Femtocells Coordination in Future Hybrid Access Deployments

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Abstract— **Femtocells provide an attractive solution to locally improve the data rates and the coverage of future mobile networks including 5G. However, nearby non-subscribed users may experience severe interference. Hybrid access operation allows femtocells to serve non-subscribers by allowing them access to part of the spectrum. In this work, we propose a distributed process that allows the hybrid femtocell to defines the spectrum access for the two types of users. The mechanism takes into account the prior condition of the users and tries to minimize the femtocell's impact to the rest of the network. We also introduce a power control mechanism within clusters of femtocells. The mechanism relieves the femtocell operating in hybrid access mode and its subscribed users, by coordinating accordingly the nearby femtocells' transmission.**

Keywords— **hybrid access femtocells; interference mitigation; heterogeneous networks;**

I. Introduction

In mobile telecommunications, the theoretical maximum throughput per link is almost reached, and higher spectral efficiency per unit area is pursued. Achieving this via macrocell infrastructure is expensive. Therefore, heterogeneous networks are expected to conquer mobile networks in this generation and the next (5G). Specifically femtocells present an attractive solution to exploit the available spectrum locally and provide better data rates and coverage [1].

Femtocells may be configured to operate in different access modes, open, closed and hybrid. In close access, femtocells maintain a list of User Equipments (UEs), known as Closed Subscriber Group (CSG), that may be served by the femtocell when within its range. However, it may cause severe interference to non–subscribers in the vicinity of the femto Base Station (BS) requiring frequency reuse schemes and power control for its mitigation [2]. 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.

Hybrid access is a compromise between the previous two. In hybrid access, both macro and femto UE (MUE, FUE) are allowed access to femtocells spectrum when inside its coverage area. However, since subscribers are the rightfully owners of the femtocell and the backhaul connection, they usually maintain a priority on resources utilization. The decision over the allocation of resources in hybrid access is a complex task and many methods have been proposed.

In [3], a power control algorithm is proposed that can provide QoS support in minimum signal-to-interference-plus-noise ratios (SINRs) for all users while exploiting differentiated channel conditions. The algorithm uses non-cooperative game theory and applies it to a hybrid access scheme through a distributed load-award association for macro users, which enables flexible user association to BSs of either tier. The authors in [4] propose a mechanism in resource partitioning that takes into account the pre-experienced SINR value of the non-CSG users, to determine the upper and lower bound of spectrum regions that may be allocated to these users.

In [5], the authors search for the optimal 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 successfully transmitted data bit by the macro users. Multichannel hybrid access femtocells are the focus of the work in [6][6]. Specifically, 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 this work, we propose a mechanism that accommodates the femtocell to define the portion of the spectrum that may be utilized by non-subscribed users. The mechanism determines the required spectrum allocation in order for the non-subscribed user to reach, if possible its levels of performance before the deployment of the femtocell.

Secondly, we propose a coordinated power control mechanism between the members of the femtocell cluster. The mechanism is triggered when a femtocell's CSG users experience performance degradation due to hybrid access operation. It then enforces nearby femto BS to adjust their transmission parameters to compensate partially for the above degradation. Its performance is compared with CSG deployment and fixed hybrid access policy in terms of user throughput through test simulations.

The rest of this manuscript is structured as follows: Section 2 describes the system model analysis. Section 3 presents the proposed mechanisms regarding femtocells transmission and in Section 4 we evaluate these mechanisms through simulations and comparisons. Finally in Section 6 our conclusions are drawn up and proposals for future work are suggested.

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II. METHODOLOGY

Hybrid access femtocell divides radio resources of a femtocell into two regions for non-CSG and CSG users. This method guarantees the CSG members' throughput is not affected by sharing the resource with non-CSG users. In this work we focus on Frequency Division Duplex (FDD) systems, and the allocation of the resources is based on Orthogonal Frequency Division Multiple Access (OFDMA), which means it is done in terms of resource blocks of 12 subcarriers, the minimum unit that can be allocated to a user.

