Incentive mechanism for uplink interference avoidance in two-tier macro-femto networks

Zhu Xiao[†], Peng Wang[†], Xu Zhang[†], Shyam Mahato[†], Lei Chen[♯] and Jie Zhang[*]
[†]University of Bedfordshire, Institute for Research in Applicable Computing, Luton, LU1 3JU, UK;
[♯]Ranplan Wireless Network Design Ltd, The Business Centre, Kimpton Road, Luton, LU2 0SX, UK;
[*]University of Sheffield, Dept. of Electronic and Electrical Engineering, Sheffield, S1 3JD, UK.
Email: {zhu.xiao; peng.wang; xu.zhang; shyam.mahato}@beds.ac.uk; lei.chen@ranplan.co.uk; jie.zhang@sheffield.ac.uk

***Abstract*—Femtocell has been considered as a promising technology in wireless communications to extend indoor service coverage and enhance overall network capacity. Two-tier networks, where the current cellular networks, i.e., macrocells, overlapped with a large number of randomly distributed femtocells, can potentially bring significant benefits. If femtocell access points (FAPs) operate within the same frequency band as macrocells, the cross-tier interference (CTI) creates a distinct impact on the system performance. This paper studies the uplink (UL) interference at FAP caused by approaching macrocell users (MUEs). It is noted that the CTI is more significant to the closed subscriber group (CSG) femtocells. We propose an incentive mechanism (IM) for CSG femtocells to alleviate the UL interference from approaching MUEs, thus preventing the femtocell users performance from degrading and protecting the neighbor FAPs that might also suffer from the UL interference. Meanwhile, the macrocell also benefits from the IM, in terms of energy saving and UL spectral efficiency. Simulation results show that close to the ideal performance when no CTI presents can be achieved with IM, demonstrating that the proposed scheme is very effective in dealing with uplink CTI.**

***Index Terms*—Femtocell, macrocell, uplink, interference avoidance, incentive mechanism**

I. Introduction

Femtocells have been considered as an important radio access technology and received wide attention in recent years. Because of their small size, low power, cost-effectiveness and high performance, femtocells are a promising solution not only to improve the indoor coverage but also to satisfy the fast growing traffic requirement within current cellular networks [1]. The two-tier networks, in this paper which refer to the macrocell overlapped by femtocells, offer a flexible solution that benefits both users and operators. By deploying the femtocell access points (FAPs), mobile subscribers within areas of degraded coverage can obtain better link quality and achieve higher data rate by accessing FAPs. This also enables the existing macrocell to increase the system capacity and throughput with a low operational cost [2].

The deployment of femtocells brings several technical challenges to the present cellular networks. One of the most urgent issues is interference. Femtocells using dedicated channels can prevent interference in two-tier networks, but this may be of little interest for network operators when the network planning, spectrum availability and efficiency are taken into consideration. Femtocells under co-channel deployment with the macrocell is proved to be a preferable option. Simulation works in [3] indicate that the method can tremendously increase the area spectral efficiency by spatial frequency reuse, while imposing minor impact on macrocell throughput. However, the co-channel deployment of femtocells comes along with cross-tier interference (CTI) in two-tier macro-femto networks [4]. As it can be foreseen that high density of FAPs will be deployed due to the high speed wireless services, the study of such issues is extremely important. In such scenarios, the interference is strongly dependent on the type of access mechanism that femtocells employ. In particular, the CTI is more significant in the two-tier networks comprising closed subscriber group (CSG) femtocells, where only the registered subscribers can access the FAPs [5]. Under CSG manner, femtocells may give rise to interference that can degrade the signal to interference plus noise ratio (SINR) at macrocell, and femtocell users might suffer significantly from the interference caused by the nearby MUEs.

In this paper, we focus on the uplink interference at CSG FAPs which results from MUEs approaching the vicinity of the femtocell. FAPs are more likely to be deployed in an area with degraded coverage provided by macrocell, such as the coverage edge. When the MUE is far away from its serving macrocell base station (MBS), a higher transmit power is needed to communicate with MBS to satisfy its target SINR. This will cause excessive UL interference to the nearby FAPs. Motivated by such a scenario, this paper proposes a method to eliminate the CTI by offering CSG FAP incentives that allow MUE to access the FAP via UL, thus ensuring the UL quality of both MUEs and FUEs.

