Coordination strategy for dense 5G femtocell deployments

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*—The demand of next generation mobile networks for high connectivity for multiple devices with tenfold data rate requires the deployment of multiple base stations of different range and capacity and their optimal management. Femtocells will play a major role in these heterogeneous networks, being a low-cost and effective solution. In this paper we propose a mechanism on management of femtocells' resources, based on spectrum allocation policies, power control and user classification. We combine hybrid access operation with user redistribution to provide a complete mechanism for resource allocation in dense femtocell deployments. Simulations show that the proposed scheme increases the capacity provided by the involved femtocells, it guarantees service to non-subscribers and balances the performance of the subscribed users improving the worst cases.**

Keywords*—*femtocells, power control, hybrid access

I. INTRODUCTION

In the upcoming dense mobile networks, heterogeneity plays a significant part. Multiple base stations of different range and capacity capabilities will be deployed to efficiently utilize the spectrum, and provide the high data rates promised by the 5G requirements. Femtocells will play a major role due to their low cost, user-maintained nature and efficiently targeting local needs. However, this massive deployment of base stations (BS) will also create interference issues on nearby users served by the macrocell or neighboring femtocells without coordination. Hybrid access femtocells provide a way to overcome partially this problem. While in open access every user may get freely served by the femtocell and in closed access only users belonging to the femtocell's Closed Subscriber Group (CSG) list may get served, hybrid access suggests a compromise. It ensures that any user within the femtocell's range has a partial access to its resources, either they belong to the CSG or not. This proves beneficial for users that do not belong to any of the nearby femtocells and at the same time suffer from the interference by them all. However, due to different priorities of the users and the private-owned nature of the femtocell, the conditions under which a user gets served and the exact amount of the resources dedicated to him/her is dependent on multiple factors and a matter of research.

The authors in [1] propose a mechanism in resource partitioning that takes into account the pre-experienced Signal to interference plus noise ratio (SINR) value of the non-CSG users, to determine the upper and lower bound of spectrum regions that may be allocated to these users. [2] searches for the allocation of channels in open access for the macro users, based on an activity profile created to compute the maximum achievable throughput and the consumed energy per transmitted data bit by the macro users. Multichannel hybrid access femtocells are the focus of [3]. It considers a randomized channel assignment strategy, and using stochastic geometry, it models the distribution of femtocells as Poisson point or Neyman-Scott cluster process to derive the distributions of SINR, and mean achievable rates. In [4] an algorithm for spectrum shared hybrid access femtocells is proposed, that determines resource allocation based on users satisfaction and on the level of network congestion. The authors in [5] propose a pricing mechanism that decides for the hybrid access of femtocells non-subscribers. In order to provide motivation for femtocells to share resources, the mechanism considers multiple femtocells by different providers that must compete for the profit gained by serving the user. While the above papers present efficient ways to utilize hybrid access femtocells' resources, they do not investigate the matter from the perspective of the coordination between several femtocells closely deployed, forming a femtocell cluster, that all or most of them operate in hybrid access.

In this paper, we exploit the upcoming 5G network density to expand the concept of hybrid access. We propose an algorithm based on coordination among the femtocells that participate in a femtocell cluster towards two goals. First to distribute the resource burden of hybrid access evenly among the femtocells, and secondly to redistribute users in order to increase the total capacity provided by the cluster. In order to respect issues arisen from femtocells being privately owned entities, we define the context of the mechanism through user classification and prioritization. We manage to increase the capacity provided by the cluster and increase the number of served users through spectrum allocation and power control. Non-subscribers in the area are spared from the accumulative interference without affecting severely individual femtocells while the redistribution of the subscribed users ensures the improved resource utilization regarding fairness and performance.

The structure of the paper is as follows. Section II presents the system model and our assumptions. Section III presents a detailed description of our proposed mechanism. Section IV contains the simulation results conducted to estimate the performance of our mechanism. Finally in the last section, we draw our conclusions.

