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Optimizing hybrid access femtocell clusters in 5G networks

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***Abstract*—Femtocells are an efficient way of reducing infrastructure costs while providing better data rates and coverage. High penetration is expected in the upcoming ultra dense 5G networks, increasing the probability of femtocells' clusters. Strong resulting interference for nearby non-subscribed users will require interference mitigation techniques. In this paper we present a mechanism where multiple femtocells coordinate their transmission to serve multiple non-subscribed users through hybrid access. First, the spectrum allocation of non-subscribed users by femtocells is determined. Then, we introduce a power control algorithm that is based on two factors. The need for compensation for the subscribed users, due to reduced spectrum, and the effect that any change in power transmission will have on neighbouring femtocells. We evaluate the effectiveness of the algorithm through simulations on individual throughput and overall achieved capacity.**

Keywords*—*hybrid femtocells, power control, clusters, next generation networks

I. Introduction

Future networks will require high speed data rates and always connectivity. Multiple base stations of heterogeneous nature will be deployed to respond to the increased demand and to pursuit high spectral efficiency [1]. However, this also means high co-layer and cross-layer interference issues between users and base stations (BS) making its mitigation one of the most important aspects that next generation networks will have to face. Many methods of interference management exist such as base stations coordination, smart allocation of resources and beamforming.

When femtocells are involved, one way to avoid strong cross-tier interference is allowing hybrid access mode. Between open access where femtocells serve users within their range indiscriminately, and closed access where they serve only a list of subscribers called Closed Subscriber Group (CSG), hybrid access allows limited access to nearby non-subscribed users. This means that when a user is within the femtocell's range, thus experiencing high interference, the femtocell may decide to allocate a portion of its available resources to serve the user. The resources may be part of the spectrum, time slot for transmission, power control etc. The main characteristic that distinguishes open from hybrid access, is that in the latter there is always distinction between a subscriber and a non-subscriber, usually prioritizing and favouring the former against the latter in resources allocation and scheduling [2].

To harvest the most benefits in resource allocation, transmission between base stations and users can be coordinated. In order to maximize the network's performance and avoid conflicts, base stations may communicate and arrange their transmission parameters accordingly. This is both important and practical. It is especially useful in the case of multiple femto Base Stations (FBS) deployed in a small area, where cross- and co-layer interference add up to great levels for non-subscribers if no transmission policy is enforced. Such femtocell clusters, may add the parameters of hybrid access to the transmission coordination capabilities.

There is significant work on the topic of hybrid access femtocells. In [3], a power control algorithm is proposed that can provide Quality of Service (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. [5] proposes a traffic-aware Orthogonal Frequency Division Multiple Access (OFDMA) hybrid small-cell deployment for QoS provisioning and an optimal admission control strategy. A novel traffic-aware utility function, which differentiates the user QoS levels with the user's priority indexes, channel conditions, and traffic characteristics, and based on this function an admission control algorithm is developed to improve QoS performance.

The authors in [6] propose a pricing mechanism that decides for the hybrid access of femtocells non-subscribers. In order to provide greater motivation for femto BS to share resources, the mechanism considers environments where multiple femtocells by different providers may serve the user, and they must compete for the profit gained by the service. In addition, an online learning algorithm adjusts the femtocell's transmission parameters by predicting the demand of the macrocell tier users. In [7] we proposed an algorithm for femtocell clusters that controls the spectrum and determines the power transmission of all femtocells when only one of them switches to hybrid access mode.

In this paper we introduce an algorithm that allows multiple femto base stations to operate in hybrid mode within the same cluster. This means that multiple non-subscribed users may be chosen to be served. When the mechanism determines the required spectrum to be allocated to each subscribed and non-subscribed user, the power control is put on effect. The

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algorithm specifically adjusts the transmission power of femtocells by reducing the power in FBSs with small performance reduction due to hybrid access mode in order to relieve the hybrid FBS with large reduction by the extra interference. This way, the mechanism tries to distribute the burden of hybrid access mode evenly among all femtocells-members of the cluster.

