

OFDMA femtocells: Intracell Handover for Interference and Handover Mitigation in Two-Tier Networks

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Abstract—This work presents a novel approach for the avoidance of cross-tier interference in two-tier networks comprised of Orthogonal Frequency Division Multiple Access (OFDMA) macrocells and femtocells. This new technique is based on the use of Intracell HandOvers (IHOs), and it makes possible that either a macrocell or a femtocell can reassign its sub-channel or power allocation upon the detection of cross-tier interference. Simulation results show that this approach is able to cope with the cross-tier interference issues intrinsic to closed access femtocells, and the increased number of HandOvers (HOs) resulting from open access femtocells.

I. INTRODUCTION

Femtocells are low-cost, low-power access points deployed by the end-customers that provide indoor coverage of a given wireless cellular standard, e.g. Long Term Evolution (LTE), Wireless Interoperability for Microwave Access (WiMAX). They are also connected to the network operator through a backhaul, e.g. optical fiber, Digital Subscriber Line (DSL). It is expected that femtocells will enhance indoor coverage, deliver high bandwidths and new services to end-customers, and off-load traffic from the existing macrocellular networks.

An extensive deployment of femtocells, which will heavily impact the architecture of current cellular systems, is foreseen [1]. The new network architecture will be divided into two clearly separated tiers, the macrocell tier and the femtocell tier. In this case, the macrocell tier will be composed of long range base stations (macrocells) that provide cellular coverage to mobile users, while the femtocell tier will be comprised of short range access points (femtocells) that offer large throughputs and new applications to indoor customers.

The topology of two-tier networks brings however new problems and creates new design challenges, as for example, the management of the electromagnetic interference between macrocells and femtocells, known as *cross-tier interference*. Cross-tier interference is defined as the decline in signal quality of macrocell users (DownLink (DL) or UpLink (UL)) due to the presence of femtocell users sharing the same spectrum and vice versa. In order to avoid cross-tier interference, an optimal solution is to assign orthogonal chunks of the available spectrum of the operator to both the macrocell and

femtocell tier, i.e. orthogonal deployment. However, this will result in an inefficient use of the bandwidth since each tier only accesses a fragment of the whole licensed spectrum. Therefore, a co-channel deployment of both macrocells and femtocells is more likely to occur, thus increasing the reuse of the carriers and decreasing the expenses of the operators. As a consequence, sophisticated self-organization techniques that tune the femtocell parameters and mitigate cross-tier interference according to channel conditions are needed.

Different self-organization techniques have been proposed in the literature in order to mitigate cross-tier interference in co-channel deployments of two-tier networks:

In [2], it is introduced a power control method for pilot and data channels that 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.

In [3], the authors present a method for coverage adaptation that uses information on mobility events of passing and indoor users. Each femtocell sets its power to a value that on average minimizes the total number of attempts of passing users to connect to the femtocells.

In [4], it is suggested the use of multiple antenna elements installed at the femtocell to create different antenna patterns. These patterns are employed to adapt the femtocell coverage in different scenarios, avoiding thus cross-tier interference towards passing users.

Moreover, OFDMA systems have the advantage of providing two dimensions (frequency and time) for the management of radio resources. Therefore, interference avoidance can be achieved not only through power and antenna management, but also through sophisticated sub-carrier assignments.

In [5], the authors propose a spectrum allocation strategy based on an orthogonal deployment of OFDMA macrocells and femtocells so that the spatial frequency reuse is maximized. However, it does not apply to co-channel deployments.

This paper, contrarily, presents a novel approach that is able to cope with cross-tier interference in co-channel deployments. This new technique is focused on two-tier OFDMA networks, and is based on the use of IHOs. Using IHOs, either a macrocell or a femtocell can reassign its sub-channel or power allocation upon the detection of cross-tier interference, avoiding thus the reuse of the same sub-channel in both tiers

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at the same area/time. The performance of the proposed IHO approach is compared with the access methods used in current femtocell deployments, i.e. closed and open access strategies.

II. CLOSED AND OPEN ACCESS

In a two-tier network, cross-tier interference is heavily impacted by the access strategy defined in the femtocell tier. The access method indicates which customers are allowed to use each femtocell. In the following, the advantages and drawbacks of the most popular access methods are depicted.