II. SYSTEM MODEL

We consider working under the Orthogonal Frequency Division Multiplexing (OFDM) system model. We follow

978-1-5090-2914-3/16/$31.00 ©2016 IEEE

the Orthogonal Frequency-Division Multiple Access scheme (OFDMA) used by Long Term Evolution Advanced (LTE-A), with 12 subcarriers per physical resource block. For the evaluation of the performance we are based on SINR calculation, through the power received by the user from the serving station, versus the interfering power received by the proximal macro BSs and femto BSs. Specifically, the SINR of a macrocell user is provided by [6]:

$$SINR_{m,k} = \frac{H_{M,k}}{\sigma^2 + \sum_{M'} H_{M',k} + \sum_{F} H_{F,k}} \quad (1)$$

where $H_{X,k} = P_{X,k} * G_{m,X,k}$ is the transmit power of base station X, multiplied by the channel gain between user m and BS X on sub-carrier k. $M, M' and\ F$ represent serving macrocell, interfering macrocells and interfering femtocells respectively. $\sigma^2 = N_0 \Delta f$ is the white noise power spectral density multiplied by the sub-carrier spacing. The calculation for a femtocell user is similar. Before the power control mechanism of Section III takes place, the pilot power transmission of the femtocell is defined in order to achieve a constant radius of coverage [7]:

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

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 macrocell antenna gain. $PL_m(d)$ denotes the average macrocell path loss at the femtocell distance d (excluding any additional wall losses and $Pmax$ is the maximum allowed transmit power). Based on the SINR found above, if $\alpha = -1.5/ln(5BER)$ with BER being the Bit Error Rate equal to 10^{-6} and $\beta_{x,k} = 1$ when the subcarrier k is assigned to user x and $\beta_{x,k} = 0$ otherwise, the practical capacity of a user x on sub-carrier k and the overall throughput of serving BS B is given by the following [6] [8]:

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

$$T_B = \sum_x \sum_k \beta_{x,k} C_{x,k} \quad (4)$$

III. Proposed scheme

The proposed scheme dictates the allocation of resources among the femtocells that have been characterized as members of the same cluster. The mechanism operates on three levels. Firstly, the distribution of users among the available BSs. Secondly, the spectrum allocation among the users that qualify to connect to any of the femtocells. Thirdly, the power levels of the femtocell's BSs. The mechanism takes into account any user that moves within the range of the femtocells-members.

A. Clustering

First we define the conditions upon the mechanism applies. A femtocell cluster has to be formed, that is multiple femtocells closely deployed. We define a femtocell to be qualified as a member of a cluster, when it is deployed at a distance of less than 25 meters of at least two other cluster members.

B. User classification

The first factor that needs to be considered prior to the power level and spectrum allocation is the classification of the users. We define three levels of significance where users can belong. The first and most important level is the CSG of the femtocell under examination. Its subscribers have rightfully the utmost priority, since the femtocell is first of all a private entity. We will refer to these as Class A users.

The second class (Class B) consists of the subscribers (CSG) again, but the ones of neighboring femtocells, that have been attributed the term cluster member of the same cluster the femtocell in question belongs to. The significance of Class B users comes after Class A and before every other user, affecting their priority and thus, the resources that they will acquire.

In the bottom of the hierarchy, there are the rest of the users. They can be users belonging to a femtocell's CSG but this femtocell is not a cluster-member, or users served by the macrocell. These users are considered last during the resource allocation, thus they are entitled the smallest portion of the resources. For convenience the user of this class (Class C) will be referred to as macrocell user, despite the fact that he may initially belong or ultimately be admitted by a femtocell.

C. Spectrum allocation and power control

Based on the classification above, the mechanism decides the spectrum allocation and the power level of every member of the cluster, under the following goals and assumptions:

i. Class A users must experience the relatively smallest decrease on performance compared to pre-hybrid mode operation. They also must retain the advantage of owing the femtocell.

ii. Class B users are eligible to find a neighbour BS to be admitted to improve their performance. Thus, they are allocated the spectrum required to increase their throughput compared to connecting to their origin femtocell.

iii. Necessary condition for the admission of a Class B user is the increase of the overall capacity offered by the two femtocells involved (target and origin), otherwise the femtocell is not admitted. This protects the reduction of capacity in favour of a single user's performance.

