*, vol. 11, pp. 1088 – 1095, 2013, 4th International Conference on Electrical Engineering and Informatics, {ICEEI} 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2212017313004520

[6] 3GPP TR 36.814 V9.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)," 3rd Generation Partnership Project, Tech. Rep., 2010.

[7] L. T. W. Ho and H. Claussen, "Effects of user-deployed, co-channel femtocells on the call drop probability in a residential scenario," in *2007 IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications*, Sept 2007, pp. 1–5.

[8] H. Claussen, "Performance of macro- and co-channel femtocells in a hierarchical cell structure," in *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, Sept 2007, pp. 1–5.

[9] H. Lei, L. Zhang, X. Zhang, and D. Yang, "A novel multi-cell OFDMA system structure using fractional frequency reuse," in *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, 2007, pp. 1–5.

[10] P. Lee, T. Lee, J. Jeong, and J. Shin, "Interference management in LTE femtocell systems using Fractional Frequency Reuse," in *12th International Conference on Advanced Communication Technology 2010 (ICACT'10)*, vol. 2, 2010, pp. 1047–1051.

[11] L. Li, M. Wei, C. Xu, and Z. Zhou, "Rate-based pricing framework in hybrid access femtocell networks," *IEEE Communications Letters*, vol. 19, no. 9, pp. 1560–1563, Sept 2015.

[12] 3GPP Technical Report 36.921, "FDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis," Tech. Rep.

[13] 3GPP TS 36.133, "Requirements for support of radio resource management," Tech. Rep.

[14] 3GPP TR 36.300, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description," Tech. Rep.

[15] C. Herranz, V. Osa, J. F. Monserrat, D. Calabuig, N. Cardona, and X. Gelabert, "Cognitive radio enabling opportunistic spectrum access in lte-advanced femtocells," in *2012 IEEE International Conference on Communications (ICC)*, June 2012, pp. 5593–5597.

[16] M. Simsek, T. Akbudak, B. Zhao, and A. Czylwik, "An LTE-femtocell dynamic system level simulator," in *Smart Antennas (WSA), 2010 International ITG Workshop on*, Feb 2010, pp. 66–71.