A. Closed Subscriber Group (CSG)

When using *closed access* [6], only the subscribers of a femtocell are allowed to connect to it. This mode may be preferred by the femtocell owners, because they do not need to share the resources of their femtocells with other customers. However, since non-subscriber may not be connected to their best server due to the access restrictions of CSG femtocells, this mode is challenging in terms of interference avoidance, e.g.:

- in the downlink, a femtocell can jam the communication of a close macrocell user connected to a far macrocell, due to the leakage of power (interference) of the femtocell from indoors to outdoors.
- in the uplink, a macrocell user connected to a far macrocell transmitting with high power can jam the connection of a close femtocell due to the imperfect shielding provided by the house walls.

B. Open access

When using *open access* [6], all users, subscribers and non-subscribers, can access any femtocell. This mode may not be preferred by the femtocell owners, since they pay for a device that is to be shared with other operator customers. Open access, however, presents some advantages such as the mitigation of cross-tier interference, due to the fact that each User Equipment (UE) is always connected to its best serving cell whether it is a macrocell or a femtocell. Nevertheless, a disadvantage of this mode is the increased number of HOs and thus signaling. For example, users moving across a residential area can continuously hand over from an open femtocell to another one, or even to the umbrella macrocell. This is risky given the possibility of HO failure, and therefore of dropped call. According to [2], there is a 2% probability that a HO results in a dropped call (increasing thus outage).

It is to be mentioned, as a conclusion, that there is a need for new approaches able to cope with the cross-tier interference issues intrinsic to closed access, and the increased number of HOs resulting from open access. In the following section, a novel approach able to deal with both aspects is introduced.

III. PRELIMINARIES

First of all, let us mention that OFDMA is a multi-user access technology where the bandwidth is divided into orthogonal sub-carriers, which are in turn combined into K groups known as *resource blocks* (LTE) or *sub-channels* (WiMAX).

It is also to be noted that mathematic variables in lower case represent magnitudes in natural units, while upper case indicates logarithmic scale, i.e. dB.

A. Neighboring cell list, measurements report and channel quality indicator

In order to select the best serving cell when the UE is in idle mode, or to carry out the HO procedure when the UE is in active mode, the UE makes continuous measurements of the Received Signal Strengths (RSSs) of the pilot channels of the neighbouring cells. Then, in order to simplify and speed up the task of the UE when monitoring the air interface, the serving cell periodically broadcasts the list of cells and pilot channels that its UEs must measure. This list is known as Neighboring Cell List (NCL). After receiving the NCL, the UE periodically (every T_{MR}) performs the appropriate measurements, and reports back the results to its serving cell, which then decides whether to start a new cell re-selection or HO procedure or take no action.

In two-tier networks, the NCL of a macrocell not only contains neighboring macrocells, but also open access femtocells. Therefore, non-subscribers must report back not only the RSSs of the pilot channels from all neighboring macrocells, but also from open access femtocells. In the contrary, UEs perform an autonomous search in order to detect CSG femtocells [7]. Note that macrocells do not provide any information about CSG femtocells in their NCL in order to minimize the impact of CSG femtocell deployments on the implementation of the current macrocell base stations.

By using a Channel Quality Identifier (CQI), UEs also report periodically (at most every 2 ms in LTE) to its serving cell, its signal quality in terms of Signal to Interference plus Noise Ratio (SINR), as well as the signal quality of a subset of resource blocks [8]. This CQI is used by the Medium Access Control (MAC) layer to perform channel-dependent scheduling, but it can also be used to trigger a HO when the SINR reported by the UE is low.

B. Handover

In a regular HO procedure, when the RSS of a neighboring cell pilot (RSS_j^{pilot}) plus a given threshold (ΔQ_{HO}) is stronger than the RSS of the serving cell pilot (RSS_m^{pilot}), a HO is triggered. Subsequently, the serving cell establishes communication with the target cell and performs a HO. However, in two-tier networks, performing a HO is not always the best choice or a possible option at all, because:

- In closed access, it is not allowed that a non-subscriber hands over from its server to a closed access femtocell.
- In open access, it is preferred to keep a mobile user connected to a macrocell than hand it over continuously and repeatedly between adjacent open access femtocells.

