Estimation-Based Non-Cooperative Power Allocation in Two-Tier Femtocell Networks

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***Abstract*—Femtocells (FCs) are low power, small-area cellular networks typically designed for use in a home or small business. The design of FC networks is challenging due to their independence of each other and of the underlying macrocell (MC) network thereby, necessitating non-cooperative resource allocation schemes. This paper develops a new distributed non-cooperative uplink (UL) power allocation scheme for FC users. Our scheme aims at fairly maximizing the throughput of femto users (FUs) based on periodic interference estimation performed by the femto access points (FAPs). We compare our scheme to the optimal centralized one. Simulation results show that our scheme presents good performances in terms of throughput and fairness.**

Index Terms—Femtocell, co-channel, adaptive power allocation, estimation, non-cooperative, throughput, fairness.

I. Introduction

A femtocell (FC) is a low power, small-area-covering wireless cellular network consisting of one Femto Access Point (FAP) and stationary or low-mobility femto users (FUs) deployed in an indoor environment such as a home or an office. FCs have recently emerged as a solution to increase both the capacity and coverage of cellular networks and to reduce capital and operational costs by delegating indoor services from the MC to FCs [1]. FCs operate in the licensed spectrum owned by wireless operators and share this spectrum with MC networks, thereby inducing significant co-channel interference that could compromise system performances if it is not taken into account. This interference arises from MC-to-FC, FC-to-FC, and/or FC-to-MC interactions. Dealing with this interference is a very challenging task due to the lack of coordination between FCs and MCs, and among the FCs themselves, which are not necessarily associated with the same Femto operator. Moreover, unlike traditional cellular networks, there is no centralized entity or common base station to perform resource allocation for different FCs deployed in the same geographic area. Therefore, traditional centralized interference mitigation and power control schemes are no longer applicable to this type of networks. Even distributed cooperative solutions are not appropriate in this context, since FCs are independent of and often cannot communicate with one another. There have been some research works recently proposed to analyze and solve the FC interference problem in UL communications. Claussen [2] evaluated the impact of deploying FCs on existing co-channel MCs based on system level simulations. On the other hand, Shi et al. [3] developed an analytical model to study the UL capacity and coverage of UMTS FCs coexisting within the MCs. Other works proposed some resource management schemes in two-tier FC/MC networks in order to reduce the interference and improve the capacity of these networks. For instance, Lee et al. [4] considered fractional frequency reuse (FFR) based on a prioritization mechanism to mitigate inter-FC interference. However, to establish these priorities, global/centralized information about FCs is required. Pyun et al. [5] also considered FFR for TDMA FCs in order to protect the FUs from macro users (MUs) interference, but they did not take into account inter-FC interference. A more recent work [6] has provided a distributed hashing-based scheduling scheme for OFDMA FCs, under the assumption of FC-MC cooperation. These different spectrum management schemes might be further improved by optimizing power allocation. Therefore, some works have been recently proposed to decrease UL co-channel interference via adaptive power allocation: In [7], Yavuz et al. tried to mitigate interference via power calibration. Jo et al. [8] proposed a simple UL power control for FCs. Their scheme adjusts the transmit (TX) power of FUs in proportion to the fed-back interference level of MCs. However, they focused only on the protection of a MC's UL communication and neglected inter-FC interference. In [9], Chandrasekhar et al. characterized the maximum achievable MC signal to interference plus noise ratio (SINR), given a set of feasible FC SINRs, using the Pareto optimality criterion. They also proposed a coordinated UL power control architecture for both MCs and FCs, which requires MCs to use their proposed power control algorithm. Their work assumes cooperation and possibility of communication between FCs and underlying MCs, which is not often the case since FCs co-located with the MC do not necessarily belong to the same cellular/wireless operator. One of the main priorities of the research community and the industry with the emergence of FCs was to ensure that the performance of the existing MC networks will not be affected by the introduction of these new entities: the FCs. Therefore, most of the related work, either focused on the protection of MC from interference originating from FCs, or coupled (femto and macro) resource management while assuming the possibility of coordination between the MBS and the FAPs, which is not always true. Therefore, in this paper we direct our attention to the problem of FC capacity improvement via adaptive power allocation to FUs. To this end, we propose a new distributed non-cooperative UL power allocation scheme for FC networks in which we try to fairly maximize the capacity of FUs while ensuring $symbiosis$ between the FCs and the the underlying MC, and inter-FCs. Our scheme is completely distributed. Each time slot, each FAP allocates power to its active FUs based on interference prediction and the SINR evolution of its local FUs. Thus, our scheme does not require any exchange of information between FCs neither between FCs and MCs. Simulations have shown that our scheme achieves good performances in terms of throughput and fairness compared to the optimal centralized case despite the absence of information exchanges between the active FCs. The remainder of this paper is organized as follows. Section II describes the system model and the motivation of our work. Section III states and formulates the studied problem. Section IV presents the detailed design of the proposed allocation scheme. Section V evaluates the performance of the proposed scheme via simulations, and compares it with the optimal centralized one. Section VI concludes the paper.