Since this could have a tremendous negative effect on the overall capacity of the cluster, the power control calculates the effect that any change in power transmission of a femtocell will have to its neighbours and executes it only if the gains are substantial compared to the negative effects. Thus, it achieves a balanced compromise among the cluster members. Finally, we compare the mechanism's performance with CSG deployment through simulations in terms of user throughput and network capacity.

The paper's structure is as follows: The next section describes the system model that we consider when evaluating the co- and cross-tier interference, as well as the power control scheme that determines the pilot power. Section III provides an in depth description of the proposed mechanism. Section IV is an extensive look of the simulating results and comparisons for the metrics mentioned above, when the mechanism is utilized. Finally, we draw our conclusions and suggest our next steps in Section V.

II. SYSTEM MODEL

In this section we describe the model we are based on, and our assumptions throughout the paper. We focus on Frequency Division Duplex (FDD) systems, and the allocation of the resources is based on OFDMA, which means it is done in terms of resource blocks of 12 subcarriers, the minimum unit that can be allocated to a user.

In order to estimate the SINR that a user receives at one point of the network we use the following model. Since SINR depends heavily on the interference added by the rest of the cells that have the user within their range, for the case of a macro-user m on sub-carrier k, the impact of both the adjacent macrocells and overlayed femtocells must be considered. As mentioned in [8] the SINR is provided by the following equation:

$$SINR_{m,k} = \frac{P_{M,k}G_{m,M,k}}{N_0\Delta f + \sum\limits_{M'} P_{M',k}G_{m,M',k} + \sum\limits_{F} P_{F,k}G_{m,F,k}} \tag{1}$$

with $P_{X,k}$ the transmit power of serving base station X on subcarrier k, where X can be the macrocell M, the neighboring macrocell M' or the 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 (f) or a macro-user (m) 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. Specifically, for a femto user f on subcarrier k interfered by all macrocells and adjacent femtocells, the received SINR is given by:

$$SINR_{f,k} = \frac{P_{F,k}G_{f,F,k}}{N_0\Delta f + \sum\limits_{M} P_{M,k}G_{f,M,k} + \sum\limits_{F'} P_{F',k}G_{f,F',k}} \tag{2}$$

In order to determine the channel gain G, the calculation of Path Loss (PL) is required according to the following expression:

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

Path loss heavily depends on the environment of the network. Regarding this paper, an urban environment is considered, thus for a macro-user in distance R from the transmitter, it is given by [9]:

$$PL(db) = 15.3 + 37.6log_{10}R + L_{ow} \tag{4}$$

where the term L_{ow} is added for the case of indoor macro-users to denote the penetration loss of the external wall.

Similarly, the suggested model according to [9] for the case of an indoor femto-user is estimated, taking into account the penetration loss due to exterior walls:

$$PL(db) = 38.46 + 20log_{10}R + L_{ow} \tag{5}$$

The practical capacity of macro-user m on sub-carrier k is given by [8]:

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

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].

For the needs of our simulations, we consider the following configuration to determine the pilot power transmission of femtocells, that is when they are first deployed and no hybrid access or coordination has taken place. 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:

$$P_f = min(P_m + G - PL_m(d) + PL_f(r), P_{max}) \tag{8}$$

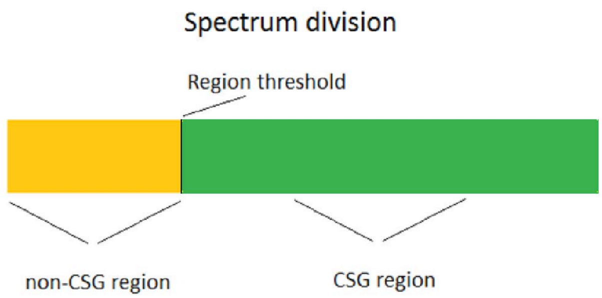

Fig. 1. Spectrum division regions in hybrid access.

