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Hybrid femto/macro rate-based offloading for high user density networks

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ABSTRACT

Nowadays, the popularity of smart phones creates huge capacity requirements for networks during mass events where thousands of people coexist in specific areas. At such events, large numbers of people use their smartphones to share pictures and download information. This behavior creates traffic profiles that differ from those typically observed in legacy -less populated- networks where lower uplink traffic volumes are generated. Thus, novel network planning and radio resource management mechanisms have to be considered for such dense network conditions, one of which is macrocell offloading. In this context, reducing the cell size has always been the best way to increase the network capacity of LTE. Femtocells are used to enable offloading data-traffic from macrocell network to increase the capacity. In this paper, to achieve efficient user offloading from macro to femtocells, we propose an offloading algorithm based on a perceived rate threshold in combination with uplink power control for hybrid femtocells also considering resource block partitioning. The proposed algorithm enhances the network capacity so that more mobile users can satisfy their minimum Quality of Service (QoS) requirements, thus the overall performance of dense cellular networks increases. The proposed offloading mechanism is assessed in terms of the achieved total throughput and outage probability figures. Simulation results demonstrate the potential increase of the number of supported users per macrocell in joint macro and hybrid femtocell deployments.

1. Introduction

Nowadays, the popularity of smart phones creates huge capacity requirements for networks during mass events where thousands of people coexist in a specific area. At such events, large numbers of people use their smartphones to share pictures and download information. Network planning for these events must consider wireless access capacity and dimensioning. Furthermore, network resource partitioning and frequency planning in dense areas create further challenges in terms of inter-cell interference [1].

One of the promising solutions that seems to be emerging in cellular networks is the femtocell deployment. Femtocells have essentially short-range (10–50 m), low-cost, low-power (10–100 mW) home base stations that are generally deployed by the end user in a plug-and-play manner and are connected to the network through a DSL or RF backhaul channel [2]. In addition, femtocells, having lower transmission power which extends the receivers battery life. Additionally, due to their smaller communication link ranges, they achieve higher Signal to Interference plus Noise Ratio (SINR) and thus provide better QoS to indoor users that is otherwise not possible via macrocell coverage operating at higher frequencies [2,3]. Compared to traditional small cells, femtocells are self-adaptive, that is they automatically integrate themselves into existing macrocellular networks which makes their large scale deployments possible [4]. The motivation for the deployment of femtocells is that they may enable offloading of macro-network mobile internet users in highly populated areas thus providing higher network capacity. In addition, users offloading, which consist of transferring users from macro to femtocells helps macro users to achieve higher throughputs as less number of users will be sharing the macro network resources. Therefore, enabling capacity offloading to femtocells will improve the overall system capacity [5].

In this study, we assume a spectrum environment in a densely populated urban area, where co-channel spectrum sharing is considered to accommodate the demands of coexisting networks. Femtocell users may use the same or different frequencies

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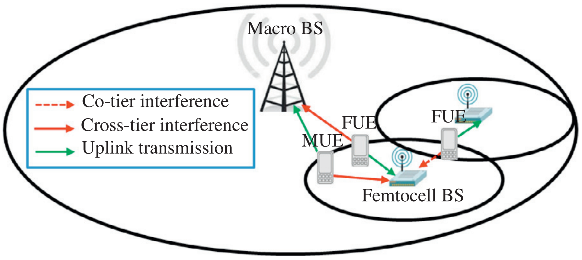

Fig. 1. Co-tier and cross-tier uplink interference.

compared to existing macrocell users. It is expected that co-channel femtocells users introduce interference to macrocell users, limiting the system capacity.

Interference coordination or interference avoidance is one of the most promising approaches to solve the problem of Inter Cell Interference (ICI) in OFDMA systems, and has taken large concentration in 3GPP for LTE [6]. The ICI in a hybrid macro/femto network depends on the underlying access mechanism for femtocells [6]. The importance of incorporating the problem of optimal femtocell resource allocation with the choice of access method, is to protect the femtocell subscribers from starvation under hybrid/open access mode. In a wireless system, there are usually two resource types that we need to manage within a femtocell: power and channels. Power is a physical resource that affects both coverage and throughput. In the case of OFDMA, channels are defined as combinations of two physical measures: sub-carriers or time-slots.

Fig. 1 shows the co-tier and cross-tier uplink interference scenarios in heterogeneous networks. Typically, femtocell user equipment (FUE) generates uplink cross-tier interference to a Macro Base Station (MBS) or (in the same way) a Macro UE (MUE) which is near the Femto Access Point (FAP) can be the source of interference to that femtocell BS. On the other hand, in co-tier interference, an FUE can be the cause of uplink interference to a neighboring FAP if it is within that femtocell's coverage area. To improving the overall network capacity we have to adopt an effective interference management technique in order to reduce interference, co-tier as well as cross-tier. In [7], a semi-autonomous SFR-based resource allocation algorithm is proposed to maximize uplink cell throughput. However, in [8] power consumption and intra-cell fairness is properly studied, which is more important in the uplink case. Also, the authors propose an uplink SFR (USFR) technique to enhance the self-coexistence of cognitive radio networks in the OFDMA. In [9], several heuristic SFR-based user scheduling mechanisms are roughly compared in terms of uplink outage probability. However, there is no combination of USFR and hybrid access femtocell to enhance the capacity and coverage of the network.