In order to overcome these drawbacks, and the limitations imposed by the closed and open access (closed access increases cross-tier interference, whereas open access increases the number of HO), the following IHO approach is proposed.

IV. INTRACELL HANDOVER

The IHO is an special case of HO, in which the source and target cell is the same. The purpose of IHO is to change one channel, which may be interfered or faded with a new clearer or less faded channel. IHO has been used, for example, in Global System for Mobile communication (GSM) networks, where the IHO is normally triggered when the UE reports a large RSS ($RxLev$), as well as a low Received Signal Quality ($RSQ(RxQual)$). Then, the GSM cell performs an IHO willing to get rid of the interfered or faded channel using a new channel in better conditions.

The main idea of the proposed approach in this paper is that when a non-subscriber that is connected to a macrocell suffers from cross-tier interference due to the presence of a nearby femtocell, the macrocell itself performs an IHO, if possible, or it casts an IHO in all interfering femtocells, otherwise.

Without loss of generality respect to the proposed IHO approach, the rest of this paper focuses only in the downlink.

A. Triggering an IHO

When the SINR of a non-subscriber UE_y^{ns} connected to macrocell M_m in sub-channel k is smaller than a given threshold $SINR_y^{IHO}$, the serving macrocell M_m requests a measurement report from non-subscriber UE_y^{ns} . In this measurement report, non-subscriber UE_y^{ns} indicates the RSS of the serving macrocell M_m in sub-channel k ($RSS_{m,y}^k$), and the RSSs of its neighboring cells \mathcal{N}_m in such sub-channel ($RSS_{j,y}^k$). Note that the neighboring cells \mathcal{N}_m of UE_y^{ns} are identified by the NCL passed from macrocell M_m to non-subscriber UE_y^{ns} ($\mathcal{N}_m \in \{N_0, \dots, N_j, \dots, N_{J-1}\}$).

Thereafter, macrocell M_m compares its $RSS_{m,y}^k$ with the other reported $RSS_{j,y}^k$ values. Then, macrocell M_m triggers an IHO only if condition (1) is verified by one of its neighboring cells N_j , and this neighboring cell is a femtocell F_n .

$$RSS_{m,y}^k < RSS_{j,y}^k + \Delta Q_{IHO} \quad \forall j \in \mathcal{N}_m \quad (1)$$

where ΔQ_{IHO} is an interference protection margin.

Thus, if femtocell F_n verifies condition (1), it is considered as a cross-tier interferer of non-subscriber UE_y^{ns} in sub-channel k , and therefore an IHO is launched. Note that the set of all interfering femtocells of non-subscriber UE_y^{ns} verifying condition (1) is denoted by $\theta_y = \{A_0, \dots, A_r, \dots, A_{R-1}\}$.

Then, the IHO procedure can be carried out either in the serving macrocell M_m or in all interfering femtocells θ_y . However, in order to minimize the signaling overhead, it is always preferred to perform an IHO in the serving macrocell M_m than in all interfering femtocells θ_y . Nevertheless, this is not always possible due to traffic load or interference conditions in the serving macrocell.

In the following, the conditions that are taken into account to decide whether an IHO is launched in the serving macrocell M_m or in all interfering femtocells θ_y are depicted, as well as the actions involved in an IHO.

B. Performing the IHO in the macrocell

An IHO is launched in the serving macrocell M_m only if:

- There is at least a free sub-channel h to which non-subscriber UE_y^{ns} can be re-allocated to (switching), and
- The interference suffered by sub-channel h is smaller than the one suffered by the currently assigned sub-channel k .

In the case that there are more than one available sub-channels in macrocell M_m , non-subscriber UE_x^{ns} is switched to the sub-channel h that suffers the least interference. This sub-channel h is selected by macrocell M_m according to the CQIs periodically reported by non-subscriber UE_y^{ns} . It is to be noticed that if there is no sub-channel fulfilling these requirements, the IHO is not performed in macrocell M_m , but in all interfering femtocells θ_y .

C. Invoking an IHO in the femtocells

If the IHO cannot be performed in macrocell M_m , it is attempted in all interfering femtocells θ_y verifying condition (1). In this case, macrocell M_m establishes communication (Section IV-D) with all interfering femtocells $A_r \in \theta_y$, and casts an IHO in all of them.