A. Related Works

Previous works have studied various interference scenarios in two-tier macro-femto networks. In [6], more than ten interference scenarios are described, in which both cross-tier interference and intra-tier interference are included and evaluated. Many works focus on the scenarios where femtocells affect the macrocell. A distributed utility based SINR adaptation at femtocells is proposed in [7]. The authors in [8] propose a joint regulation scheme for FAP transmit power and radio resource usage is designed. These methods aim at reducing the impact to MUE by suppressing the femtocell downlink power, or combining with the spectrum rescheduling

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

strategy. For addressing the UL interference at MBS from FUE, the open-loop and the closed-loop control for adjusting the maximum transmit power of FUE are proposed in [9]. All the above attempts are seeking to reach the tradeoff between minimizing the DL and UL interference at macrocells and ensuring the system performance at femtocells.

While all the interference scenarios in [6] are important to tackle, we mainly focus on the UL interference at FAPs from approaching MUEs in this paper. A similar situation is taken into account in [10]. An adaptive UL attenuation is employed as an effective way to mitigate the UL interference caused by MUEs, but this will incur a penalty because it harms the quality of femtocell uplink. The idea based on channel reallocation and handover are also introduced to solve this problem [4]. A universal frequency reuse scheme for interference avoidance is proposed in [11], the results from moderately loaded networks show that the capacity is increased greatly over the spectrum separation. As employing frequency reuse to avoid interference relies on the utilization of the spectrum resource in two-tier networks, the high user density and large scale FAP deployment will produce a large system burden for frequency planning, which might result in low spectrum efficiency. MUE brings with the UL interference when it is just moving around or close to FAPs. In such cases, it is not necessary to let MUE handover in FAP. For the femtocell which happens to be constantly fully loaded, MUE is unable to handover even if it is open access. In addition, handover is not applicable for CSG FAPs. Recently, the inter-cell interference coordination (ICIC) and its enhanced version eICIC, offer alterative options that make use of the almost blank subframes (ABSFs) to alleviate CTI [12]. However, most studies on ICIC focus on the DL interference, the feasibility for UL interference mitigation has not been proven.

B. Contributions

In this paper, we propose a UL only access strategy for CSG femtocells to alleviate the cross-tier uplink interference from MUEs. The strategy imposes an incentive mechanism for each FAP to detect the UL interference caused by a MUE, and the most interfered FAP allows the MUE to connect to it via the uplink only. Normally, FUEs that are served by a CSG FAP would not like to share radio resource with mobile MUEs, unless there are incentives by which the UL interference to this FAP could be removed or reduced. The cost is that the FAP has to release UL radio resources and assign them to the interfering MUE. But since the cross-tier interference is reduced, the loss of radio resource can be counter balanced. It is worth noting that the proposed incentive mechanism will not impact the downlink data transmission from the FAP to its attached FUEs. Moreover, the interfering MUEs are able to save UL power after lowering their transmit power. Those MUEs may also get better UL quality from the nearby FAP that is much closer in comparison to the MBS. The neighboring FAPs, which might be interfered by the MUEs, also benefit from this incentive mechanism as the interference from MUEs can be significantly reduced with low transmit power.

The remainder of the paper is organized as follows. System and interference scenario are introduced in Section II. Section III is devoted to present the incentive mechanism for UL interference avoidance. In Section IV, the analysis for improved throughput is presented. Simulations and conclusions are given in Sections V and VI, respectively.

II. System Model And Interference Scenarios

In this paper, we study the UL interference of co-channel two-tier macro-femto networks under LTE standard [13]. In LTE, Single Carrier-Frequency Division Multiple Access (SC-FDMA) is adopted as the UL physical layer access technology with a resource block (RB) as the basic scheduling resource. The macrocell coverage is considered as a disc area with a radius r_M. In femtocell, only the registered FUEs can be served by FAP within a disc area with a radius r_F. The least distance among FAPs should not be smaller than $2r_F$, which means all FAPs have their own non-overlapping coverage areas. B_M denotes the total available RBs for macrocell and femtocells. The omnidirectional antenna is used for MUE, FAP and FUE. When a MUE comes near the coverage of femtocell, it may give rise to UL interference at FAP.