Current offloading algorithms do not focus in dense areas, and most of the current work is related to downlink SINR-based offloading such as [10,11,12]. But, in [13,14,8] the authors use rate-based offloading focusing on downlink power control and using open access mode femtocells. In this paper we propose an effective offloading mechanism from a macro LTE cell to hybrid access femtocells by using rate association. The offloading mechanism is based on applying the corresponding resource allocation mechanism to allocate radio channels effectively to both the macro and femto cells by using Orthogonal SFR in uplink, and using uplink power control for managing the resources.

The rest of the paper is organized as follows: in Section 2, we present the related state of the art in femto cell access control and offloading. Section 3, presents the proposed algorithm for hybrid femto/macro rate-based offloading, combined with rate-based offloading and Orthogonal Soft Frequency Reuse (OSFR). Performance assessment and results are presented in Section 4. Section 5 concludes the paper.

2. Femto cell access control and offloading

In dense areas, due to the high cost of network extension via macro base stations (MBSs), the femtocells may assist in offloading users from the congested MBSs to enhance their (QoS) and increase the overall system capacity. Macro-offloading is very sensitive to the type of environment: Rural, Urban, Dense Urban, Home / residential. The environment type reflects on the density of cellular users and femtocells. Also, the choices of femto access modes are highly dependent on femtocells' density. In open area with low density of femtocells, the open access mode could be used. However, in cases of high density of femtocells, the hybrid access mode should be preferred [15].

2.1. Femtocell access control

An important aspect of femtocell design is the access mechanism. Femtocells can be configured in three different types of access modes: open, closed and hybrid [16,17]. In open access, whenever the users are within the range of a FAP, they get connected to the FAP. In the case of closed access, only particular users (subscribers) get access to the FAP, to avoid unwanted traffic congestion [18]. The hybrid access mode allows nonsubscriber users to attach to the femtocell but with an upper limit on the amount of the allocated femtocell resources. Hybrid access may be used in case of enterprise femtocells [17]. The access conditions to a femtocell by an outside user can be defined by each operator separately and the admission of such a user may be controlled by the owner [19].

In the case of closed access femtocells, and specifically when a cell edge macrocell user equipment transmits near a femtocell an 'uplink deadzone' may be created. A worst case scenario is when a nonsubscriber macrocell user enters a house that hosts a closed subscriber group femtocell resulting in powerful cross-tier interference on both uplink and downlink. In dense femtocell deployments, severe co-tier interference can also be experienced when a user installs a femtocell in the immediate neighborhood of another closed access mode femtocell that is already in use. Open/hybrid access mechanisms are being considered in order to mitigate both networks' cross-tier and co-tier interference caused by closed access in femtocell.

In [20] it is suggested that open access helps in mitigating uplink cross-tier interference and improves network-wide area spectral efficiency resulting in increase in overall network capacity. On the other hand, open access negatively affects the performance of femto owners who will have to share their resources with other users. Open access also greatly increases the number of handovers between cells -due to the movement of outdoor users- which is unfavorable to network operators as it results in increasing the signaling overhead as well as experiencing call dropping due to handover failures. From the above discussion, it seems that femtocell subscribers prefer closed access in order to reserve all the femtocell resources to themselves, while open access (in a selective way to avoid frequent user switching) is the preferred approach for the network operators as it enhances the overall network throughput and enables offloading traffic from the macrocell as well.

Rather than considering a fixed access control scheme like open or closed access, the hybrid access mode is an effective method for admission control and handoff management for users to achieve the desired network objectives [21]. Hybrid access scheme can balance between advantages and disadvantages of the other two access modes [22].

2.2. Offloading

To increase the capacity due to femtocells, capacity offload (transferring users from macro to femtocells) helps macro users to achieve higher throughput since fewer users share the macro network resources and this improves the overall system coverage and capacity to offer better QoS, not only to indoor users but also to outdoor users [5]. Therefore, a more balanced user association reduces the load on the macrocell, allowing it to better serve its remaining users.

In [23,24], the authors showed that increasing the number of the femto access points has the greatest impact on the tier association probability at the cost of increasing the percentage of idle femto access points. This can be avoided in cases of massive events, where all deployed access points will operate close to their capacity limits.

In [25] the study focuses on the uncoordinated co-channel deployment of closed subscriber femtocell groups. The authors considered the number of carriers available to the operator, their configuration, and also how users were assigned to carriers and cell types. To analyze macro offloading of 3 G femtocells, the study showed the combination of adaptive femtocell power calibration with a macro-user frequency allocation method that considered the SINR (signal-to-interference-noise ratio) difference between the mixed (macro-femto) and a macro-only scenario. In [26], the authors concluded that it is difficult for 3 G femtocells to operate under closed access mode if the respective femto access points cannot regulate their transmit powers (due to the increased co-channel interference). whereas if these femtocells were operating as open access there would be many benefits in terms of improved coverage and macro traffic offloading to the femto cellular network.

There are a few recent investigations of the cell association problem in HetNets [27]. HetNets are much more sensitive to the cell association policy because of the massive differences in cell sizes. These unequal cell sizes result in very unequal loads in a max-SINR cell association, assuming a relatively uniform mobile user distribution. That is, if users simply associate with the strongest BS (in single tier scenarios), the load differences in macrocell networks are limited constrained since all cells will have roughly the same coverage area. But in HetNets, the opposite is true, making the problem considerably more complex, and the potential gains from load-aware associations larger. The uplink power control algorithms in HetNets are depending on the cell association [27]. We can associate users to the base stations that offer the best Signal to Interference plus Noise Ratio (SIR) or Signal to Noise Ratio (SNR) or SINR or rate.