Moreover, and according to the availability of sub-channels in the interfering femtocell A_r , the IHO procedure differs. When there are available sub-channels in A_r , a sub-channel *switching* process is executed, while when there are no available sub-channels, a distributed *power control* is applied.

1) Switching approach for IHO in the femtocells:

Switching is only possible when there is at least one available sub-channel h in the interfering femtocell A_r . Then, the femtocell subscriber UE_x^s , which is currently connected to sub-channel k , can be transferred to the free sub-channel h . In this way, sub-channel k is liberated, avoiding thus cross-tier interference to non-subscriber UE_y^{ns} . Note that if there are more than one available sub-channels in femtocell A_r , subscriber UE_x^s is switched to the sub-channel h that has the least interference according to its CQIs.

2) Distributed power control for IHO in the femtocells:

If there is no availability of free sub-channels in the interfering femtocell A_r , then one option would be to disconnect UE_x^s from sub-channel k for a period of time ΔT_{IHO} in order to avoid cross-tier interference towards non-subscriber UE_y^{ns} . However, this approach, called *forbidding*, results in a reduction of the throughput of femtocell A_r , which is not desirable.

Then, instead of disconnecting UE_x^s from sub-channel k , the power transmitted by A_r in sub-channel k is reduced for a period of time ΔT_{IHO} . In this way, cross-tier interference towards non-subscriber UE_y^{ns} is mitigated (primary objective), while the throughput of femtocell A_r is enhanced compared to that of the forbidding approach (secondary objective).

The target of this distributed power control is to set the power P_r^k , with which all interfering femtocells $A_r \in \theta_y$ transmit in sub-channel k , to a value $P_r'^k$ that ensures a given signal quality targeted $SINR_y^{target}$ to non-subscriber UE_y^{ns} .

In order to achieve the targeted $SINR_y^{target}$, the maximum interference i_y^{max} that non-subscriber UE_y^{ns} can tolerate is:

$$i_y^{max} = \frac{rss_{m,y}^k}{sinr_y^{target}} - \sigma \quad (2)$$

where σ represents the background noise.

The macrocell then asks all interfering femtocells $A_r \in \theta_y$ to decrease their transmit power in sub-channel k from p_r^k to $p_r'^k$ so that i_y^{max} is respected for non-subscriber UE_y^{ns} . Furthermore and in order to avoid unfair power decrease requests among femtocells, the power decrease is weighted by macrocell M_m using the RSSs reported by non-subscriber UE_y^{ns} from each interfering femtocell $A_r \in \theta_y$ according to:

$$p_r'^k = i_y^{max} \cdot \underbrace{\frac{rss_{r,y}^k}{\sum_{\forall r} rss_{r,y}^k}}_{i_{r,y}^{max}} \cdot \underbrace{\frac{p_r^k}{rss_{r,y}^k}}_{p_{r,y}^k} \quad (3)$$

where $i_{r,y}^{max}$ is the maximum interference that femtocell $A_r \in \theta_y$ is allowed to cause to non-subscriber UE_y^{ns} and $p_{r,y}^k$ is the path loss between both of them. Then, (3) simplifies to:

$$P_r'^k = P_r^k - \Delta P^k = P_r^k - 10 \cdot \log_{10} \left(\frac{\sum_{\forall r} rss_{r,y}^k}{i_y^{max}} \right) \quad (4)$$

being ΔP^k the power reduction in decibels requested for sub-channel k , which is computed by the macrocell M_m and passed on (Section IV-D) to all interfering femtocells $A_r \in \theta_y$. It is to be noted that this power reduction ΔP^k is equal for all interfering femtocells $A_r \in \theta_y$.

Finally, it can occur that if femtocell A_r is already transmitting low in sub-channel k or $SINR_y^{target}$ is too large, the power decrease request ΔP^k might have the same effect as switching off the sub-channel. In this case, sub-channel k is *forbidden* in femtocell A_r for a period of duration ΔT_{IHO} , avoiding cross-tier interference towards non-subscriber UE_x^{ns} . However, it must be mentioned that subscriber UE_x^s is only disconnected from sub-channel k if it can afford it, i.e. UE_x^s has allocated more sub-channels or carries a service where delay is not crucial such as best effort, non-real time service.