II. Network Model

We consider a single-carrier two-tier cellular system consisting of N_{FC} FCs (with coverage radius R_F) overlaid on one MC (with coverage radius R_M), where both of them operate over an identical carrier frequency f. Each FC consists of one FAP and N_{FU} femto-users (FUs). On the other hand, the MC consists of one macro base station (MBS_0) and N_{MU} macro users (MUs). We assume that both FCs and MC use TDMA as a channel access technique, that is, we assume that time is slotted and at every time slot only one MU is active per MC and only one FU is active per FC. We denote the currently active MU by m and the currently active FU associated with the femto access point FAP_i by u_i. In this work, we consider the UL communication stream; i.e., communication from MU to MBS_0 and from FUs to FAPs. We also assume that these UL communications are synchronized [10][1]. We denote MUs' and FUs' maximum transmit powers respectively by P^m_{max} and P^f_{max}, where P^f_{max} is relatively small compared to P^m_{max}. In our network, we assume that there are no FCs in the vicinity of the macro base station, and that the maximum power used by FUs, P^f_{max}, is low enough so that UL communications at FCs will not cause harmful interference at the macro base station, MBS_0. Hence, this study focuses on and addresses the UL interference at active FAPs, created by their neighboring active MUs and FUs. The physical channel is represented by a combination of path-loss, log-normal shadowing and Rayleigh fading. The channel gain g_{ji} of user j to base station i is modeled in compliance with the ITU specifications [11], according to which at time slot t

$$g_{ji}(t) = K_j d_{ji}^{-\alpha_j}(t) S_{ji}(t) \tag{1}$$

[1] Once turned on and before initiating any communication, FCs get synchronized to the cellular core network using an asymmetric communication link such as xDSL thanks to an enhanced version of IEEE 1588 [10].

where K_j is a constant factor, $d_{ji}(t)$ represents the distance from user j to base station i at time t, α_j the path loss propagation factor related to the transmission environment (we distinguish between three environments cellular, indoor, and indoor-to-outdoor), and S_{ji} represents the log-normal shadowing realization at time t with a standard deviation of $8dB$ for MUs and $4dB$ for FUs. We have superimposed the Rayleigh fading to this model by simply multiplying these channel gains by their corresponding Rayleigh fading coefficients F_{ji} in order to take into account the non-line-of-sight (NLOS) nature of the outdoor-to-outdoor/outdoor-to-indoor signal propagation. In fact, the impact of NLOS propagation conditions is significant especially in urban zones. Let $G_{ji}(t) = F_{ji}(t) g_{ji}(t)$ denote the resulting channel gain for transmission from user j to base station i at time t. Hence, given that there is only one active MU per time slot and only one active FU per FC per time slot, the signal to interference plus noise ratio (SINR) of the transmission from FU u_i belonging to FC i to its FAP_i at time slot t is

$$\gamma_i(t) = \frac{g_{ii}(t) P_i(t)}{I_i(t)} \tag{2}$$

where $P_i(t)$ denotes the transmission power of FU u_i at time t, and $I_i(t)$ (Eq. 3) is the interference experienced by FAP_i at time t due to the transmission of FU u_j $(j \neq i)$ of neighboring FCs and the transmission of the simultaneously active MU m.

$$I_i(t) = \sum_{u_j; j \neq i} G_{ji}(t) P_j(t) + \sigma_i(t) \tag{3}$$

where $\sigma_i(t) = G_{mi} P^m(t) + n_i$ with $P^m(t)$ denoting the transmission power of the active MU m at time t and n_i denoting the additive white Gaussian noise at FAP_i. Thus, under this physical interference model, the throughput of FU u_i can be expressed as

$$Th_i = \frac{\sum_{t=1:T} C_i(t)}{T} \tag{4}$$

where $C_i(t) = W \log_2(1 + \gamma_i(t))$ is FU u_i's Shannon capacity with W representing the channel bandwidth in Hz.