2.3. Cell association

A joint optimization of channel selection, user association and power control in HetNets is considered in [23,24,25,26,28], aiming to minimize the potential delay, which is related to the sum of the inverse of the per-user SINRs, where the SINR takes into account the load when computing the interference. In [27,29], and [30] the improvement of load balancing was proposed by improving an intelligent cell association policy that assigns users to BSs to offer them the best user-perceived rate. This rate will depend on both the SINR and the load.

In legacy cellular networks it is typically assumed that mobile users connect to the strongest BS, which offers the best SINR. If we assume that all BSs are fully loaded, transmitting and receiving packets in all their time-frequency blocks at all times, such a scheme can easily be shown to optimize sum throughput, where each BS just communicates with its max-SINR user in each block. The SINR equation is given by,

$$SINR_i = \frac{\frac{P_{tx,i}}{L_{ij}}}{\sum_{\substack{k=1\\k\neq i}}^{n} \frac{P_{tx,k}}{L_{kj}} + N},\ \ i = 1, 2, \ldots, n \ and\ \ j = 1, 2, \ldots, m \qquad (1)$$

Where $P_{tx,\,i}$ is the user i transmit power, L_{ij} is the user i pathloss, $P_{tx,\,k}$ is the user k transmit power that use the same resource block (RB), L_{ij} is the path loss of the user that use the same RB and N is the total noise power.

Two clear problems immediately arise [10]. First, maximizing SINR per user is not a very realistic objective, and cell-edge users will be ignored. In a macrocell-only network, the max-power coverage regions for each BS are designed to have roughly the same amount of traffic. That is, over time, more BSs are deployed in areas that generate more traffic, while populated areas get fewer BSs. Many femtocells will have just a few users, so the loads vary considerably from no load at all to heavy loads in cases of sustained file downloading or video streaming. However, through various model relaxations, in [27] the authors were able to approximate numerically an upper bound on the rate distribution and a distributed algorithm that nearly achieves it. The rate gains are very large compared to max-SINR association, on the order of two times for “average” users and three times for cell edge users. The rate offered by base station j would be approximately [11]:

$$R_j = \min\left\{T_{max}, \frac{\mathrm{B}}{K_j}\log_2\left(1 + SINR_j\right)\right\} \qquad (2)$$

Where K_j is the number of users currently being served by that BS, B is the bandwidth and T_{max} is the maximum throughput.

Uplink power control is considered in user association or offloading, to physically manage the resources. Uplink power control relies on each user updating its power based on the total received power at the base station [12]. Uplink power control is employed in wireless systems in order to assist users with bad channels and limit overall interference as seen by users. In addition, resource allocation is important to choose an appropriate access control mechanism. This will ensure that the femto subscriber is not deprived of femtocell resources, when the femtocell allows connections to nonsubscriber users under open/hybrid access mechanisms. By using game theory in [14] the authors propose an uplink power control as a non-cooperative game in CDMA and they use a cost function defined as the difference between a linear pricing scheme proportional to transmitted power, and a logarithmic, strictly concave utility function based on the SIR of the mobile. In [8] they also use non-cooperative game theory involving also linear system constrained power control in OFDMA. By that, they solve both the uplink transmit power control problem and the subchannel allocation problem.

In our proposed framework the user perceiver rate association with power control depends on linear system constrained power control as explained in [8,27]. This enables cellular users to be assigned to their nearest femtocells and solves the problem of uplink dead zones at the femtocell due to severe cross-tier interference, and therefore enables macrocell offloading.

3. Hybrid femto/macro rate-based offloading scheme

In our system, we consider a single macrocell base station that is located at the center of a hexagonal grid of radius R. The simulation has been implemented in MATLAB environment and has been used for conducting the simulation experiments (see Fig. 2). We have deployed the femtocells manually and in a systematic/symmetric way, since unplanned deployment faces several problems and challenges in terms of interference management and

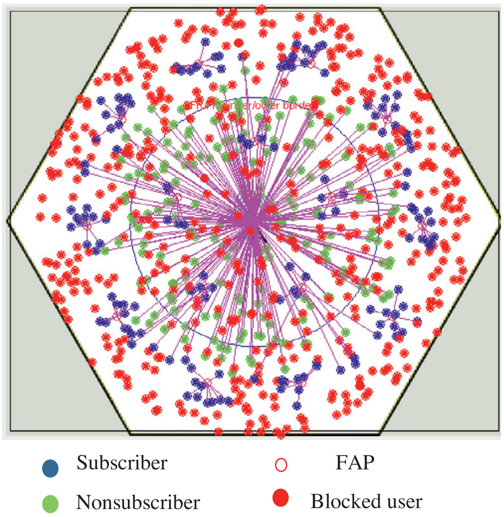

Fig. 2. Femtocell network architecture.

Algorithm 1 Hybrid femto/macro Rate-Based Offloading algorithm.