When the same spectrum is utilized by two BSs, the resulting interference is evaluated through the achieved Signal to Interference and Noise Ratio (SINR) of the users. For a user connected to a macrocell and interfered from neighbouring macrocells and adjacent femtocells, this is given through [7]:

$$SINR_{m,k}=P_{M,k}G_{m,M,k}/(N_0\Delta_f+\sum_{M'}P_{M',k}G_{m,M',k}+\sum_F P_{F,k}G_{m,F,k}) \quad (1)$$

where $P_{M,k}$ is the transmit power of serving macro base station on subcarrier k, $G_{m,M,k}$ is the channel gain between the serving BS and user m on subcarrier k and channel gain from neighboring macrocells are denoted by $G_{m,M',k}$. Similarly, $P_{F,k}$ is the transmit power of neighbouring femtocell F on subcarrier k and $G_{m,F,k}$ is the channel gain between macro user m and neighboring femtocell F on subcarrier k. N_0 is white noise power spectral density, and Δ_f is the sub-carrier spacing. Similarly we compute the femtocell experienced by a user connected to a femtocell. The channel gain is evaluated by:

$$G=10^{(-PL/10)} \quad (2)$$

where, PL represents the propagation path loss and for an indoor macro user in distance R is estimated by [9]:

$$PL(db)=15.3+37.6log10(R)+L_{ext} \quad (3)$$

with L_{ext} representing the penetration loss of an external wall. Similarly, PL between a femto BS and a UE is given by:

$$PL(db)=38.46+20log10(R)+L_{int} \quad (4)$$

with L_{int} representing the penetration of an interceded internal wall. The respective capacity, then, becomes:

$$C_{m,k}=\Delta f*log_2(1+aSINR_{m,k}) \quad (5)$$

where a is defined by a=-1.5/ln(5BER). The overall throughput of serving macrocell M can then be expressed [8]:

$$T_M=\sum_m\sum_k\beta_{m,k}C_{m,k} \quad (6)$$

where $\beta_{m,k}$ notifies the sub-carrier assignment for macrousers. 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 capacity and throughput [8].

For the needs of our simulations, we consider the following configuration to determine the initial power transmission of femtocells. The method is introduced in [10], and ensures a constant coverage femtocell radius. 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 P_max. The FBS transmit power can be calculated in decibels as:

$$P_f=min(P_m+G_\theta-PL_m(d)+PL_f(r), P_{max}) \quad (7)$$

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 macro BS in which the femtocell is located and G_θ is the antenna gain. $PL_m(d)$ denotes the average macrocell path loss at the femtocell distance d (excluding any additional wall losses).

III. PROPOSED MECHANISMS

In this section we propose two mechanisms that dictate femtocell transmission parameters. The first coordinates femtocells and macrocells, to establish hybrid access mode for femtocells when required. The second takes place between femtocell clusters, i.e. multiple femto BS deployments in a small area, and how they coordinate their power transmission, to relief the performance reduction of an individual femto BS, because of its hybrid access operation.

A. Threshold region determination

When a non-subscribed user is connected to a femtocell, a portion of its resources will be allocated to this user. The spectrum allocated to the external user should be dependent on various parameters. Full freedom cannot be granted, and a upper limit must be set to protect primary (subscribed) users. Since they are in priority due to the private ownership of the femtocell and the utilization of their own backhaul connection, the selection favors them. A factor of at least 3 is chosen to be a fair maximum allocation between the different type of users. For simplicity, we decide that each femtocell may serve up to one non-subscribed user.

On the other hand, a minimum portion of the spectrum must be preserved for non-subscribers regardless of other conditions. The minimum value is based on the performance of the non-subscribed user. Thus, instead of determining a minimum spectral percentage, we set a minimum throughput value that the user must reach (if possible), when connected to the femto BS.

Defining the percentage between the two limits is the next step of the mechanism. The main concept is that deploying a femtocell must have a minimum impact on the rest of the network. Therefore, the femtocell will allocate resources to the non-subscribed user in order to compensate for its impact on the latter's performance. The mechanism takes into account the throughput achieved by the user before the deployment of femtocell and it will try to reproduce it, by its own right.

It is noted that this approach tries to ensure that the allocated spectrum will compensate for the impact to the user by this femtocell, and this femtocell only, and not by any other sources of interference, such as other femtocells in the area. Although this would usually require a major part of femtocell's spectrum, we study indoors scenarios with a significant distance from the macrocell base station. The attenuation for the macro user is therefore significant, and the prior user's performance would be easy to reach. This scenario is highly likely since it represents exactly the conditions that would make a femtocell deployment necessary.

So if CAP_{bef} denotes the throughput of the non-subscriber before the deployment of femtocell, and CAP_{aft} is the target throughput of the user under the service of the femtocell, then we want $CAP_{bef} = CAP_{aft}$ which, based on the model described in Section 2, yields to:

$$REQ_{subc}=TOT_{subc}*(log(1+SINR_{u,m}))/(log(1+SINR_{u,f})) \quad (8)$$

REQ_{subc} represents the subcarriers that must be allocated by the femto BS to the user, in order to reach earlier level of performance and TOT_{subc} is the subcarriers the user used to utilize when he was connected to the macrocell. $SINR_{u,m}$ and $SINR_{u,f}$ are the SINR experienced by the user, when he is connected to the macrocell and femtocell, respectively.