III. Problem Statement and Formulation

In this paper, we aim at maximizing the capacity of FCs while accounting for some of their specificities, such as their low power operation, the lack of cooperation among the FCs, and between the FAPs and the macro BS. As mentioned before, a FAP is a small device that is installed in an indoor environment, like a home or an office, to provide access to its indoor users. Typically, FAPs are not associated with the macro cellular networks, and henceforth, they are likely to be managed and owned by different entities/operators. They are, however, expected/assumed to operate over the same wireless channel that the underlying macro cellular network uses. Therefore, there is a need for mechanisms that manage the exploitation of the common wireless channel by the FUs so that their physical capacity in terms of achievable throughput is fairly increased. The key challenge as well as the focus of this work is on how FCs can effectively allocate the transmission powers of their associated FUs in spite of the lack of coordination among FCs themselves as well as between FCs and the macro cellular network, in order to maximize their throughput. The problem of uplink (UL) power allocation to FUs can be formulated as a non-linear program (NLP):

$$\max_{P_i(t)} \sum_{i\in\Omega_t} w_i(t)\log_2\Big(1+\frac{g_{ii}(t)P_i(t)}{\sum_{(j\in\Omega_t, j\neq i)} G_{ji}(t)P_j(t)+\sigma_i(t)}\Big)$$
$$P_i(t) \leq P^f_{max} \quad \forall i \in \Omega_t$$
$$P_i(t) \geq 0 \quad \forall i \in \Omega_t$$

where $\Omega_t = \{u_i$: FU u_i is active/scheduled during time slot $t\}$. We recall that in our study we assume that FCs use TDMA; that is, there is only one active FU per FC at a given time slot. This NLP should be run every time slot before the scheduled FUs start communicating. It aims at allocating power to FUs with the objective of fairly maximizing their overall achievable throughput. In fact, the objective function is expressed as the maximization of a weighted sum of the channel capacity (and consequently the throughput) of FUs. The weights $w_i(t)$ somehow translate the fairness in power allocation to simultaneously active FUs. Indeed, if an active FU $i \in \Omega_t$ has not been allocated power at time slot t (i.e. $P_i(t) = 0$) via this optimization program, its associated weight will get incremented by one for the next time slot during which it will be active. Hence, this optimization program (expressed as a maximization of a weighted sum) privileges the FUs that have higher weights (i.e., those that have been activated less frequently during their scheduled/assigned time slots). This power allocation is subject to maximum transmission power P^f_{max} constraints, where P^f_{max} is assumed to be low enough to avoid interference with the UL communication from the active MU and the macro base station (MBS_0). Note that this NLP can be solved optimally only if there exists a centralized entity that monitors all the FAPs deployed in the MC. In fact, solving this NLP requires that each FAP possesses a global knowledge about all the other FC properties, namely their schedule, their positions, their channel gains, their transmission power, etc. However, as clearly stated in the system model, for the case of FCs, assuming and relying on a centralized approach is not realistic; i.e., it is not practical to assume the existence of a centralized entity that can gather and have such a global information. Moreover, the FCs themselves are isolated entities that are independent of one another, and therefore they are unable to communicate/cooperate among each others. With this in mind, in this work, we design and propose a non-cooperative power allocation scheme that allows each FAP to efficiently allocate power to its active FUs in a distributed manner; i.e., without requiring information exchange with the surrounding FAPs nor with the macro BS.

IV. Estimation Based Power Allocation

In this section, we present our scheme which consists of determining at every time slot the amount of power to be used by each active FU in order to increase its chances of getting a higher throughput. In our scheme, at every time slot, each FAP reports some interference related measurements to its active FU to help it decide the amount of transmission power it needs to use. Since FCs cannot communicate with each other, each active FU, say FU u_i, associated with FAP_i will decide the amount of power to use at time slot t by estimating the amount of interference $I_i(t)$ that will be experienced by FAP_i during the time slot t. This estimate is calculated based on the measurements provided by FAP_i and is denoted as $\widehat{I}_i(t)$.