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 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 scheme

In this section we propose the mechanism that dictates femtocell transmission parameters. After the allocation of spectrum resources of femtocells when hybrid access is enabled, we introduce the power control mechanism that determines the power levels of the members of the femtocell clusters, in order to balance the performance reduction of the femto BS that operate in hybrid access.

A. Spectrum threshold determination

Hybrid access femtocell divides radio resources of a femtocell into two regions for non-CSG and CSG users (Fig. 1). This method guarantees that the non-CSG users will always have access to a minimum portion of the spectrum, and that CSG users will always have priority on the spectrum by deciding a larger portion for them.

In this paper, we consider that each femtocell may serve up to one non-subscriber. When a femtocell admits such a user, it will allocate spectrum to the non-subscriber trying to reproduce the performance the user would have without the interference caused by the femtocell. This is aligned to the principle that a new installed femtocell should cause the minimum negative impact to existing elements of the network. Reproducing their prior performance and at the same time maintaining the greater part of the spectrum to CSG users is possible, because we consider indoor scenarios where macrocell service levels are small nevertheless and users' requirements will be small too. This scenario is highly likely since it represents exactly the conditions that would make a femtocell deployment necessary.

So in order to determine the required portion of spectrum allocation we denote CAP_{bef} as the throughput of the non-subscriber before the deployment of femtocell, and CAP_{aft} the target throughput of the user under the service of the femtocell. Thus, we want $CAP_{bef} = CAP_{aft}$ which, based on the model described in Section 2, yields to [7]:

$$\frac{REQ_{subc}}{TOT_{subc}} = \frac{(log(1+SINR_{u,m}))}{(log(1+SINR_{u,f}))} \tag{9}$$

REQ_{subc} represents the number of 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 number of 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.

B. Proposed power control

After the allocation of resources for all non-subscribers has been determined, the power control among the femtocells in clusters takes place. We consider a femtocell cluster when multiple femto BSs are located within 15 m distance from each other. In the cluster every femtocell may operate in hybrid access mode. The power control is based on the concept to compensate for the reduction on the performance of the subscribers because of the hybrid access. However, instead of increasing the FBSs' power transmission, it decreases their neighbours' that have suffered less or none reduction from hybrid access mode operation. Thus, the performance of the former is increased due to less interference.

The choice of which femto base stations will subject to the reduction and to what degree, is based on their own hybrid access parameters. The principle is to distribute the burden of the femtocells operating in hybrid access to the entire cluster, in a fair way. This means that FBSs with none or small spectrum allocation to non-subcarriers will experience greater reduction in their power transmission if this is found to be beneficial to the ones who exhibit more reduction due to hybrid access.

However, reduction of a nearby base station may have not a significant effect on its neighbour. This may be due to large distance, interference from multiple sources or significant noise. Thus, adjusting downwards its power levels would have a negative effect on its performance, without any satisfying benefit for the neighbouring femtocell, causing a great decrease in overall capacity. In order to protect FBSs from reducing their power transmission without a similar gain, the reduction depends on the effect this change would have. Thus the reduction is subject to its impact by the following equation for each neighbouring femtocell:

$$IMPj,i = \frac{P_{j,k}G_{x,j,k}}{N_0\Delta f + \sum_M P_{M,k}G_{x,M,k} + \sum_F P_{f,k}G_{x,f,k}}, f \neq i \tag{10}$$

which represents the fraction of the SINR reduction on a user connected to femtocell i caused from FBS j, to the reduction caused by the total interference the user experiences.