We stress again the fact that $SINR_{u,m}$ is calculated disregarding the interference of the femtocell that the user will eventually connect to (since it represents the state before the femtocell deployment in the area). However, it takes into account the presence of neighbouring femtocells that might contribute to the interference.

Similarly, we extract the minimum subcarriers say REQ_{min} that, as mentioned, are determined in order to reach the minimum throughput, even when its performance before the femtocell deployment was worse. When this is the case, femtocells improve the coverage and performance of the entire network, regardless the subscription list. So the spectrum allocated to the non-CSG is determined through:

$$REQ_{subc}=max(REQ_{min},min(REQ_{subc},0.25*TOT_{subc}) \quad (9)$$

B. Power control for femtocell cluster

Multiple femtocells within a small area is a highly possible future scenario. Inadequate services in an area will probably lead many different individuals to the femtocell solution. When a non-subscribed user is located near such a cluster of femtocells, he may experience high interference. The main source of the interference will most likely be the closer femtocell, but neighbouring femtocells will also contribute. In hybrid access mode above, the femtocell would allow access to its resources to the non-subscribed user. This, however, will reduce the capacity of its subscribed users while the rest femtocells will remain unaffected. Below, we propose a scheme according to which all femtocells in the cluster have to share the burden of providing services to the non-CSG user.

When a femtocell serves a non-subscriber, its capacity decreases depending on the level of access it provided to the user. In a cluster, its capacity suffers due to neighbouring femtocells, too. Instead of allowing this hurtful combination to occur, when a femtocell serves a non-user, it will notify its neighbours of the event, in order for them to reduce their power transmission. Thus, instead of a single femtocell to suffer a large decrease in its performance, all femtocells – members of the cluster will exhibit a small decrease.

So, if the relative decrease in the subscribers' performance due to less available spectrum is:

$$DEC_{cap}=1-CAP_{aft}/CAP_{bef} \quad (10)$$

To distribute the decrease, we set the target performance to represent half the actual reduction:

$$CAP_{tar}=0.5*DEC_{cap}+CAP_{aft}/CAP_{bef} \quad (11)$$

and we pass the reduction to the entity representing the interference in the model of Section 2, through which we find the required SINR to be:

$$SINR_{tar}=(2^{CAPtar*log_2(1+aSINR_m)}-1)/a \quad (12)$$

Since in this case we investigate indoors scenarios and especially femto clusters where multiple femto BS are located near to each other, it is safe to assume that the major part of interference comes from these neighbouring femtocells, and the interference induced by the macrocell can be ignored. This means that we merely adjust those femtocells' power levels by the required factor, that is:

$$P_{new}=(SINR_{tar}/SINR_{curr})P_{curr} \quad (13)$$

Since, as result, multiple femto BS will adjust their transmission downwards, the interference of neighbouring femtocells will decrease, too. Thus the above reduction in the power transmission, and therefore in SINR, represents the maximum probable reduction in their performance.

While the neighbouring femtocells will probably abide by the request, there is a chance that they have granted spectrum of their own to nearby non-subscribers, and in this case, of course they will disregard the message entirely.

IV. PERFORMANCE EVALUATION

The simulator's network configuration consists of multiple macro sites of radius 250m, wherein multiple femto base stations have been deployed in random positions. The macro base station is considered to be located at the center of each site, transmitting with a predefined power value of 46dBm.

All femtocells, subscribed and non-subscribed users are considered to be located indoors and in distance from the macro BS greater than the half of macrocell's radius. Femtocells initially transmit at the power levels described in Section 3, before the cluster power control of Section 4 is initiated. Table 1 summarizes the default values used during the simulation.

TABLE 1 SIMULATION PARAMETERS

Parameter	Value
Number of macro BS	17
Macrocell Radius	250m
Macro BS TX Power	46 dBm
Carrier frequency	2 GHz
External/Internal Walls' penetration loss	15dB/10dB
Bandwidth	10MHz
Modulation type	64QAM
Subcarrier spacing	15 kHz

Fig. 1 displays the CDF of SINR for MUE when there is no interference and when the FBSs have been deployed in CSG mode. Since we examine exclusively users that are located inside the range of the femtocells, the decline of their SINR is significant. This is also explained by the fact that macro UEs are located indoors along with the femtocells. Thus, the attenuation due to external walls along with the interference has a significant effect on their performance.