D. Macrocell - femtocell Communication

In order to cast an IHO in an interfering femtocell, the macrocell needs to communicate with this femtocell. This communication could be established over:

- The backhaul connection using the core network infrastructure, e.g. Radio Access Network Application Part (RANAP) in Universal Mobile Telecommunication System (UMTS), S1 in LTE [9].
- A direct interface between macrocells and femtocells. This solution has synergies with LTE, which has defined an X2 interface for signaling between existing eNodeBs.
- The mobile user, who could relay data from a macrocell to a femtocell and vice versa [10].

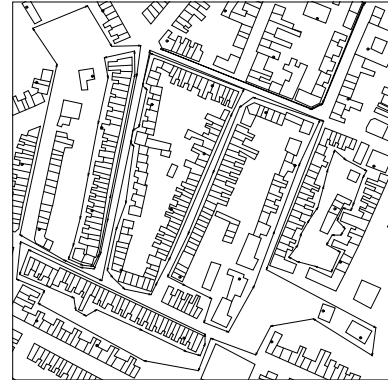


Fig. 1. Residential area covered by 1 macrocell and 32 femtocells. Each femtocell premises contains 8 indoor users, while 8 pedestrian users are located outdoors, being their routes also indicated.

TABLE I
SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Scenario size	300m × 300m	M Ant. Pattern	Omni
Simulation time	800 s	M Cable Loss	3 dB
Macrocells	1	F TX Power	10 dBm
Femtocells	30	F Ant. Gain	0 dBi
Non-subscribers	8	F Ant. Pattern	Omni
Subscribers	8 per femto	F Body Loss	0 dB
Carrier	2.3 GHz	UE Ant. Pattern	Omni
Bandwidth	5 MHz	UE Noise Figure	7 dB
DLsymbols (T_{DL})	19	UE Body Loss	0 dB
Frame duration	5 ms	T_{MR} and Δt_m	50 ms
Sub-carriers (SC)	512	$SINR_y^{thres}$	3 dB
Sub-channels (K)	8	$SINR_y^{target}$	10 dB
M radius	500 m	ΔQ_{IHO}	1 dB
M TX Power	35 dBm	ΔT_{IHO}	10 s
M Ant. Gain	0 dBi	Path Loss Model	Free space

V. EXPERIMENTAL SEPTUP

The scenario under scrutiny is a residential area with a size of 300×300 m in the town of Luton (U.K.), containing 438 premises of which by around 400 are dwelling houses. 32 of these houses were selected to potentially host an indoor femtocell. Assuming that 3 operators with equal customer share provide services in this area, these 32 femtocells represent an approximate 25% penetration. Besides these femtocells, the scenario is also covered by a macrocell located 200 m south and 200 m east from the center of this scenario (out of it). The scenario and parameters used in this experimental evaluation are shown in Figure 1 and in Table I, respectively.

In this simulation, the path loss predictions are based on a free space model, in which a wall loss of 10 dB is assumed.

The different types of users follow a well-defined behavior:

- Subscribers are located inside the houses with femtocell and do not move.
- Non-subscribers are located outdoors and move along predefined paths according to the pedestrian model presented in [11].

It is considered that the macrocell hosts 8 non-subscribers, while the 32 femtocells host 8 subscribers each. Since every UE requests one full sub-channel (19 Orthogonal Frequency Division Multiplexing (OFDM) symbols) for DL transmission, and because there are 8 sub-channels available, this is a worst

TABLE II
INTERFERENCE PROTECTION MARGIN ΔQ_{IHO}

ΔQ_{IHO} [dB]	-1.5	-1	-0.5	0	0.5	1	1.5
Outage	82	80	74	50	24	0	0

TABLE III
PERFORMANCE COMPARISON(800 s SIMULATION)

Method	Closed Access	Open Access	IHO forbidding	IHO PC
Total HO attempts	-	130	94	102
Average Hand IN attempts per femtocell	-	2.06	2.61	3.18
Hand IN attempts at macrocell	-	64	0	0
HO Outage	-	44	0	0
Interference Outage	95	1	0	0
Non-subscribers tier throughput [Mbps]	1.77	2.07	1.92	1.88
Subscribers tier throughput [Mbps]	112.99	113.083	112.68	112.81

case scenario, in which both the macrocell and the femtocells are fully loaded.