So the adjustment in power transmission is relative to the difference of the performance reduction between FBSs due to hybrid access, and the effect of this power transmission change on every neighbour:

$$PC(i) = \sum (SINR_{d,i} - SINR_{d,j}) * a * IMPj, i \quad (11)$$

where a ensures that any power reduction will take place only in respect to the femtocells that have suffered greater reduction in their SINR due to hybrid access.

$$a = \begin{cases} 1, & \text{if } SINR_{d,j} - SINR_{d,i} > 0 \\ 0, & \text{otherwise} \end{cases} \quad (12)$$

Assuming that most of the interference originates from nearby femtocells we can easily extract the required decrease in power transmission of the neighbours through:

$$P_{new(i)} = (1 + PC(i)) * P_{curr}(i) \quad (13)$$

where $P_{new(i)}$ and P_{curr} are the new and the current power level transmission of the femto BS, respectively. The assumption is based on the fact that femtocells are indoors and in a significant distance from the macrocell antenna, a scenario that would lead to multiple femtocell utilization.

When the power control concludes, the mechanism starts again when any change is detected, such as additional users arrival etc. Below we summarize the mechanism.

Algorithm 1 Power control

for non-subs user u near a femtocell i **do**
  {calculate required spectum for hybrid access}
  $REQ_{subc} = \frac{TOT_{sub} * (log(1+SINR_{u,m}))}{(log(1+SINR_{u,f}))}$
end for
for femtocells i,u $\in$ cluster and j u's user **do**
  {calculate effect of FBSs to neighboring FBSs' users}
  $IMP(i,j) = (Impact\ on\ j\ by\ i)/(Impact\ by\ all)$
  {calculate power adjustment}
  $Padj(j) = \sum IMP(i,j) * a * (SINR_{d,j} - SINR_{d,i})$
  where $a = \begin{cases} 1, & \text{if } SINR_{d,i} - SINR_{d,j} > 0 \\ 0, & \text{otherwise} \end{cases}$
  {calculate power transmission}
  $P_{new(j)} = (1 + PC(j)) * P_{curr}(j)$
end for

IV. Performance Evaluation

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

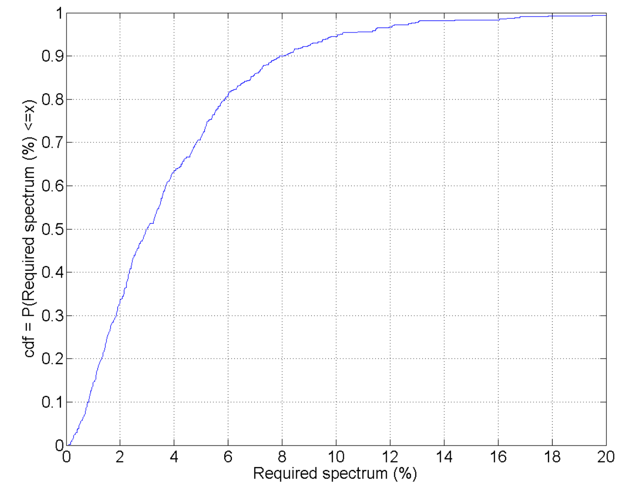

Fig. 2. Necessary spectrum allocation to non-CSG users.

A. Simulation parameters

The simulator's network configuration consists of 9 macro sites of radius 250m, wherein 100 femtocells have been deployed. The femtocells are uniformly distributed to the cell area defined by the cell edge and the condition the distance from the macrocell is greater than 125m (half the cell radius). This scenario is realistic because places that are further away from the macro BS are more likely to be chosen, since weak signal will act as a drive for a femtocell purchase. 100 subscribed users are deployed in the proximity of the femtocells, considering for simplicity and without affecting the outcomes that each one serves exactly one CSG user. 100 non-subscribed users are also deployed in the area. Each femtocell may serve up to one non-subscribed user. The users' position is considered fixed and a full buffer traffic model is considered.

The macrocell base station is located at the center of each site, transmitting with a predefined power value of 46dBm, while the maximum allowed power transmission for femtocells is set to 20dBm. Clusters are considered multiple close-by femtocell installations, with atleast three femtocell members. In order for a femtocell to be considered a member, it must be deployed in a maximum distance of 15m from two other femtocell-members of the cluster. The environment is considered urban affecting the calculation of the path loss and justifying the increased probability of high density femtocell deployment. Table I provides an overview of the simulation parameters. Values' selection was based on [11].