Consider multiple FAPs overlaid in a single macrocell, the randomly located femtocells are modeled by a Spatial Poisson Point Process (SPPP) [5]. The UL interference caused by a MUE can take place in three cases, 1) when the wireless signal from the MBS is blocked by obstacles like buildings, 2) when the MUE is inside the coverage area of the FAP, and 3) when the MUE is at the coverage edge of the macrocell and close to a FAP. Whether a MUE is able to satisfy the required SINR requirement or not depends on the quality of UL between MUE and MBS. Based on the UL power control strategy, in above cases the MUEs need to increase their transmit power to meet the target SINR, which will bring strong UL interference to nearby FAPs. In some extreme situations MUE has to transmit at the maximum power, which could result in excessive cross-tier interference. In this paper we focus on a single macrocell case, thus UL interference from the MUEs served by the neighbour macrocell is not considered for analytical tractability. Also, the UL interference from FUEs affecting their neighbour FAPs are ignored as we assume there is no overlap among femtocells coverage areas.

III. Uplink Interference And SINR

The incentive mechanism for interference avoidance (IMIA) proposed in this paper is based on the fact that the CSG FAP enables the MUE which causes UL interference to connect with it, at the expense that the attached FUEs have to share the UL radio resource with this MUE. In such a case, only the UL connection of MUE needs to be switched from MBS to FAP. Therefore, despite the loss of bandwidth to its own FUEs, this FAP will benefit greatly because the interference is removed completely. Meanwhile, its neighbor femtocells, which are possibly heavily interfered by this MUE before the UL access, are purely beneficial because the MUE can transmit with a lower power thus impose minimum UL interference.

A. Interference Analysis

The interference occurs when the same UL RBs are assigned to both MUEs and femtocells at the same timeslot. Assuming MUEs have the uniform UL data requirement and each MUE uses R_{MM} RBs, where the bandwidth of one RB is B_{RB} that consists of 12 subcarriers. All subcarriers within an RB have the same shadowing and fading [8].

Interference zone. All MUEs are located uniformly in the coverage area of the macrocell. Theoretically, any MUE can cause the interference at the FAPs as long as it uses the same RB with a FUE. Note that when the MUE is quite far away from FAPs, the UL interference can be neglected. We define an interference zone for each FAP. Once MUE enters this zone, its UL signal will be considered as the interference to FAP if it happens to use the same RB simultaneously. The distance threshold D_I denotes the radius of the interference zone for a FAP. The UL interference will be taken into account when distance d_{mf} between MUE and FAP is less than D_I. Note that $D_I < r_F$ and interference zones of FAPs might be partially overlapped, which means one MUE could bring UL interference to multiple FAPs. It is suggested in [6] that the minimum separation between a MUE and a FAP is 27m when the MUE transmits at the maximum power (e.g., 21dBm). We set D_I to be 30m in this paper for the simulation.

B. Femtocell Uplink SINR

Consider that a MUE transmits at the maximum power $P_{Mx,Tx}$ and causing UL interference o FAPs. Given that a RB used by the MUE and the ith FAP, the femtocell received uplink SINR can be presented as

$$SINR_{FAP,UI}=\frac{P_{F,Tx}G_f/L_F}{P_{Mx,Tx}G_m/L_{M,i}+\delta} \tag{1}$$

where $P_{F,Tx}$ is the identical transmit power among FUEs, G_f and G_m are the antenna gain of FUE and MUE respectively. $L_{M,i}$ and L_F denote the uplink attenuations of MUE and FUE. δ denotes the power of additive white Gaussian noise. $L_{M,i}$ and L_F can be expressed by

$$\begin{cases} L_{M,i} = L_{sh,M} \cdot L_{fd,M} \cdot L_{p,M}\left(d_{mf,i}\right) \cdot L_W \\ L_F = L_{sh,F} \cdot L_{fd,F} \cdot L_{p,F}\left(d_f\right) \end{cases} \tag{2}$$

where $L_{sh,M}$ denotes the Lognormal shadowing from MUE to FAP and $L_{sh,M} \sim LN\left(\mu_M, \sigma_M^2\right)$. $L_{sh,F}$ denotes the Lognormal shadowing from FUE to FAP and $L_{sh,f} \sim LN\left(\mu_f, \sigma_f^2\right)$ [8], $L_{fd,M}$ and $L_{fd,F}$ denotes the Rayleigh flat fading [8]. L_W represents the wall-penetrated loss. $L_{p,M}$ and $L_{p,F}$ denotes the path loss from MUE and FUE to FAP respectively. $d_{mf,i}$ is the distance between MUE and the ith FAP. d_f is the distance between FUE to FAP.