The dramatic decrease calls for different approaches. In Fig. 2, we examine macro UEs' performance when hybrid access mode is allowed by the femtocells, compared with CSG. For hybrid access mode, we evaluate two cases. In the first case, the femtocell sets a default number of subcarriers that MUE may have access. This number is predetermined and cannot change. The second case of hybrid access, follows the scheme described in the previous chapter. More subcarriers become available in order for the femtocell to compensate for the impact it caused.

An upper limit of available subcarriers has been set, for the MUE not to drain all resources from the rightfully femtocell subscribers. At the same time, a minimum number of subcarriers is always reserved when a MUE is nearby and experiences low SINR, even if its inadequate performance is not due to femtocell. This way, femtocell deployment boosts the performance of MUEs across the network, when the latter are deployed in areas with attenuated macrocell signal. This includes cases of cell-edge users or users inside multi-floor or multi-apartment buildings. In the figure we also depict the capacity of MUEs before the deployment of femtocell for comparison.

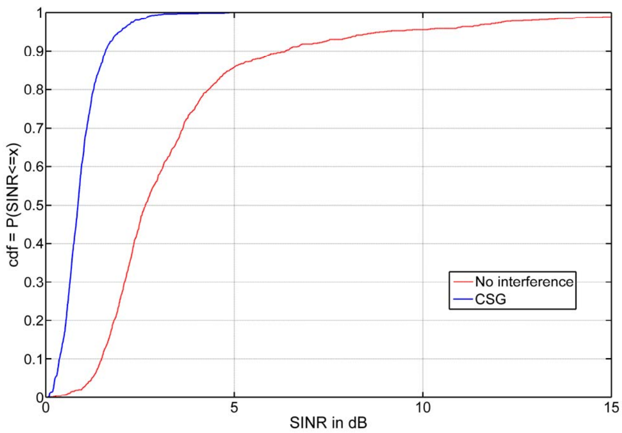

Fig. 1. CDF of MUEs' SINR before and after the deployment of CSG femtocells.

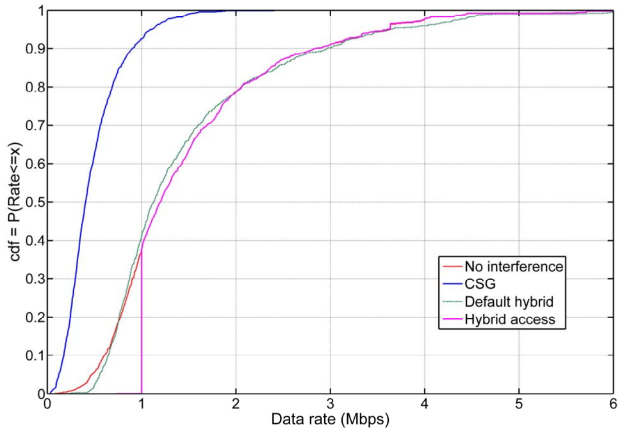

Fig. 2. CDF of non-subcribed users data rates for the different access modes.

Fig. 3 shows the percentage of spectrum that is allocated to MUEs by the femtocells across the network. The number of subcarriers varies, depending on the performance the macro UE exhibited initially due to its distance from the macrocell and femtocell BS and the penetration loss.

Although MUE benefits from femtocell resource allocation, CSG users utilize less spectrum. To investigate the impact of hybrid access compared to CSG on femto users performance, Fig. 4 depicts the resulting CDF of throughput for femto users when resource allocation follows the scenario investigated above.

As expected, CSG case provides the best performance for the subscribers due to higher resource utilization. However, both the default and the adaptive hybrid setup offer adequate high level of services, probably without the femto user acknowledging the decrease in the performance.

The latter illustrates the benefits of hybrid access, since for a small decrease in FUEs' performance, the entire network is benefited. Even subscribed users are benefited in the long term, since with the high level of femtocell penetration that is expected, chances are high the CSG user will become non-CSG user interfered by other femtocells when not in his premises.