B. Experimental results

Fig. 2 shows the percentage of spectrum that each femtocell needs to grant for usage by non-subribers. Since we consider indoors scenarios, with a significant distance from the macrocell base station and assume only one non-subscriber per femtocell, the spectrum allocation is capable to reproduce these users' prior performance and does not exceed 20% in the worst case.

The performance of hybrid users before the femtocells installment is reproduced fully, as can be seen in Fig. 3.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Inter-site distance	500 m
Bandwidth	20 MHz
Modulation Mode	64QAM
Subcarriers bandwidth	15 KHz
Carrier frequency	2 GHz
Wall penetration loss	20dB
BS transmit power	46 dBm
White noise power density	-174 dBm/Hz

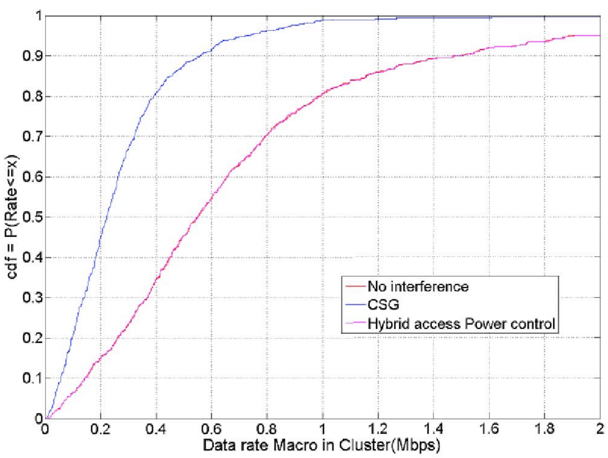

Fig. 3. Capacity of non-subscribers.

The figure depicts the non-subscribers users, before femtocell deployment, and the cases where FBSs operate in CSG and hybrid mode. It can be easily seen that the first and the last cases coincide.

C. Power control without IMP factor

The power control scheme performance is first evaluated without taking into account the IMP parameter and the results are shown in Fig. 4. The figure shows in columns the data rate initially, the data rate when hybrid access has been deployed and finally when power control is applied for every femto BS in a cluster where only the first femtocell operates in hybrid mode. In the third column, the adjustments of the neighbors of a femtocell can be seen (femtocells 2,3 and 4), in order to compensate for the first femtocell's decrease due to less spectrum utilization. The improvement can be seen in femtocell 1 that comes from the reduction of the interference caused by its neighbours.

The figure can also show the disadvantage of the scheme in this form, since although it is fairer, it requires a reduction from all neighbours that result to a relative small improvement of the first. As we have mentioned, this may cause a significant reduction to the overall capacity, because the decrease in neighbouring femtocells power transmission, may be disproportionate to the resulting improvement of the hybrid femtocells performance. Thus, adjusting downwards its power levels would have a negative effect on their performance,

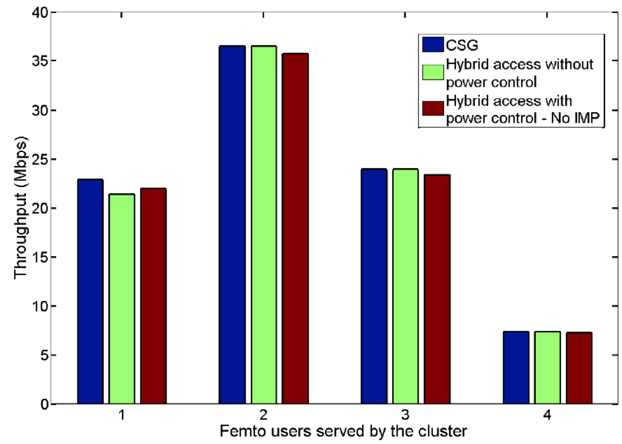

Fig. 4. Capacity of CSG users without including IMP parameter.

without any satisfying benefit for the neighbouring femtocell, causing a great decrease in overall capacity. In order to avoid the above case, we evaluate first if a probable reduction will have a corresponding positive impact on its neighbours as explained in section III.