iv. Class C users are allocated the spectrum required to achieve the performance they experienced before the deployment of the femtocell. These are the main victims of a cluster, since they experience the accumulative interference. The aforementioned rule is aligned with the general guideline that a newly deployed femtocell must have minimum impact on the existing network. Recreating the prior performance can be achieved with little resources, since we examine indoor scenarios and prior performance is degraded by the attenuation.

v. The power levels of each femtocell are determined in order to avoid extensive decrease on the performance of individual femtocells because of the aforementioned hybrid access operation. Thus, power control compensates for the decrease of less spectrum utilization by Class A and Class B users, by balancing power levels in favour of femto BSs that have allocated significant resources to Class C users, and at the expense of BSs that have allocated little or none at all.

These goals define the context of resource management by respecting femtocell owners, redistributing subscribers optimally among the BSs (through the introduction of Class B users) and admitting non-subscribers with the least individual cost. Expressing the above formally, for the spectrum allocated to the first class $SP_{A,X}$, the second class $SP_{B,X}$ and the third class user $SP_{C,X}$, where X denotes the base station the user connects to, we get :

$$\frac{SP_{C,F}}{SP_{C,M}} = \frac{(log(1 + SINR_{C,M}))}{(log(1 + SINR_{C,F}))} \tag{5}$$

based on the system model of section II and because we want $THR_{BEF} = THR_{AFT}$ (restriction iv), with THR_{BEF} denoting the throughput of the non-subscriber before the deployment of femtocell, and THR_{AFT} the target throughput of the user under the service of the femtocell. The above activates the restriction (v), where the power control distributes the loss of the part of that femtocell's spectrum to the rest members of the cluster. Thus, the power adjustment downwards will be greater for femtocells with small decrease on their subscribers' SINR, in order to decrease interference to their neighbours that have allocated more spectrum to hybrid access. Thus the power adjustment for femtocell i is:

$$PC(i) = \sum (SINR_{d,i} - SINR_{d,j}) \cdot a \cdot \frac{P_{i,k} G_{x,i,k}}{N_0 \Delta f + \sum\limits_{M} P_{M,k} G_{x,M,k} + \sum\limits_{F} P_{f,k} G_{x,f,k}}, f \neq j \tag{6}$$

$$where\ a = \begin{cases} 1, & \text{if } SINR_{d,j} - SINR_{d,i} > 0 \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

The first term makes sure that reduction depends on the femtocell's SINR reduction ($SINR_{d,i}$) compared to its neighbours ($SINR_{d,j}$).. The second term a makes sure that any power reduction will take place only for femtocells experiencing large reduction. Finally, the third term represents the effect that the adjustment will have to its neighbours. The latter protects from unnecessary power reduction (and ultimately capacity reduction) when no benefit is expected. Under the assumption that as a member of the cluster, the dictating sources of interference are nearby femtocells, we then evaluate the power transmission of femtocells through:

$$P_{new(i)} = (1 + PC(i)) \cdot P_{curr}(i) \tag{8}$$

with $P_{new(i)}$ and P_{curr} denoting the new and the current power level transmission of the femto BS, respectively. Restrictions (i),(ii),(iii) can be expressed by:

$$min : \frac{SP_{B,B} \cdot log(1 + SINR_{B,B})}{log(1 + SINR_{B,A})} \tag{9}$$

$$max : min(\frac{SP_{TOT}}{\#users}, SP_{TOT} - \frac{SP_{A,M} \cdot log(1 + SINR_{A,M})}{log(1 + SINR_{A,F})}) \tag{10}$$