1: **Distribute** Femtocells manually and Users randomly.
2: **Associate** nonsubscriber users to MBS
  Offload subscriber users to FAPs
  if femtousers<K
    Offload the most interfering nonsubscriber users near to FAP to FAP
    end if
  if macrousers<100
    If femtousers>=K
      Associate subscriber users to MBS
    end if
  end if
3: **Divide** RBs into 7 parts F1, F2…F7 to distributed to femto and macro users by using OSFR
    if R>125% in the outer region
      F7 for macro users, and f1, f2… f6 for femto-users
    else % in the inner region
      F1, F2…F6 for macro-users, and f7 for femto-users
    end if
4: **Calculate** interference for macro and femto users
5: **Calculate** SINR for all users
6: **Calculate** the total throughput and outage probability

backhaul constraints [11]. Also, with deploying femtocell in systematic way we can avoid problems related to inter-femtocell interference (co-tier interference).

The proposed algorithm considered only frequency domain RBs, so there is no scheduling in the time domain; one user always uses a specific RB in all timeslots within a frame. In the proposed algorithm, a user (nonsubscriber or subscriber) is assigned to a nearby femtocell based on combined uplink power control and user-perceived rate association .When a femtocell base station deploys hybrid access control, it can choose to serve cellular users based on certain metrics like number of users in cell and user perceived rate thresholds. A user is assumed to satisfy its minimum QoS criteria if its perceived rate is at or above its perceived rate threshold, otherwise it is considered to be in outage. Also, if the femtocell is filled with K users (K being the maximum users per cell) then the additional users are considered to be in outage. We assume in this paper, in case of a macro cell, that we have 100 RBs and each user is assumed to be allocated with one RB. In closed access femtocells we assume to have maximum 4 concurrent voice calls but in hybrid and open femtocells we may have from 16 to 32 concurrent calls or data sessions as in enterprise femtocells [31], so in dense areas we prefer to use this type of femtocells.

In this paper, we consider a two-tier network model with OFDMA femtocells sharing the entire spectrum with the macrocell base station. With intelligent resource management we can enhance frequency reuse in the OFDMA-femtocell tier and maximize cell throughput by reducing both co-tier and cross-tier interference. The objective is to enhance the capacity and the throughput by using hybrid access algorithms depending on rate based offloading and to also reduce interference and maximize cell throughput by using orthogonal SFR.

The pseudo code of proposed algorithm is given as 'Algorithm 1' with the steps summarized as follows:

Step I. Distribute the femtocells equally. The subscriber and nonsubscriber users will be distributed randomly.

Step II. First, associate the cellular/nonsubscriber users to Macro Base Station (MBS). Second, to give the higher priority to subscriber users, associate them to Femto Access Points (FAPs). Rate-Based Offloading (RBO) is used in the association as described in section A. Third, offload the most interfering cellular users in range of femtocells to FAPs. One has to check if the femto user, for each FAPs, is less than K; then it is possible to associate the cellular users to FAPs. Finally, associate the rest of the subscriber users that are far away from the FAPs to an MBS by calling an RBO. These steps are shown in Fig. 3.

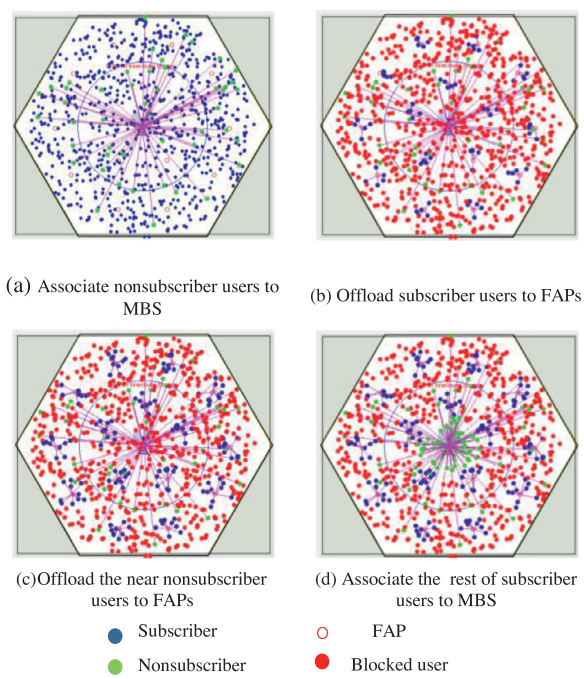

Fig. 3. The main steps for hybrid femto/macro rate-based offloading.

Step III. Use OSFR to allocate the resources by dividing the RBs into 7 parts labeled as F1, F2 up to F7. This will be described in section B. Then we can see the users in different cell whether as co-tier or cross-tier using the same RB.

Step IV. Calculate the interference for macro and femto users using interference Eq. (3).

$$I_i = \sum_{\substack{k=1 \\ k\neq i}}^{n} \frac{P_{tx,k}}{L_{jk}}, i = 1, 2, \ldots, n \text{ and } j = 1, 2, \ldots, m \quad (3)$$

where k is the users use the same RB, j is the i base station, $P_{tx,\,k}$ is the transmit power for user k, L_{jk} is the pathloss, d is the distance between j and k.

Step V. Calculate the SINR from Eq. (1).

Algorithm 2 Rate-Based Offloading.