A. General Description of Proposed Algorithm

Our proposed solution consists of the following steps: At the initial time slot t_0 (i.e., the very first time slot), the active FU u_i chooses a random value of $P_i(t)$ that satisfies the maximum power constraint, and uses it to start its communication with its associated FAP (FAP_i). At each subsequent time slot $t \neq t_0$, each active FAP_i measures the amount of interference $I_i(t)$ (given in Eq. 3) that it receives. This measured interference will then be used to estimate the amount of interference, $\widehat{I}_i(t+1)$, that FAP_i is expected to experience during the next time slot. FAP_i can also measure the received SINR, $\gamma_i(t)$, corresponding to FU u_i's UL transmission that is active at time slot t. We assume that FAP_i is able to estimate the value of channel gain $\widehat{g}_{ii}(t)$ of its currently active FU (before it actually starts communicating) using some well-known filtering technique [12]. These measurements are important, because they will help the active FU u_i decide the amount of power it needs to use as explained later (in our algorithm presented below). Recall that time is assumed to be slotted, where each slot consists of an UL subslot (communication from u_i to FAP_i) and a downlink (DL) subslot (communication from FAP_i to u_i). Hence, the measurements made by the FAP at the UL subslot of slot t can be transmitted to FU u_i (belonging to FC i) during the DL of subslot t. These measurements will be used by FU u_i to calculate $\widehat{I}_i(t+1)$ (the predicted value of $I_i(t+1)$) and decide on the amount of transmission power that it will use at time slot $(t+1)$. In order to have good estimation values, we assume that each FU is scheduled over N_{TS} contiguous time slots (where $N_{TS} > 3$).

B. Proposed Transmission Power Allocation

Once the active FU u_i acquires all necessary information from its associated FAP (via the DL of time slot $(t-1)$), it decides on the amount of power it needs to use at the UL of time slot t using the following algorithm, which consists of two main tests:

Test 1: Wireless Channel Condition.
If $\widehat{g}_{ii}(t) = 0$, then FU u_i decides not to transmit at time t; i.e., it sets its transmission power $P_i(t)$ to 0, because of the bad wireless propagation conditions. Otherwise, if

$\widehat{g}_{ii}(t) \neq 0$, the active FU u_i runs Test 2 below.
Test 2: Transmission Power Determination.
In this test, FU checks whether its SINR, $\gamma_i(t-1)$, (given in Eq. 2) achieved at the previous time slot is included in the interval $[\gamma_i^{min}, \gamma_i^{max}]$, and decides on the value of its transmission power $P_i(t)$ accordingly. Based on this value of $P_i(t)$, it decides whether to update the value of γ_i^{min} or γ_i^{max}. The detailed description of this test is presented below.

1) First Case: If $\gamma_i(t-1) < \gamma_i^{min}$, then

- Set $P_i(t) = \frac{\widehat{I}_i(t)(1+\varepsilon(t-1))\gamma_i^{min}}{\widehat{g}_{ii}(t)}$ if this fraction does not exceed P_{max}^f. Otherwise, set $P_i(t) = 0$.
- Set $\gamma_i^{min} = \beta\gamma_i^{min}$ if $P_i(t) = 0$, where $0 < \beta < 1$ is a chosen design parameter.

2) Second Case: If $\gamma_i(t-1) > \gamma_i^{max}$, then

Let:

$$P_{desired}^{max} = \frac{\widehat{I}_i(t)(1+\varepsilon(t-1))\gamma_i^{max}}{\widehat{g}_{ii}(t)}$$

$$P_{desired}^{min} = \frac{\widehat{I}_i(t)(1+\varepsilon(t-1))\gamma_i^{min}}{\widehat{g}_{ii}(t)}$$

- If $P_{desired}^{max} \leq P_{max}^f$, set $P_i(t) = P_{desired}^{max}$
- Else if $P_{desired}^{min} \leq P_{max}^f$, set $P_i(t) = P_{desired}^{min}$ and update $\gamma_i^{max} = \beta\gamma_i^{max}$
- Else set $P_i(t) = 0$ and update $\gamma_i^{max} = \beta\gamma_i^{max}$