Algorithm 1 Resource allocation

```
Define clusters and categorize users
-Class A: Subscribers
-Class B: Same cluster's femtocells' subscribers
-Class C: Others
if Class C then
    {calculate required spectrum for Class C}
    SP_{C,F} = SP_{C,M}·(log(1+SINR_{C,M})) / (log(1+SINR_{C,F}))
end if
Power control for all femtocells in the cluster to compensate for distribute hybrid access impact
for femtocells i,u ∈ cluster and j u's user do
    {Poweradjustment = (SINRnegativereductiondifference)* (Impact on j by i)/(Impact by all)}
    Padj(i) = ∑(SINR_{d,i} − SINR_{d,j})· a· P_{i,k}G_{x,i,k} / (N_0Δf + ∑_M P_{M,k}G_{x,M,k} + ∑_F P_{f,k}G_{x,f,k}), f ≠ j
    where a = 1, if SINR_{d,j} − SINR_{d,i} > 0; 0, otherwise
    {calculate power transmission}
    P_{new(i)} = (1 + PC(i)) * P_{curr}(i)
end for
if Class A OR Class B then
    allocate all available spectrum
end if
if Class A AND Class B then
    calculate min/max spectrum for Class B user while below rules apply
    min : SP_{B,B}·log(1+SINR_{B,B}) / log(1+SINR_{B,A})
    max : min(SP_{TOT}/#users, SP_{TOT} − SP_{A,M}·log(1+SINR_{A,M}) / log(1+SINR_{A,F}))
    CAP_{BEF} < CAP_{AFT}
end if
```

with $SP_{B,B}$ denoting the spectrum the user of the second class utilized when served by its origin femtocell, $SINR_{B,A}$ and $SINR_{B,B}$ the same user's SINR when connected to its neighboring and origin femtocell, respectively, $SINR_{A,M}$ and $SINR_{A,F}$ the first class user' SINR when connected to its femtocell and the macrocell, respectively and SP_{TOT} the available femtocell spectrum. Any change on the topology may trigger re-evaluation. Algorithm 1 summarizes the mechanism.

IV. Performance evaluation

In this section we present the results obtained by the evaluation of the proposed scheme with the help of simulations.

A. Simulation parameters

For the simulation we consider a network of 12 macrocells of 250m radius. The macrocell BS is located at the center of each cell, transmitting at 46dBm. 250 femtocells and their subscribers were deployed randomly. Each femtocell could have up to three subscribers. Their deployment was random up to 15 meters away of the BS. Next, 250 non-subscribed users were deployed in the area to represent candidate users for hybrid access. Users were considered static in urban

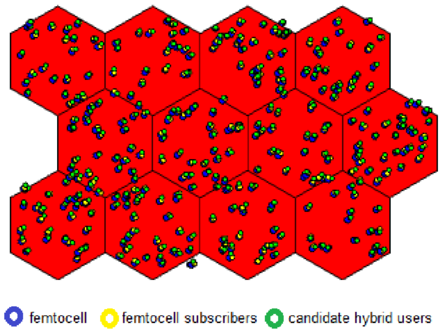

Fig. 1. Instance of the topology during the simulations.

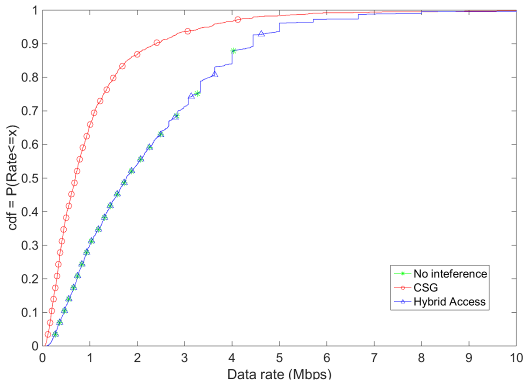

Fig. 2. Class C users' data rate before and after the interference from nearby femtocell and when connected to it. The latter restores fully the initial performance, therefore the No interference and Hybrid Access cases coincide.

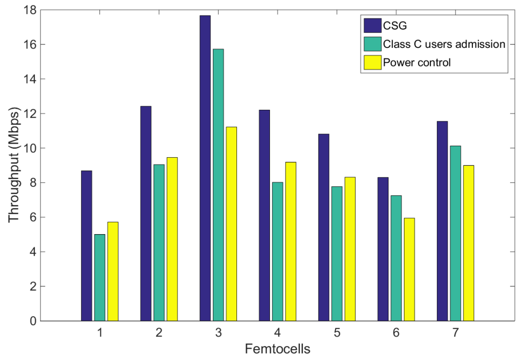

Fig. 3. Data rate of the subscribers of 7 femtocells-cluster members in CSG mode, after hybrid access mode (less spectrum) and after power control.