1: **Initialize** allocation vector, R_{th}, flag = 0
while association-flag = 0
  Clear A, B matrixes
2: **Set** matrix A=−1./L_{ij}, a=$2^{\frac{R_{th}\times K}{B}}-1$
  for 1:Nusers
   A (i,i)=1./$a_i L_i$
  end for
  Set matrix B, B= Noise power
   if (A is nonsingular)
   association-flag =1
3: Users adapts its power depend on perceived rate threshold
$P_{tx,i}=((2^{\frac{R_{th}\times K}{B}}-1)\times(\sum_{\substack{k=1\\k\neq i}}^{n}\frac{P_{tx,k}}{L_{kj}}+N))\times\ L_i$
 else
  delete one element from allocation vector
 end if
end while

Step VI. Calculate the total throughput for all users using Eq. (4), and outage probability [36] using Eq. (5).

$$C_i\ (Throughput_i)=\min\{T_{max},B*\log_2(1+SINR_i)\},\ \ i=1,2,\ldots,n \tag{4}$$

Where T_{max} is the maximum throughput, B is the bandwidth.

$$P_{out}=\frac{\sum Outage\ users}{\sum Users\ Allocated\ an\ RBs} \tag{5}$$

3.1. Rate-Based Offloading (RBO)

Here we focus on the transmission power control sub-problem, and study multi-cell transmission power control as a constrained linear system. The optimal transmission power control strategy in each cell can optimize the each user's session power consumption as well as power efficiency.

Assume that there are n users, m base stations and a common radio channel. The transmitter power of the i_{th} user is P_i. Furthermore, we assume the i_{th} user is assigned to the j_{th} base station.

Regarding the RBO given in Algorithm 2 with the steps summarized as follows,

Step I. Initialize the allocation vector that contains the pathloss for each user in the cell. After that, users of that cell are sorted according to their pathloss values. To calculate the transmission power of the users, the user perceived rate threshold R_{th} is set according to the minimum QoS requirements. Also, initialize the association flag to zero.

Step II. Define a transmission power vector as in Eq. (6):

$$P_{tx,i}=[P_{tx,1},P_{tx,2}.P_{tx,3},\ldots\ldots.,P_{tx,n}] \tag{6}$$

Where $P_{tx,\ i}$ the optimal transmitter power for the i_{th} user for i = 1, 2, . . . , n.

Let us consider the following constraints for the i_{th} user rate R_i and $P_{tx,\ i}$ as in Eqs. (7) and (8). Where P_i^{max} is the maximum allowed power for each user.

$$R_i\geq R_{th}, \tag{7}$$

$$0\leq P_{tx,i}\leq P_i^{max} \tag{8}$$

The user transmission power should be larger than zero to be real according to user perceived rate threshold. Then the system should satisfy Eq. (9),

$$\left(\left(\left(2^{\frac{R_{th}\times K}{B}}-1\right)\times\left(\sum_{\substack{k=1\\k\neq i}}^{n}\frac{P_{tx,k}}{L_{kj}}+N\right)\right)\times L_i\right)-P_{tx,i}=0,$$
$$i=1,2,\ldots,\mathrm{n}. \tag{9}$$

Where L_i is the user i pathloss, N is the total noise ratio, R_{th} is the user perceived rate threshold, K is the number of users currently being served by that BS and B is the band width. Rewriting the Eq. (9) will result in Eq. (10) to describe the individual $P_{tx,\ i}$.

$$P_{tx,i}=\left(\left(2^{\frac{R_{th}\times K}{B}}-1\right)\times\left(\sum_{\substack{k=1\\k\neq i}}^{n}\frac{P_{tx,k}}{L_{kj}}+N\right)\right)\times\ L_i \tag{10}$$

Writing the above equation into the matrix form:

$$P_{tx,i}=A^{-1}\times B \tag{11}$$

$$a=2^{\frac{R_{th}\times K}{B}}-1 \tag{12}$$

Where A and B are given by Eqs. (13) and (14),

$$A=\begin{bmatrix}\frac{1}{a_1L_{11}} & -\frac{1}{L_{21}} & \cdots & -\frac{1}{L_{n1}}\\ -\frac{1}{L_{12}} & \frac{1}{a_2L_{22}} & & -\frac{1}{L_{n2}}\\ \vdots\ \vdots & & \ddots & \vdots\\ -\frac{1}{L_{1n}} & -\frac{1}{L_{2n}} & \cdots & \frac{1}{a_nL_{nn}}\end{bmatrix} \tag{13}$$

$$B=\begin{bmatrix}N\\N\\\vdots\\N\end{bmatrix} \tag{14}$$

Step III. Finally, check if matrix A is nonsingular., If this condition met, then the users are associated with the BS and we calculate the power for each user with Eq. (10). Otherwise, remove one element from the allocation vector until a nonsingular matrix is found then assign the users to a base station. For the users that are not assigned, the allocation vector is built again and these steps are repeated for all base stations to minimize the transmission power and, at the same time, associate the user to the corresponding base station.

3.2. Interference mitigation

Many inter-cell interference avoidance/mitigation mechanisms have been proposed in the literature. Since the use of universal frequency reuse suffers from intercell interference, the new generation networks, such as WiMAX and 3GPP LTE, apply fractional frequency reuse(FFR) [15], with which a whole frequency band is partitioned into sub-channels and different sub-channels are assigned to adjacent cells .