D. Complete power control mechanism

Fig. 5 estimates the performance of the power control scheme including the IMP factor when applied on the same topology. In addition, in this case, all femtocells are required to operate in hybrid access, to serve nearby non-subscribed users. More specifically, each of the femtocell members of the cluster serve up to one non-subscribed user. Similar to the above figure, the columns represent the initial state (CSG), the performance when non-subscribers have been admitted and finally the performance when power control has been enforced. This is depicted for all femtocells that participate in the specific cluster.

Depending on the level of reduction compared to the average reduction observed in the cluster, the algorithm tries to reach the average as a measure of fairness, as explained in the previous section. The algorithm does not always achieves this goal, since for some cases it calculates that a probable reduction would not have an equal positive impact to any other femtocell, that would make it justified. This can be seen by observing the fourth FBS which does not present any significant change in its performance. For the first femtocell that represents the one experiencing the largest percentage decrease due to hybrid access, we can observe a slight increase which comes as a result of the decrease of its neighbours two and three.

The last column of the last femtocell also shows a positive side effect of the above power control mechanism. Since some BSs are required to decrease their power levels, some femtocells users may experience an increase in their performance, even compared to their initial status, as a result of the reduction of interference.

Fig. 5 also shows that changes on power transmission are relative small when all members have suffered a similar reduction, since there is already the balance the mechanism

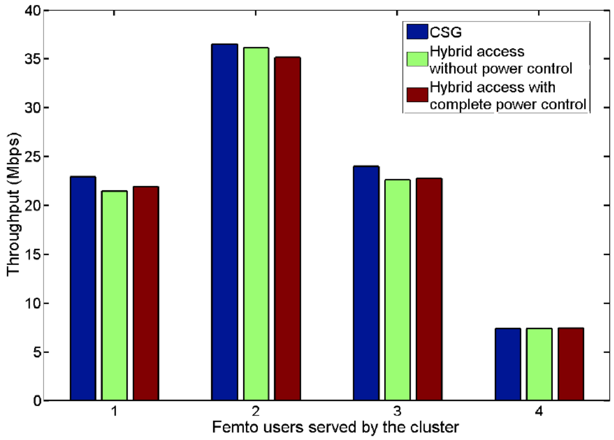

Fig. 5. Capacity of CSG users for the entire power control scheme.

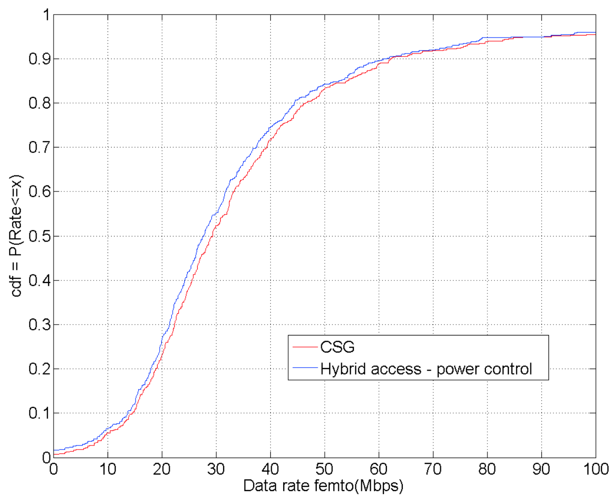

Fig. 6. Comparison of overall capacity of the two approaches.

tries to achieve. Instead, when there is a large difference in hybrid access utilization by neighbouring femtocells, adjustments may be severe, both improving the performance of worst case hybrid FBS but also reducing the overall capacity of the cluster as well.