It is to be noted that a UE cannot transmit when its SINR is lower than the SINR threshold of the lowest Radio Access Bearer (RAB) defined in the network, in this case, 2.88 dB . Following the behavior of real time services, a non-subscriber is considered to be in outage (dropped call) when it is not able to transmit for a given period of time. In this case, this period of time is fixed to 200 ms as recommended by [12] for Voice over IP (VoIP).

Further information about the dynamic system-level simulation such as channel modeling, interference modeling, throughput calculation, etc. can be found in [13].

VI. EXPERIMENTAL RESULTS

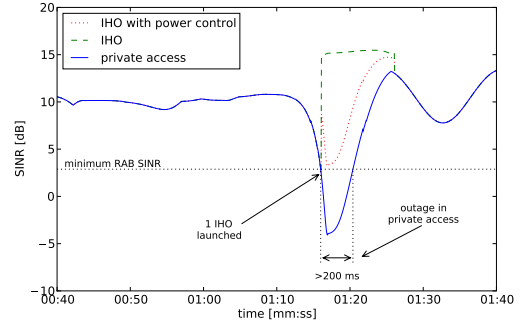
Let us mention that, in this case, the IHO threshold $SINR_y^{IHO}$ has been set to 3 dB , which is a value slightly larger than that of the lowest RAB defined in the network. In this way, the IHO is launched before the non-subscriber cannot achieve any RAB, and it falls in an outage.

A. Parameter ΔQ_{IHO} analysis

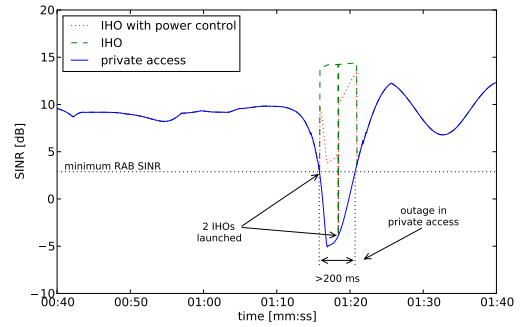
Table II shows the network performance in terms of the outage of non-subscribers, when using IHOs with different values of the interference protection margin ΔQ_{IHO} . It has been observed that if ΔQ_{IHO} is low, e.g. $\Delta Q_{IHO} = -1$, a large number of outages occurs. The reason behind this is that IHOs are launched either too late, when the non-subscriber is already in outage, or they are not even launched. In the contrary, if ΔQ_{IHO} is too large, IHOs will be launched in order to solve a problem (cross-tier interference) that does not even exist, increasing network signaling. In view of the results of Table II, $\Delta Q_{IHO} = 1\text{ dB}$ will be assumed in the remaining results because it seems to guarantee, in this case, outage avoidance. However, it is worth mentioning that ΔQ_{IHO} may have to be tuned for different environments and femtocell penetrations.

B. Parameter ΔT_{IHO} analysis

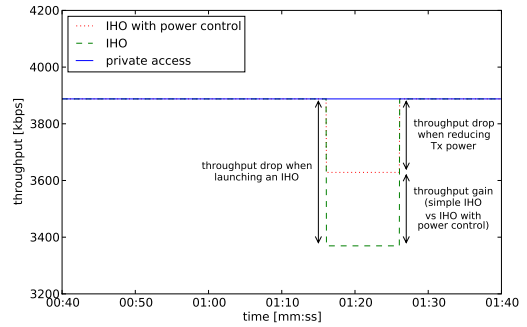
Figure 2 illustrates the variations of the SINR of a non-subscriber through time, while it moves across the scenario.



(a) IHO with $\Delta T = 10\text{ s}$



(b) IHO with $\Delta T = 2.5\text{ s}$



(c) Femtocell throughput

Fig. 2. SINR level of a non-subscriber, while moving across the scenario.