In SFR, the channel bandwidth is divided into seven sub channels, F1, F2... F7. The user terminals that are close to their home BS, are considered as 'inner' users, and operate on all the available sub-channels (reuse-1 scenario) because they are protected

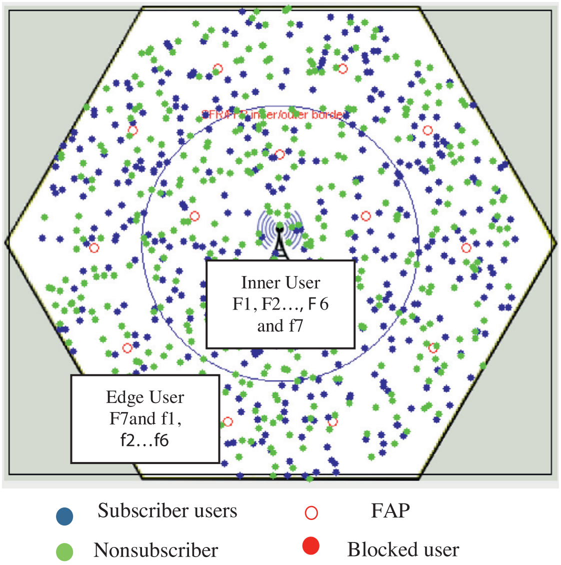

Fig. 4. Orthogonal Soft Frequency Reuse (OSFR).

from inter-cell interference. The user terminals far away from their home BS, are considered as 'outer' users, and can be allocated only a fraction of the available sub-channels. In co-channel operation, femto users in the inner regions of macrocells are assigned sub-channels F1, F2…F7, while those in the outer regions are assigned the identical subchannel with their overlay macro users. The inner zone is defined as a circle with radius R_i,where $R_i < R/2$, and the outer zone is defined as a circular ring with radius R_o where $R/2 \le R_o < R$. The total radius of the cell is R.

Since FAP is a low complexity BS, orthogonal radio resource allocation can be applied to mitigate interference and reduce the complexity. Fig. 4 shows the proposed OSFR pattern where macro-cells reserve sub-channel group F7 for femto users in the inner region. The notations Fi and fi refer to macro users and femto users respectively for the same subchannel. Also, femto users outside the inner region occupy six sub-channels and macro users use only the seventh sub-channel to avoid inter-interference. This proposed OSFR radio resource allocation is expected to dramatically reduce the interference in high femtocell-density scenarios.

In this study, we deploy the femtocells on symmetrical locations equally spaced apart, to 'spread' the interference uniformly and to avoid co-tier interference [32], because users will not necessarily perceive a clear aggressor, but often multiple interfering signals of similar strength. In dense environments the number of femtocells per square meter increases. Therefore, the chances of experiencing interference from more than one Femto Base Station (FBS) also increases.

4. Simulation results

In the conducted simulations a single macrocell base station is considered. This base station is located at the center of a hexagonal grid of radius R. The simulation has been implemented on MATLAB environment. The parameter values that were considered are shown in Table 1.

To measure the performance, we have considered two metrics: total throughput as calculated in Eq. (4), and outage probability as expressed in Eq. (5).

The impact of dense corporate FAP deployment in a dense urban macro network is evaluated in terms of macro offload on uplink.

Table 1
Simulation parameters.

Parameter	Value
Cellular layout	Hexagonal grid
Simulation Scenario	Dense urban
Macrocell Radius	250 m
Femtocell Radius	30 m
Femto User max TX Power	20 dBm
Macro User max TX Power	46 dBm
Outdoor/Indoor Walls Loss	15 / 7 dB
LTE Bandwidth (MHz)	20 MHz
Pathloss Exponent	2.7
Standard deviation in Shadowing coefficient	6
UE Distribution	Random
FAP Distribution	Uniform

Table 2
Scenario description.

Scenario	Description
Scenario A	Cellular users' density from 100 to 200. Without FAPs and with 20 FAPs in open, closed, hybrid access mode.
Scenario B	Cellular users' density set to 200, with 20 FAPs. Increasing number of subscriber users from 20 to 180. FAPs in open, closed, hybrid access mode.
Scenario C	Cellular users' density set to 200. Adding (5, 10 …25) FAPs. FAPs in hybrid access mode. Interference Management: Reuse-1, SFR and OSFR.

Three different scenarios are presented and labeled A, B and C. Scenarios A and B simulate the macro offloading for open, closed and hybrid access modes. In scenario A, the number of FAPs is set to 20 and we increase the number of users from 100 to 200. In scenario B, the number of cellular users is set to 200 with 20 FAPs and the average total users' throughput is calculated by increasing the number of subscriber users from 20 to 180. The rest of the users are considered as nonsubscribers. On the other hand, in scenario C, our proposed hybrid access mode is considered only by setting the number of cellular users to 200 and increasing the number of FAPs from 5 to 25. Scenario C simulates the macro offloading using different interference management schemes which are Reuse-1, SFR and OSFR. The scenarios' main properties are described in Table 2.

In this section we analyze the overall performance of a two-tier network model under our proposed hybrid access control scheme. In scenario A and B, we compare the average total users' throughput and average outage probability in the case of closed, open and hybrid access modes. With the improved capacity achieved using our algorithm. Uplink power control using RBO algorithm in all access mode is used. In hybrid access, the proposed hybrid femto/macro rate-based offloading algorithm is used which includes RBO.