IV. Incentive Mechanism Based UL Interference Avoidance (IMIA)

A. Incentive Mechanism

Operational algorithm. Let N_F denote the total number of the deployed FAPs in the macrocell. The design of incentive mechanism can be implemented as follows.

1: Each FAP senses the interference signal from MUEs and calculates their distances;
2: Ignore the MUEs that are out of interference zones of every FAP;
3: **UL interference avoidance**;
   - Suppose each MUE affects one or several FAP(s) simultaneously. The most interfered FAP, where $d_{mf} = \min(d_{mf,i}, i = 1, 2, \ldots, N)$, lets the interfering MUE access (only in uplink);
   - This FAP reallocates the UL RBs among its served FUEs and the accessing MUE, wherein R_{MF} RBs are assigned to the UL accessing MUE. Here we assume $R_{MF} < R_{MM}$ and consider that the MUE can obtain better link quality by UL connection to FAP;
   - A power adaption is designed for the UL accessing MUE, in which the MUE's transmit power will be adjusted according to its target throughput Thr_M and the UL quality from its UL served FAP;
4: Repeat Step 3 for all MUEs that may cause UL interference.

UL SINR by applying IMIA. We denote a MUE as an inner interfering MUE if it is inside the coverage zone of a FAP and an outer interfering MUE if it is inside the interference zone but outside the coverage zone of a FAP. Following this, we further divide the MUEs that are inside the interference zone of a FAP into four categories according to their location. Each category will be processed differently with IMIA. Taking FAP_2 as example as shown in Fig.1. Each category of MUE a,b,c and d are described as follows:

1) $MUE\ a$ is located inside coverage of FAP_2, namely $d_{mf} \leq r_F$. MUE a is inner interfering MUE in FAP_2, which causes the worst UL interference at FAP_2. It might also create interference at FAP_1 as it is an outer interfering MUE to FAP_1;

2) $MUE\ b$ is the outer interfering MUE of FAP_2 as well as FAP_3, namely $r_F < d_{mf} \leq D_I$. Assume that it is closer with FAP_2;

3) $MUE\ c$ is the outer interfering MUE of FAP_2 as well as FAP_3. Assume that it is closer with FAP_3. $MUE\ b$ and $MUE\ c$ bring less interference at FAPs because of the wall blocking;

4) $MUE\ d$ is the inner interfering MUE of FAP_1 and the outer interfering MUE of FAP_2.

When the IMIA is implemented, the interference from MUEs to their attaching FAPs will be eliminated. However, interference to the neighbor FAPs still exists as one MUE may affect several FAPs simultaneously. Let $P_{MF,Tx}$ denote the MUE transmit power after IMIA. For the inner interfering MUEs, such as $MUE\ a$ in FAP_2 and $MUE\ d$ in FAP_1, if $P_{MF,Tx} \leq P_{F,Tx}$, the MUEs will not cause any interference to the neighbor FAPs since the inter-femtocell UL interference is not considered in this paper. In the case of the outer interfering MUEs, such as $MUE\ b$, which is UL-accessing to FAP_2, the interference to the neighbor FAP_3 still exists as the distance difference from $MUE\ b$ to FAP_2 and FAP_3 is not very large. A similar situation takes place in $MUE\ c$, FAP_1 and FAP_2. R_{MF} RBs are allocated for $MUE\ a$ and $MUE\ b$ after

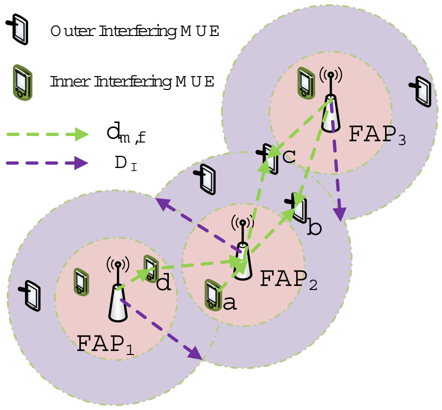

Fig. 1. Inner interfering and outer interfering MUEs

the UL accessing with FAP_2. Since $R_{MF} < R_{MM}$, the interference used to be present on $(R_{MM} - R_{MF})$ RBs will be removed in FAP_2. Hence the SINR for these RBs is equal to $P_{F,Tx}G_f/L_F + \delta$ due to no interference. For the outer interfering MUEs, $MUE\ c$ will access in FAP_1 but continue impacting FAP_2. While $MUE\ d$ might affect FAP_2 after its UL connection to FAP_3, as long as its transmit power is larger than $P_{F,Tx}$. Replace $P_{Mx,Tx}$ by $P_{MF,Tx}$ in Eq.(1), FAP SINR by applying IMIA in each RB can be rewritten as