This figure is going to be used to analyze parameter ΔT_{IHO} . When closed access is utilized, Figure 2(a) shows how the SINR of a UE sharply drops when it walks close to a femtocell that uses the same sub-channel, causing outage. Contrarily, when the IHO approach (forbidding sub-channels) is used, Figure 2(a) shows how, in the same situation, an IHO is launched and the SINR of the UE recovers, avoiding outage. This case, after $\Delta T_{IHO} = 10\text{ s}$, the femtocell starts using again the 'forbidden' sub-channel used by the non-subscriber. Nevertheless, it is not a problem since the UE is far away from the femtocell coverage area. However, if the femtocell starts using the 'forbidden' sub-channel before the non-subscriber moves out of the femtocell coverage, launching another IHO would be necessary to prevent cross-tier interference. This way, the number of IHOs increases and thus the network signaling, which is not desired (Figure 2(b) with $\Delta T_{IHO} =$

2.5 s). Results show that $\Delta T_{IHO} = 10$ s performs well, in this case, for pedestrian users in order to prevent the launch of a set of consecutive IHOs to cope with a given source of cross-tier interference.

Moreover, Figure 2(a) and Figure 2(b) also show the variations of the SINR of a non-subscriber through time, when the IHO approach is used with power control. This case, sub-channels are not forbidden, but the power applied to them by the interfering femtocells is decreased. This is done in a controlled manner in order to protect the non-subscriber from cross-tier interference. As a result, the SINR of the non-subscriber is not as large as when forbidding sub-channels, but the outage is avoided and the femtocell throughput is enhanced. Figure 2(c) shows a case in which power control does not recover the full throughput capacity compared to CSG, but provides a gain with respect to the forbidding approach. In this case, this throughput gain is by around 200 kbps, which is enough to hold real time services such as VoIP (12.2 kbps).

C. Outages and throughput analysis

Table III shows the results in terms of network outages and throughput of a performance comparison between closed and open access and the IHO approach:

1) *Outages due to interference*: Closed access deployments are severely affected by outages due to cross-tier interference. As soon as a non-subscriber walks near by a femtocell using the same sub-channel, it falls in outage. In the contrary, in open access, the number of outages due to interference are notably reduced, since non-subscribers are allowed to connect to the strongest cell, turning the strong interferer into their serving cell. However, even if a non-subscriber is connected to a femtocell, the aggregate of co-tier interference from neighboring femtocells can disrupt its service. When using IHOs, outages are further reduced to zero, since the reuse of the same sub-channel at the same area and time is avoided.

2) *Outages due to HO failure*: In the case of open access, the number of outages because interference is notably reduced, but outages due to HO failure still exists, since there is a 2% probability of that a HO results in a dropped call (outage).

3) *Non-subscribers throughput*: Open access offers the best performance, since non-subscribers are always connected to the best available server. Nevertheless, this enhancement comes at the risk of suffering outage due to HO failure. However, the IHO approach performs better than closed access, while also warranting the avoidance of HO failure.

When comparing the IHO approach with forbidden sub-channels and power control, it is to be noticed that when using power control the non-subscribers throughput is reduced at the expense of enhancing the subscribers (femtocells) throughput, while warranting outage avoidance in both cases.

4) *Subscribers throughput*: Open access achieves the best subscribers throughput. This is due to the fact that when a non-subscriber connects to a femtocell, a sub-channel is released in the macrocell, thus decreasing cross-tier interference towards the existing femtocells. In addition, it is worth mentioning that

the IHO approach achieves a worse performance than both open and CSG access. The reason behind this is that when the IHO is based on sub-channel forbidding or power control, the interfering sub-channel is banned from the femtocell or the power allocated to it is reduced, resulting thus in a throughput loss for the femtocell. However, by reducing the femtocell throughput, the IHO approach is able to neglect the number of non-subscriber outages. Moreover, it is to be mentioned that this kind of IHO only happens when the macrocell and femtocells are fully loaded, if not an IHO based on sub-channels switching occurs with no throughput loss associated.

VII. CONCLUSION

In this paper, a new approach was presented for the avoidance of cross-tier interference in two-tier OFDMA networks. This method is based on the use of IHOs, and it is able to:

- Mitigate cross-tier interference, solving the main disadvantage of CSG femtocells.
- Reduce the number of handover attempts and thus signaling and outage, which are considered the main drawbacks of open access femtocells.

The interference reduction of non-subscribers comes at the expense of signaling and reducing the subscribers throughput in some cases, i.e. if macrocell and femtocells fully are loaded. However, due to the nature of the services used by subscribers, the impact of power reduction is, in average, not crucial for femtocell connectivity.

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