Fig. 5 shows the results for scenario A. The macro-only network, without FAP, achieves minimum total throughput. In case of closed and hybrid access modes, the cellular users are split in half. The first half is considered as subscriber users and the second half represents nonsubscriber users. According to Fig. 5, we can conclude that we can divide the analysis of the results into two parts: When the number of users is less than 180, all access modes have similar average total users' throughput. When the number of users more than 180, the curves representing the average total users' throughput increase similarly in open and hybrid access modes and outperform the closed access mode curve that has lowest average total throughput. The average total throughput in hybrid access increases about 10% compared to closed access mode in case of 200

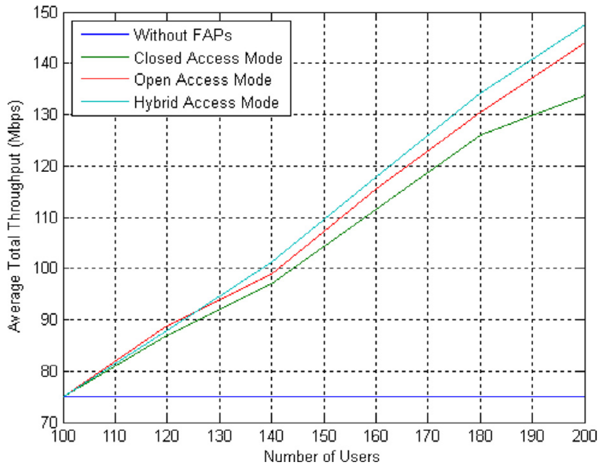

Fig. 5. Average total users throughput in closed, open and hybrid access mode for scenario A.

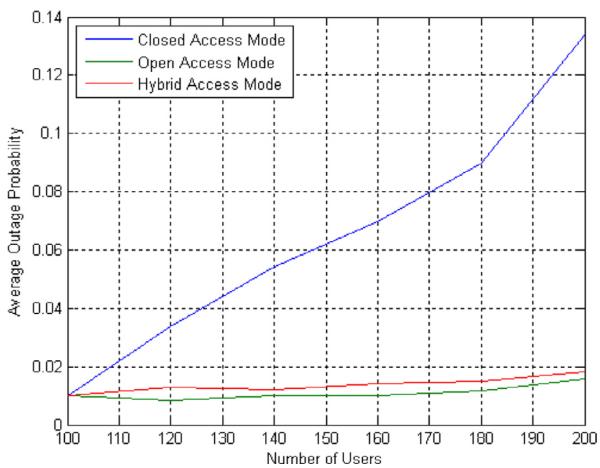

Fig. 6. Average outage probability in closed, open and hybrid access mode for scenario A.

users, and increases about 2% compared to open access mode. In closed access mode, every FAP can handle 4 users, and the MBS can handle 100 users, therefore 20 users should be blocked in the case of 200 users.

Closed access mode achieves a smaller total users throughput in comparison with the open and hybrid access modes. This is because the closed access mode can serve only 4 concurrent calls of subscriber users. In closed access, handoff to nearby femtocells is not possible and, thus, the number of dropped nonsubscriber users increases sharply at high user densities resulting in an increase in the outage probability. Moreover, closed access leads to severe cross-tier interference on the uplink to the femto subscriber. In closed access, the outage probability of the femto users is large when the network is heavily loaded and, accordingly, the average throughput is substantially reduced. Open and hybrid access modes have similar values of total users' throughput. This is because they can serve the same amount of users. On the other hand, in open access mode any users who are not able to get the macro service, can connect to FAPs. So, the femto users can go far away from FAPs thus this will increase the pathloss value and decrease the user throughput. In Fig. 6, the outage probabilities of the closed, open and hybrid access modes are illustrated. Closed access mode has the highest outage probability when compared with open and hybrid access modes. Also, the outage probabilities of open and hybrid access modes are always close to each other.

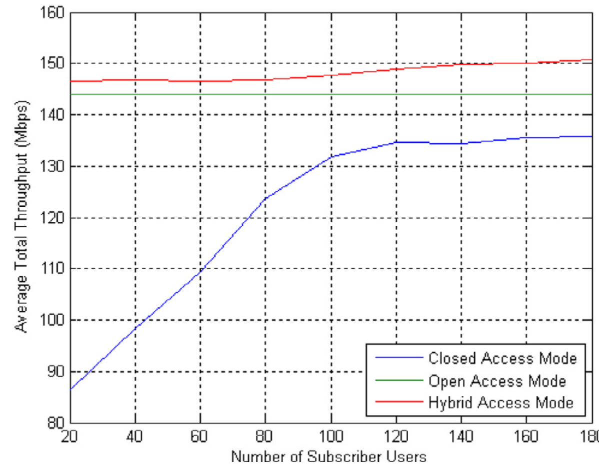

Fig. 7. Average total users throughput in closed, open and hybrid access mode for scenario B.

In scenario B, the number of total users is set to 200 and the number of subscriber users is increased as 20, 40, 60…180 to view and compare the efficiency of different femto access modes. This case is shown in Fig. 7, where it is observed that the total users' throughput of the hybrid access mode has the highest value in comparison to the other two modes. Also, the performance of hybrid access mode increases with the increase of cellular users. Moreover, open access mode has a better throughput than closed access mode. Also, Fig. 7 shows that open and hybrid access modes have a close average total users' throughput, with increasing in hybrid access around 4% in all cases. However, closed access always has lower average total throughput especially in the case of 20 subscriber users, because a nonsubscriber that can't be served by a closed FAP become 180, and macrocell can serve 100 users only, so, 80 users will be blocked. In the case of more than 100 subscribers, the performances of the three access modes are close to each other, with the closed access being only 7% worse than open access. Therefore, we observe clearly the performance benefits of our proposed hybrid access mechanism, which achieves the highest total user throughput in all cases. In the following, we consider the hybrid access mode in scenario C.