$$SINR_{FAP,IM} = \frac{P_{F,Tx}G_f/L_F}{P_{MF,Tx}G_m/L_{M,i} + \delta} \tag{3}$$

B. UL Throughput studies

Average throughput. We assume each femtocell uses the entire available bandwidth B_M. The average throughput TH_F per resource block in femtocell without UL interference from MUEs can be given by

$$TH_F = B_{RB} \cdot \log_2\left(1 + P_{F,Tx} \cdot G_f/L_F - \delta\right) \tag{4}$$

Let $N_M(t)$ denote the number of MUEs up to time t (starting from time 0). Assume that $N_M(t)$ follows the Poisson distribution with mean λ. We also assume that the inter-arrival time of MUEs follows the exponential distribution and the holding time of MUEs follows the exponential distribution with mean holding time $1/\mu$. For an observation window $[0, T]$, there are total $N_{m,T} = \left(D_I^2/r_M^2\right) \cdot N_M(T)$ MUEs that have entered the interference zone of each single FAP in average. At time instant T, the average throughput for femtocell can be given by:

$$\begin{aligned} TH_{FAP,UI} &= \left(1 - \frac{N'_{m,T} R_{MM}}{B_M}\right) \cdot TH_F \\ &+ \frac{R_{MM}}{B_M} \sum_{k=1}^{N'_{m,T}} B_{RB} \log_2\left(1 + SINR_{FAP,UI}\right) \end{aligned} \tag{5}$$

Incentives. Consider FAP_2 in Fig.1, let N_a, N_b, N_c, N_d denote the numbers of MUE category a, b, c, d respectively. We have $N'_{m,T} = N_a + N_b + N_c + N_d$. $R_{MF,a}$, $R_{MF,b}$, $R_{MF,c}$, and $R_{MF,d}$ denote the RBs allocated by their individual UL accessed FAP. The average throughput for each RB in a single FAP after applying the incentive mechanism is given as

$$\begin{aligned} TH_{F,IM} &= \left(1 - \frac{N_a R_{MF,a} + N_b R_{MF,b}}{B_M}\right) \cdot TH_F \\ &+ \frac{B_{RB}}{B_M} \sum_{i=1}^{N_c} R_{MF,c} \log_2\left(1 + SINR_{IM,i}\right) \\ &+ \frac{B_{RB}}{B_M} \sum_{i=1}^{N'_d} R_{MF,d} \log_2\left(1 + SINR_{IM,i}\right) \end{aligned} \tag{6}$$

where $SINR_{IM}$ is the SINR after IMIA for a given RB that is used by MUE $c(d)$ and FAP_2, which can be followed by Equ.(3). N'_d denotes the number of d category MUEs that still affects FAP_2, namely $P_{MF,Tx} > P_{F,Tx}$. From the first term of this summation, a category MUEs and b category MUEs are not causing UL interference at FAP_2 due to the IMIA while they need total $(N_a R_{MF,a} + N_b R_{MF,b})$ RBs to satisfy their data requirement. This also results in less available RBs for FUEs that are served by FAP2. The second term shows that c category MUEs can still affect FAP_2 even it connects with FAP_3. In addition, they occupy less RBs and transmit at lower power compared with the situation before IMIA. The last term shows that the interference comes from $(N_d - N'_d)$ d category MUEs is completely removed. Nevertheless, a total of N'_d MUEs of category d will still affect FAP_2 but with low transmit power because of the good UL quality from FAP_1.