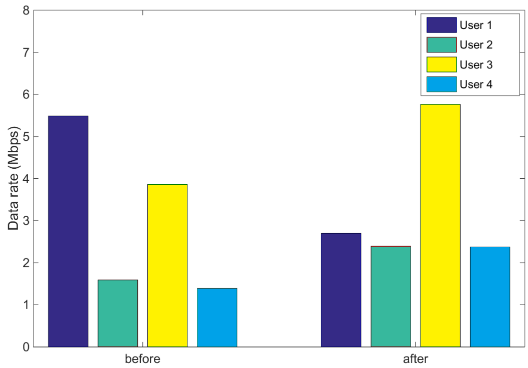

Fig. 4. Throughput of 4 subscribers of two femtocells before and after user redistribution. Initial distribution of 1 and 3 users to each femtocell leads to 2 users per femtocell with fairer throughput and increased overall capacity

environment with full buffer traffic. Path loss calculation was based on LTE-A specification [9]. The available spectrum was 10MHz. The selection of simulation parameters was based on 3GPP specifications [9] and LTE simulator [10]. Experiments depicting Cumulative Distribution Functions (cdfs) were conducted 20 times and the average results are presented. In the figures depicting cdfs, the lines represent hundreds of points, therefore the markers appearing on these lines have only been placed scarcely to facilitate distinction between the lines.

B. Performance results

To evaluate the mechanism, we first present the effect that each step of the algorithm has on the performance of the users and then its overall impact. Starting from the resource allocation for the Class C users, Fig. 2 depicts the performance of these users on three instances: if there would be no femtocell in their proximity, when the femtocells are deployed under CSG operation mode and when the users gets admitted to them according to the scheme. We observe two important things from the figure. First, we note the significant impact of interference on nearby non-subscribers. Secondly, we see that the mechanism's goal was achieved since femtocells restored successfully the performance of these users and the two lines (No Interference and Hybrid access) coincide.

Next we examine the impact of the above user admissions by the femtocells on their subscribers and how the power control attempts to eliminate part of it by distribution among the members of the cluster. Fig. 3 depicts an instance of a cluster containing 7 femtocells. For each femtocell we present three states (columns) of the performance of their subscribers (Class A,B users): when the femtocell operates in CSG, when hybrid access is established to admit Class C users and when the power control is in effect. The first column of each member is always the largest since it represents the CSG case where all resources are utilized by the subscribers. The second makes obvious the uneven decrease on the performance between the members depending on the resources required to be allocated in hybrid access. The third column shows how the power control balances this effect by increasing data rate for femtocells 1,2,4 and 5 that had suffered greater decrease at expense of femtocells 3,6 and 7 that had experience smaller decrease (as a percentage). As explained in previous section the impact of power control depends on how much uneven hybrid access is among the members and how much the topology allows it without significant loss in overall capacity.

Then we examine the effect of users' redistribution. Fig. 4 presents an instance of two femtocells that initially serve 1 (User 1) and 3 users (Users 2,3 and 4), respectively. The figure shows their performance before and after the admission of User 2 by its neighboring femtocell. This leads to the performance increase of Users 2,3 and 4 at expense of User 1. The way the mechanism is structured allows User 1 to still experience adequate data rate, while increasing the one of users with the worst performance, and improving the overall capacity these

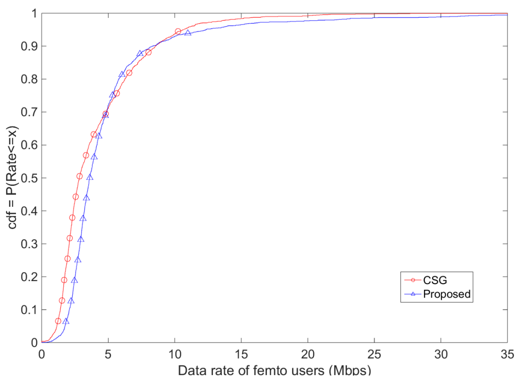

Fig. 5. Cdf of the capacity provided by the femtocells whose users were affected by the redistribution. Overall provided capacity was improved.