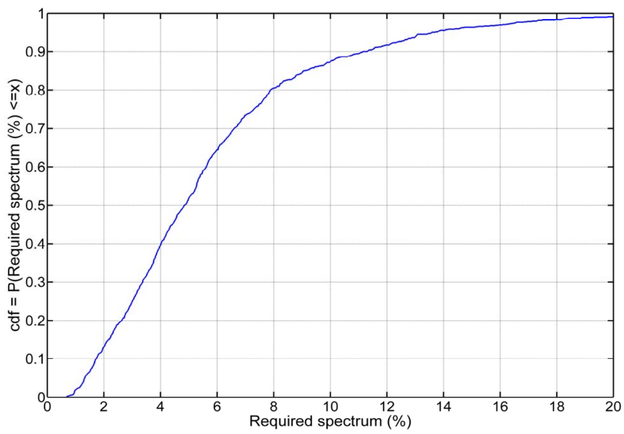

Fig. 3. Percentage of available spectrum required by the femto BS to maintain prior performance for non-CSG users.

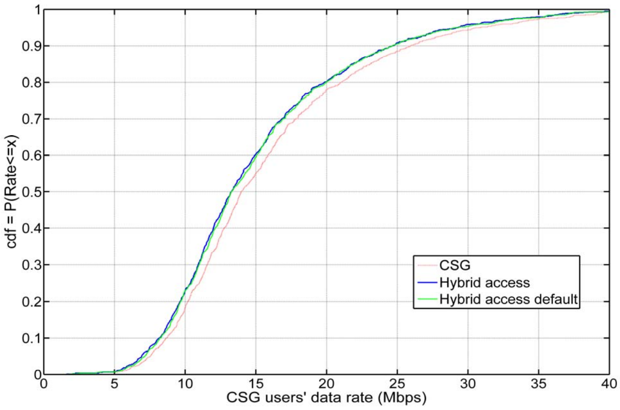

Fig. 4. CDF of CSG users throughput for the different access modes.

For the study of the power control mechanism, we increase the number of femtocells, to increase the occurrence of clusters. Fig. 5 displays the three stages of the mechanism for the three femtocell members of the cluster: a) the throughput of the femto BSs initially in CSG mode, b) the throughput they offer to their subscribers in hybrid access, and c) when power control distributes the impact of hybrid access across all femtocells of the cluster. The first set of columns represents the femto BS in hybrid access mode. The two remaining sets represent the neighboring femtocells that will require adjusting their transmission, in order to disburden the first femtocell.

The hybrid access femtocell has improved partially its performance, at the expense of its neighbors. It is noted that, since the factor which affects neighbors' transmission was based on the assumption that most of the interference comes from them, the improvement of the hybrid access femtocell might vary. For a femtocell near the macrocell, and the cross-tier interference dominating its performance, the improvement in its throughput will be much less, and may not be worth the reduction of neighboring femto BS. It is worth to note that while many femtocells are affected by the power control mechanism, the entire capacity is not significantly affected.

V. Conclusions and Future Work

In this paper, we introduced a scheme for the femtocells to decide the portion of spectrum that may be allocated to nearby macro users. The mechanism takes into account the user's performance prior of the femtocell's deployment. The simulations showed that the mechanism performs adequately, preserving non-subscribed users' data rate, and boosting it when they are located near the edge of the cell. At the same time, the performance of the subscribed users is not significantly affected.

Moreover, we introduced a power control scheme for hybrid access in femtocell clusters. The algorithm fairly distributes the burden of macro users' service by a femtocell, to all femto BSs. The algorithm is not only fair but also improves the performance of the hybrid femtocell. Moreover, it has the beneficial effect to make the decrease of the performance almost unnoticeable to CSG users, while the overall capacity stays mostly unaffected.

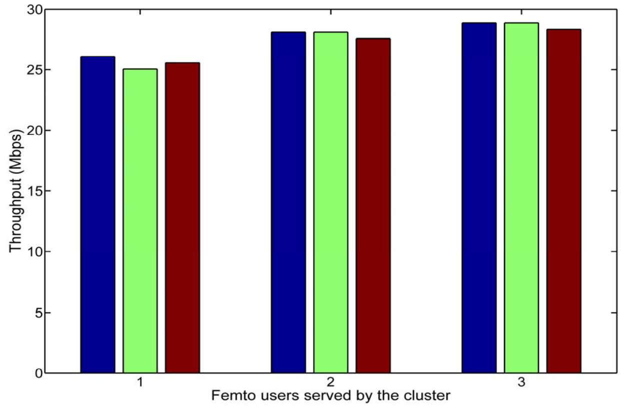

Fig. 5. Power control for 3 femto BS in a cluster. Femto BS 1 is the femtocell in hybrid access, and 2,3 are the neighbouring femtocells. The first column is the initial throughput, the second when hybrid access is employed and the third when the power control is enforced.

An extension of this work would be to consider multiple non-CSG users and to define the actions taken by the femto BSs within the cluster to distribute optimally the users as well as the available radio resources.

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