We can summarize the $Incentives$ in each single FAP and its neighbors:

i). The number of interfering MUEs is decreased greatly. $(N_a + N_b + N_c + N_d)$ is the total number of interfering sources for FAP_2, while it reduces to $(N_c + N'_d)$ after IMIA;

ii). FAP_2 has to release a total of $(N_a R_{MF,a} + N_b R_{MF,b})$ RBs to assign to a category MUEs and b category MUEs, while for $[N_a(R_{MM} - R_{MF,a}) + N_b(R_{MM} - R_{MF,b})]$ RBs, FAP_2 can operate in a non-interfering environment, which used to be interfered significantly. Notice $R_{MF,a(b)}$ is smaller than R_{MM}. This benefits FAP_1 and FAP_3, as there will be less RBs affected by MUEs a at FAP_1 and MUEs b at FAP3, respectively;

iii). The transmit power is reduced for the interfering MUEs, e.g. MUE c can lower its transmit power due to its connection with FAP_3 and thus benefit FAP_2. The similar operations can be done for MUE d and FAP_1, as well as MUE b and FAP_2, which benefit FAP_2 and FAP_3;

iv). After IMIA, MUEs can save energy and get better UL connection from FAPs, and macrocell can have more available UL spectrum resource.

V. Simulation And Numerical Results

To evaluate the performance of the proposed incentive mechanism based UL interference avoidance, we consider one marcocell overlapped by multiple femtocells, where the macrocell and all the femtocells share the whole frequency spectrum. The system parameters are shown in Table I. Assuming femtocells are fully loaded with all RBs being used in each individual FAP. Consequently, once one MUE is located inside of interference zone of any FAP, there will be UL interference affecting the FAP receiver. The RB reuse ratio for a single FAP is employed to describe how many RBs are reused by FUEs and the interfering MUEs. For example, if RB reuse ratio is 0.4, it means 40 RBs out of total 100 are used by interfering MUEs. Each MUE is assigned 2 RBs, which means there are 20 MUEs causing UL interference at the FAP. We conduct a two-hour simulation, FAPs and MUEs are randomly placed in the macrocell. We calculate the statistical average SINR and throughput in each RB for every FAP with different RB reuse ratio from 1000 simulations.

TABLE I
SYSTEM PARAMETERS

System parameters	value
Coverage of MBS/FAP	$250m/15m$
Carrier Frequency	2GHz
Total RBs (B_M)	100
RBs assigned to MUE	2
RBs assigned to MUE after IMIA	1
MUE/FUE antenna gain (G_m/G_f)	0dBi/0dBi
MUE maximum transmit power	21dBm [13]
Target throughput for MUE (Thr_M)	256kbps/512kbps/1Mbps
FUE transmit power	-14.83dBm [6]
Pathloss from MUE to FAP	$28 + 35 * log_{10}(d_{mf})$ [6]
Pathloss from FUE to FAP	$38.5 + 20 * log_{10}(d_f)$ [6]
LN shadowing from MUE to FAP	10dB
LN shadowing from FUE to FAP	4dB
Rayleigh flat fading MUE to FAP	6dB
Rayleigh flat fading FUE to FAP	4dB
Wall-penetrated loss	10dB

Fig.2 and Fig.3 show the FAP average SINR and FAP average throughput against RB reuse ratios, respectively. In Fig.2, The upper curve is without UL interference. This can be regarded as the ideal case, in which the performance depends on the FUE transmit power, signal attenuation and noise. The bottom one and the middle three curves present the results with UL interference and by applying IMIA, respectively. It is shown that the SINR in both are getting down as RB reuse ratio is increasing. This is because a high RB reuse ratio means more MUEs come, thus bringing more interference. However, the average SINR by applying IMIA decreases more slowly. When considering the low RB reuse ratio, such as less than 0.3, the performance of IMIA is nearly the same as the ideal case, especially when the RB reuse ratio is below 0.1. A similar set of results for FAP average throughput can be found in Fig.3 as well. When the RB reuse ratio is high, for example, larger than 0.7, as shown in Fig.2 and Fig.3, IMIA can obtain more than 25dB gain on average SINR and 100% improvement on average throughput comparing with the UL interference case, while only getting 10dB SINR loss and 25% throughput loss to the ideal case.