This can be observed better in Fig. 6 which presents the impact on subscribed users that each approach results to. It can be seen that as expected CSG performs better. Hybrid access showcases a reduction attributed to non-subscribed users served. In addition, the proposed power control on hybrid access further decreases the overall capacity since it is based on downward adjustment of power transmission. However between the two approaches, there is not such a significant difference. Given the served non-subscribers and the overall fairness of the scheme, the trade off can be conditionally beneficial.

The benefit of fairness between the base stations under the power control can be better seen in Fig. 7. The figure depicts the relative change in the throughput for each femtocell within

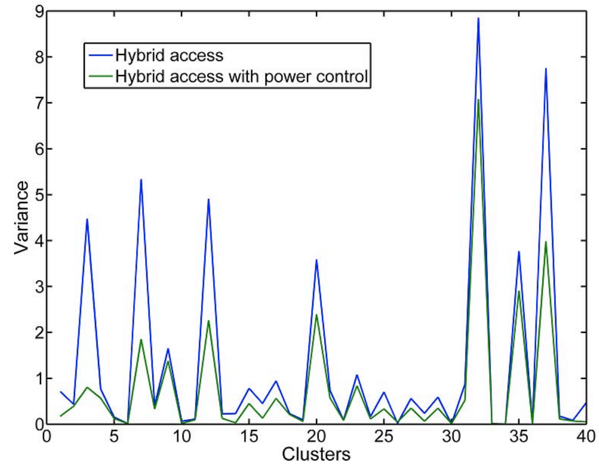

Fig. 7. Change in throughput for cluster femtocells.

the cluster. Smaller relative change shows that the performance reduction due to spectrum sharing across the members were more homogeneous suggesting a fairer distribution of the negative effects the hybrid access may have. This also means that users will experience smoother changes when a femtocell admits a non-subscriber and goes from CSG-like utilization of resources to hybrid access mode.

Finally, an extra advantage of the algorithm is the slight improvement of macrocell users in the vicinity of the femtocell cluster, that do not eventually get admitted to any femtocell. Since the algorithm is based solely on the reduction of cluster's power transmission, trying to relief users connected to neighbouring FBSs, non subscribers will also benefit from the resulting interference reduction in the area.

V. Conclusion and Future Work

In this paper, we introduced a power control mechanism for femtocell clusters. The mechanism allows all members of the cluster to operate in hybrid access mode if necessary, estimating the necessary spectrum to be given to non-subscribers for the latter to reproduce previous data rate levels. Then it calculates the resulting reduction in subscribers' performance within a femtocell cluster, and distributes the reduction burden fairly among the members.

This is achieved by reducing the power levels of the FBSs that suffer the least reduction from hybrid access, in order to reduce the interference caused on neighbouring FBSs that suffer greater reduction. A check is taking place in order to confirm that such a reduction has a worthy similar positive effect.

The simulation results showed that the mechanism smooths the worst cases for FBS subscribers, reducing the effect of hybrid access passing a part of the reduction to neighbouring femto base stations. Macrocell users connected to a femtocell maintain the performance level achieved prior to the installation of the nearest femtocell, while users who are served by the macrocell BS are slightly relieved from the power reduction of the FBSs. The drawback is a reduction of the overall capacity of the cluster regarding the subscribed users. However, the algorithm using the check, limits the reduction to acceptable levels.

As a next step of this work, dynamic spectrum allocation and the admission of multiple non-subscribed users per femtocell are possible fields that are worth further investigation. Multiple non-CSG users will require greater level of coordination between the cluster in order to define the admission policy of these users, their optimal distribution to the cluster members and the allocation of the available radio resources.

Coordination among the members of the cluster will also play a major role, if investigating the case where a user can utilize resources from two BS simultaneously. This interesting field will add flexibility and it will increase the utilization of available resources. However, it will also add complexity that will require methods to establish the proper coordination among the BSs, as well as more complex methods to determine its exact utilization.

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