3) Third Case: If $\gamma_i^{min} \leq \gamma_i(t-1) \leq \gamma_i^{max}$, then

Let:

$$P_{desired}^{max} = \frac{\widehat{I}_i(t)(1+\varepsilon(t-1))\gamma_i(t-1)}{\widehat{g}_{ii}(t)}$$

$$P_{desired}^{min} = \frac{\widehat{I}_i(t)(1+\varepsilon(t-1))\gamma_i^{min}}{\widehat{g}_{ii}(t)}$$

- If $P_{desired}^{max} \leq P_{max}^f$, set $P_i(t) = P_{desired}^{max}$
- Else if $P_{desired}^{min} \leq P_{max}^f$, set $P_i(t) = P_{desired}^{min}$
- Else set $P_i(t) = 0$

In our algorithm, γ_i^{min} and γ_i^{max} are two design parameters; γ_i^{min} is greater than γ_i^{th} (the SINR threshold); γ_i^{max} is at least three times as high as γ_i^{th}; and $\varepsilon(t-1)$ is the interference estimation error, expressed as

$$\varepsilon(t-1) = \frac{|I_i(t-1) - \widehat{I}_i(t-1)|}{\max(I_i(t-1), \widehat{I}_i(t-1))}$$

Our proposed algorithm uses the weighted moving average technique to compute the estimated value of interference $\widehat{I}_i(t)$, as it gives more importance to the most recent interference measurements. In fact, we assume that the interference measured in the previous time slot is the closest to the current interference value. The rationale behind the use of γ_i^{min} and γ_i^{max} in our algorithm (Test 2) is to try to figure out the optimal $\gamma_i(t)$ (i.e., the one that would allow us to achieve optimal throughput). This is made via successive adjustments of γ_i^{min} and γ_i^{max}: Note that in our algorithm, we decrease these two parameters whenever their use would incur a zero power for user u_i. In fact, we know that the transmission power P_i of FU u_i (and consequently its SINR γ_i) cannot be increased indefinitely to maximize its throughput not only because of the maximum power constraint, but also and most importantly because of the behavior of FU u_i's throughput Th_i (as shown in Eq. 4) as a function of P_i. Indeed, as P_i increases, Th_i also increases up to a point where it reaches its maximum and after which it starts decreasing again. Here, as P_i increases, I_j (the interference experienced at FAP_j, $j \neq i$) increases and hence the power P_j of FU u_j increases too to overcome this high interference (I_j). As a consequence, the interference at FAP_i (i.e., I_i) will also increase, thereby decreasing Th_i. Therefore, we decided to bound the value of γ_i and consequently that of P_i so that Th_i is maximized without impacting the achieved throughput of other FUs that are simultaneously active with u_i. In other words, the incentive behind our algorithm is to try to fairly maximize the throughput of the different FUs without needing to exchange information among their FAPs.

V. Performance Evaluation

In this section, we evaluate the performances of our proposed distributed algorithm, and compare it with the optimal centralized one presented in Section IV.

A. Performance Metrics and Simulation Settings

1) Performance Metrics: The goal of this work is to provide a distributed, non-cooperative scheme for power allocation with the two objectives of: (i) increasing FUs' overall achievable throughput, and (ii) maximizing fairness among them. To this end, the following two metrics are used to evaluate and analyze the performance of the proposed power allocation scheme.
Average Throughput: is the average per user achieved data rate. It is viewed as a metric of assessing how well the scheme performs from a user's point of view.
Fairness Indicator: represents an important metric for distributed, non-cooperative/selfish systems, where some resources (e.g., wireless channel) need to be shared by a set of users that all try to maximize and go after their own benefit. The idea here is to quantify and assess how fair the proposed scheme is in terms of the FUs' achieved throughput, by using the following fairness indicator F [13].

$$F = \frac{(\sum_{i=1:N_{tot}} Th_i)^2}{N_{tot}(\sum_{i=1:N_{tot}} Th_i^2)}$$

TABLE I
SUMMARY OF SIMULATION PARAMETERS

Maximum FU Power P^f_{max}	125 mWatt
Maximum MU Power P^m_{max}	1 Watt
Femto SINR Threshold γ^{th}_i	3.2dB
Channel Bandwidth W	160Mbps
Carrier Frequency f	2.5GHz
Number of Simulation Slots	3000 Time Slots
Total number of femto-users N_{tot}	288 FUs
SINR Bounds Update Factor β	0.9

Fig. 1. Per-FU average achievable throughput

where N_{tot} is the total number of FUs. This metric is viewed as a metric of assessing how well the scheme performs from a network's point of view.