As mentioned in the previous sections, the total number of MUEs during t that may enter the FAP's interference zone is $N_{m,t} = \left(D_I^2/r_M^2\right) \cdot N_M(t)$. If total N_f FAPs are deployed in the macrocell, there will be $N_{m,t}/N_f$ MUEs entering each FAP in average. Therefore, in most cases there would not be a large number of MUEs arriving at one single FAP. This is in line with the low RB reuse ratio scenario, in which IMIA can obtain the approximate performance with the ideal case. One of the extreme situations is that most MUEs are in the interference zone of one FAP. Looking into when RB reuse ratio is 0.9 to 1, according to Fig.2 and Fig.3, IMIA can obtain more than 30dB gain on average SINR and 200% improvement on average throughput compared with the UL interference case, while only getting less than 14dB SINR loss and 34% throughput loss to the ideal case. Meanwhile, the RB reuse ratio for the rest of FAPs should be relatively low. Therefore, these FAPs surely benefit a lot because the most interfered FAP tackles most of the interfering MUEs.

When looking into the average SINR and throughput for FAP after IMIA under different MUE throughput requirements, it is found that only a minor gap exists among the middle three curves from Fig.2 and Fig.3, even if the RB reuse ratio is increasing. Notice that $\left(N_c + N_d^{'}\right)$ MUEs bring interference at FAP after IMIA. Normally $N_d^{'}$ is small because most d category MUEs, as described in section IV, would not cause interference because of the low transmit power (smaller than $P_{F,Tx}$). A rough estimation for the proportion of c category MUEs in the total MUEs shows less than $\left(D_I^2 - r_F^2\right)/3D_I^2$, namely < 0.25 according to the parameters setup in Table I. Their required transmit powers for reaching the target throughputs are not differing greatly. As a result, they barely have significant influences on the average SINR and average throughput of FAP_2 when the target throughputs are 256kbps, 512kbps and 1Mbps respectively.

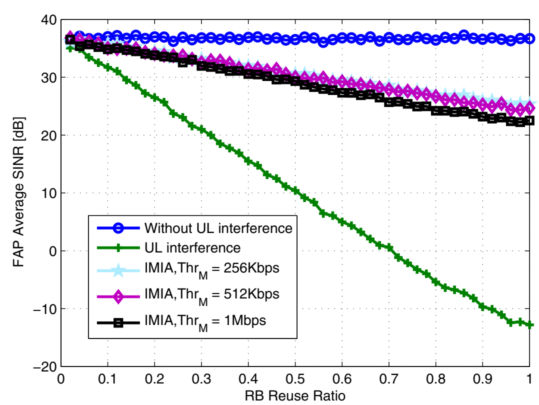

Fig. 2. Average UL SINR in femtocells

MUEs also benefit from the incentive mechanism. Fig.4 gives the CDF of average MUE transmit power with different target throughputs. The MUE transmit power is even lower than the FUE transmit power when Thr_M = 256Kbps (or 512Kbps). This is due to the target throughput for MUE being much smaller than that in FUEs (normally 2Mbps). As Thr_M increases to 1Mbps, MUE transmit power is still lower than the maximum value of 21dBm. Given that in some cases MUEs are unable to communicate with MBS even with maximum transmit power due to the poor UL quality,

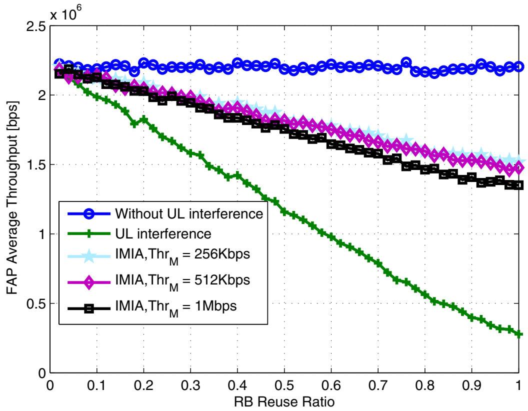

Fig. 3. Average UL throughput in femtocells

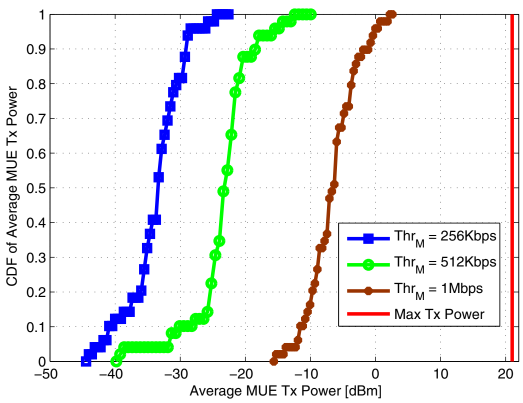

Fig. 4. CDF of UL transmit power for MUE after IMIA

IMIA can reduce MUEs' power consumption greatly, while still allowing MUEs to achieve a fair enough throughput even with less RBs allocated. Moreover, macrocell will have spare UL RBs and improve the average throughput because it does not need to serve the UL-accessed MUEs that used to be its responsibility.