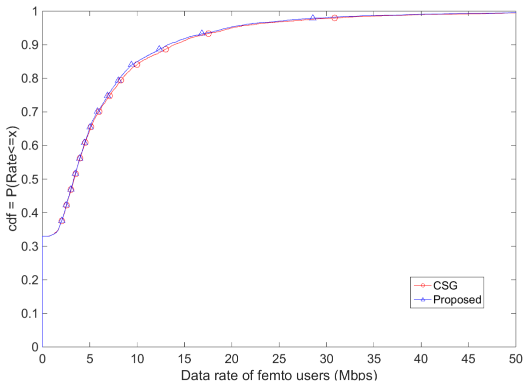

Fig. 6. Cdf of the capacity provided by the entirety of femtocells in the network before and after the proposed algorithm. Power control and user redistribution made the decrease due to hybrid access negligible.

two femtocells provide to their subscribers. The increase of the overall capacity can clearly observed in Fig. 5, where we see the overall capacity provided by femtocells that participate in the redistribution of the users, before and after the algorithm.

Finally, Fig. 6 presents the capacity of every Class A and B user before and after the entire algorithm takes place. These users are subscribers thus we compare the algorithm with their performance under CSG mode. We see that the reduction of their performance is insignificant considering that at the end of the algorithm hundreds of non-subscribers have been admitted by the femtocells. It is the power control and the redistribution of the users that makes the mechanism compensate almost completely for the loss of resources due to hybrid access.

C. Limitations

There are some limitations regarding the algorithm's applicability. In scarce deployments where no clusters are formed, the power control and the user re-association do not apply. In addition, the power control applies to scenarios where the femtocells have allocated different portion of spectrum to non-subscribers. If the femtocells have dedicated a similar amount, it has little benefit and it results to unnecessary computational burden. Finally, distributed mechanisms suffer from femtocells' communication limitations and computational capabilities and signalling overhead. Communication between femtocells is supported in LTE-A through X2. Regarding computational capabilities and signalling overhead, there are novel suggested approaches that could be adapted to overcome or mitigate these problems [11].

V. Conclusions and Future Work

In this paper, we presented a complete scheme of resource management that extends hybrid access mode in femtocells. It is based on femto BSs clustering and user classification, and defines the context for power control, spectrum allocation and user redistribution. Based on the evaluation, the introduced algorithm was found to have multiple advantages. It restores non-subscribers performance through hybrid access operation mitigating the interference and decreasing the load of the macro tier. It distributes the burden of non-subscribers admission to multiple BSs improving the fairness and reducing the extreme deterioration on individual ones. Finally, it increases the utilization of resources through redistribution of users increasing the capacity provided by the femtocells in the cluster, improving the performance of the worst case users and respecting the owners of the femtocell. On the downside, power control and non-subscribers' admission have a small negative impact on the subscribed users' performance.

References

[1] K.-T. Cho and B. H. Ryu, "Partitioning resource priority regions for hybrid access mode femtocells," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on*, 2012, pp. 625–630.

[2] E. Bernal-Mor, V. Pla, D. Gutierrez-Estevez, and J. Martinez-Bauset, "Resource management for macrocell users in hybrid access femtocells," in *Global Communications Conference (GLOBECOM), 2012 IEEE*, 2012, pp. 1859–1864.

[3] Y. Zhong and W. Zhang, "Multi-channel hybrid access femtocells: A stochastic geometric analysis," *Communications, IEEE Transactions on*, vol. 61, no. 7, pp. 3016–3026, 2013.

[4] M. I. Afaz Uddin Ahmed, Mohammad Tariqul Islam and M. Ghanbarisabagh, "Dynamic resource allocation in hybrid access femtocell network,," *The Scientific World Journal*, vol. 2014, no. Article ID 539720, p. 7 pages, 2014.

[5] Y. Chen, J. Zhang, and Q. Zhang, "Incentive mechanism for hybrid access in femtocell network with traffic uncertainty," in *Communications (ICC), 2013 IEEE International Conference on*, June 2013, pp. 6333–6337.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] 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.

[11] 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.