2) Simulation Method and Settings: We implemented both the centralized solution and our scheme in MATLAB. We ran our simulations, analyzed them, and plotted our results also using MATLAB. In our simulations, we generated a grid network with one macro base station in the center surrounded by $N_{FC} = 96$ uniformly placed FAPs and $N_{MU} = 20$ randomly generated macro users. Each FC has a transmission range $R_F = 20m$ and consists of one FAP placed in the center and $N_{FU} = 3$ femto users generated randomly in its coverage area. In our simulation, we assume that the MC and the FCs operate over the same wireless channel. We also assume that both femtocells and the MC use TDMA as a channel access mechanism. For evaluation purposes, we varied the inter-FAP distance from $10m$ to $45m$ in order to vary the network coverage ratio. Unless otherwise stated the number of contiguous time slots assigned per femto user N_{TS} is fixed to 10. The main simulation parameters are summarized in Table I.

B. Simulation Results

1) Throughput Performance: Fig. 1 shows the per-FU average achieved throughput for various time frames (one time frame equals 30 time slots). First, note that in the long run, our scheme achieves 50% of the optimal throughput obtained via the centralized optimization program. Second, observe that both schemes, our distributed and the centralized, are stable as the average per-FU throughput does not fluctuate much; they both quickly converge to a fixed value. For the proposed distributed scheme, the convergence time is around 10 time frames (i.e. 300 time slots which is equal to 6 seconds). Fig. 2 shows the per-FU average throughput as a function of the FC coverage ratio. We define the coverage ratio as the ratio of the total FC area to the total MC area. From Fig. 2, we can clearly see that the average throughput achieved with the centralized scheme decreases rapidly as the FC coverage ratio increases. In fact, it decreases from 158 Mbps for femto-coverage-ratio=0.08 (8%) to 110 Mbps for coverage ratio equal to 0.85 (85%). In other words, the decrease is of 623 kbps for 1% increase in the coverage ratio for throughput obtained with the centralized scheme, whereas the decrease of throughput

Fig. 2. Impact of the FC Coverage Ratio on the average achieved throughput

Fig. 3. Impact of the number of per-FU Contiguous Time Slots on the average achieved throughput

achieved with our scheme is barely noticeable. For our scheme, the decrease ratio is of the order of 129 kbps for 1% coverage ratio increase. Hence, although our scheme does not achieve as much throughput as the centralized approach does, it presents better performances in terms of scalability. We also study and show in Fig. 3 the impact of varying the number of contiguous time slots assigned per FU on the average achieved throughput. Note that the average throughput obtained with our scheme increases from 60Mbps to 70Mbps as the number of contiguous slots assigned per FU increases from 4 to 22 slots. This is because the estimation error is smaller for higher assigned numbers of contiguous slots. Indeed, the more slots a FU has, the more interference measurements/samples it gets, the more accurate its interference estimates is, and consequently the better the decision of the allocated transmission power is. On the other hand, observe that the performances of the optimization program is independent of the number of contiguous slots assigned per femto-user, which is expected.

2) Fairness Performance: Fig. 4 shows the fairness indicator of the proposed scheme when varying the time frame index. The figure shows that our scheme achieves good fairness performances. Observe that fairness indicator reaches up about 0.65. Therefore, not only does our scheme perform in a distributed manner; i.e., each FC runs the algorithm without needing to cooperate or exchange information with the surrounding FCs, but also ensures good fairness among the users by allowing them to achieve approximately equal amounts of throughput. This is because each FC takes into account the presence of surrounding FCs by estimating the interference they might incur and by bounding and adjusting the SINR achieved by its associated active FU so that it would not harm the communication of surrounding FUs. In Fig. 5, we also show that the fairness performance of the proposed scheme is not affected by the increase of the FC coverage ratio, which further confirms its suitability to areas with high FC coverage such as the urban areas.

VI. CONCLUSION

This paper proposed a distributed, non-cooperative uplink power allocation scheme for FC networks. Through simulation, we showed that our scheme achieves good

Fig. 4. Fairness indicator as a function of time frame index

Fig. 5. Fairness indicator as a function of the FC Coverage ratio

throughput performances while ensuring fairness among all active femto-users. In addition, we showed that our proposed scheme presents good scalability property, which makes it suitable for femto-networks deployed in urban areas.

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