VI. Conclusion

In this paper, we study the UL interference at femtocells caused by the approaching MUEs and have proposed an incentive mechanism based interference avoidance (IMIA) scheme for CSG femtocells. By IMIA, femtocells are encouraged to allow the interfering MUEs to implement the UL access, which refers to only UL connection, in order to remove or reduce the UL interference for themselves and their neighbor femtocells. Despite the fact that those femtocells have to allocate RBs to the interfering MUEs, the method benefits both tiers in the two-tier network. Simulations have demonstrated that femtocells can alleviate the UL interference significantly. Meanwhile, macrocell have more RBs available after IMIA for the rest of MUEs and the UL only accessing MUEs can still achieve a relatively high throughput, but with a much lower transmit power. One further work is to consider the method in UL interference mitigation with multiple macrocells and multiple femtocells.

Acknowledgment

This work was supported by the EU-FP7 IAPP@RANPLAN under grant No. 218309 and EU-FP7 iPLAN under grant No. 230745.

References

[1] J. Zhang and e. a. Guillaume de la Roche, *Femtocells Technologies and Deployment*. Wiley, Jan 2010.
[2] V. Chandrasekhar, J. Andrews, and A. Gatherer, "Femtocell networks: a survey," *IEEE Commun. Mag.*, vol. 46, no. 9, pp. 59–67, sep 2008.
[3] H. Claussen, "Performance of macro- and co-channel femtocells in a hierarchical cell structure," in *IEEE PIMRC 2007*, Sep 2007, pp. 1–5.
[4] Z. Shi, M. C. Reed, and M. Zhao, "On uplink interference scenarios in two-tier macro and femto co-existing umts networks," *EURASIP Journal on Wireless Communications and Networking*, Jan 2010.
[5] X. Ping, V. Chandrasekhar, and J. Andrews, "Open vs. closed access femtocells in the uplink," *IEEE Trans. Wireless Commun.*, vol. 9, no. 12, pp. 3798–3809, Dec 2010.
[6] (2008, Dec) Interference management in umts femtocells - white paper. Femto Forum.
[7] V. Chandrasekhar, J. Andrews, T. Muharemovic, and Z. Shen, "Power control in two-tier femtocell networks," *IEEE Trans. Wireless Commun.*, vol. 8, no. 8, pp. 4316–4328, Aug 2008.
[8] X. Chu, Y. Wu, D. Lopez-Perez, and X. Tao, "On providing downlink services in collocated spectrum-sharing macro and femto networks," *IEEE Trans. Wireless Commun.*, vol. 10, no. 12, Dec 2011.
[9] H. Jo, C. Mun, J. Moon, and J. Yook, "Interference mitigation using uplink power control for two-tier femtocell networks," *IEEE Trans. Wireless Commun.*, vol. 8, no. 10, pp. 4906–4910, Oct 2009.
[10] M. Yavuz, F. Meshkati, S. Nanda, A. Pokhariyal, N. Johnson, B. Raghothaman, and A. Richardson, "Interference management and performance analysis of umts/hspa+ femtocells," *IEEE Commun. Mag.*, vol. 47, no. 9, pp. 102–109, Sep 2009.
[11] V. Chandrasekhar and J. Andrews, "Uplink capacity and interference avoidance for two-tier femtocell networks," *IEEE Trans. Wireless Commun.*, vol. 8, no. 7, pp. 3498–3509, Jul 2009.
[12] D. Lopez-Perez, I. Guvenc, G. de la Roche, M. Kountouris, T. Quek, and J. Zhang, "Enhanced intercell interference coordination challenges in heterogeneous networks," *IEEE Commun. Mag.*, vol. 18, no. 3, pp. 22–30, Jun 2011.
[13] 3GPP, *LTE Release 10*, 3GPP Std. [Online]. Available: http://www.3gpp.org/Release-10