When the UE has lower transmit power as a result of using uplink power control, then we have positive effect on the uplink interference from femtocells to macrocells. But, in dense deployment the resource partitioning is needed, together with power control, to eliminate interference from neighboring cells. With uplink power control the effect of resource partitioning will be little, because most of co-channel interference will be eliminated.

In the reuse-1 techniques, where every frequency resource is available in all places of the macrocell, resource blocks are randomly assigned to the femto users, regardless of the resource blocks that are used by the macro users. Therefore, a macro user and a femto user may use the same resource blocks and thus cause interference to each other. The SFR and OSFR schemes avoid this interference at minimal degradation. It is observed from the graph that due to mitigation of interference in the femtocells and macrocell the throughput has increased for all the macro and femto users using SFR and OSFR. As shown in Fig. 8, the interference is slightly high when using reuse-1 scheme when the same frequency band is used. This is due to the large cross-tier interference when reusing the same frequency in the outer and the inner region for macro and femto users. In OSFR, six subchannels are assigned to the femto users outside the inner region and one subchannel is assigned to the femto user in the inner region. Unlike macro users, most of the subchannels are assigned to the inner region and one

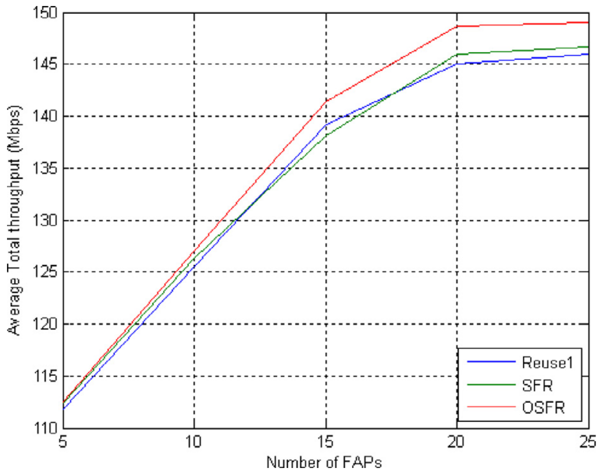

Fig. 8. Total throughput with macro and femto users in the inner and edge region for scenario C.

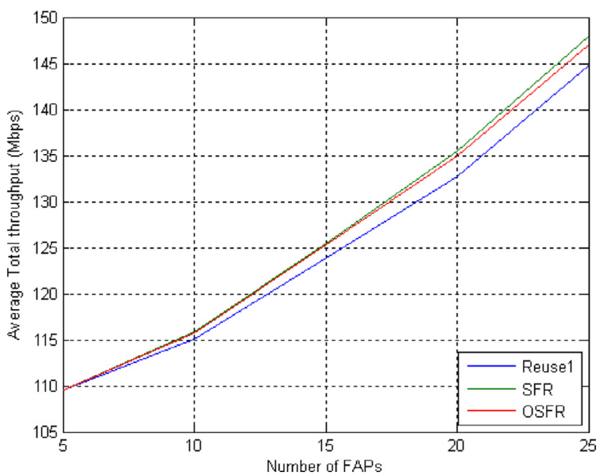

Fig. 9. Total throughput when macro users in the inner region for scenario C.

subchannel is assigned to the outer region. Fig. 8, shows the case where the congestion is distributed in all macrocell region, especially in the edge region where, the using of SFR gives almost the same result of reuse-1 case. But, when the number of femtocells is 25, reuse-1 throughput is 146 Mbps, similarly for SFR it is 146.7 Mbps but in the proposed OSFR, it is increases to 149 Mbps which is much better than the compared schemes. This is due to the fact that in OSFR, by increasing the number of channels in the femtocells in the edge region, the throughput is increased. Also, the performance of OSFR, in this case will increase when the number of femtocell and the number of users is increasing. But in Fig. 9, macro users were situated in the inner region of macrocell, SFR uses seven frequency bands divided into the inner and edge region. In this case, most of the subchannels are assigned to the users in the inner region, thus the performance and throughput of the inner region is increased. The proposed OSFR and SFR in this case have similar throughput as per. Fig. 9 which, shows that when the numbers of femtocell is 25 for reuse-1, throughput is 144.832 Mbps, and for SFR throughput is 148.34 Mbps. As for the proposed scheme, throughput is decreased to 146.9 Mbps. So the improvement of SFR is about 3.5 Mbps than reuse-1. Also with the increase in the number of FAPs, the performance of SFR increases. Finally, the proposed OSFR has better performance in case the users are situated in all the region of the macrocell especially in the edge region, because users use subchannels/RBs that are orthogonal to their overlay macro users, by assigning a new RB to that user if possible. Thus, we can get the highest total users throughput.

5. Conclusion

This paper has focused on the issue of the performance of co-channel macrocells and femtocells in high user density areas. We have evaluated the capacity performance of a two-tier femtocell network under different access control modes. In the closed access mode, handoff to nearby femtocells is not possible and, thus, the number of dropped users increases sharply at high user densities resulting in an increase in the outage probability. In the case of the hybrid mode, cellular users are assigned to a nearby femtocell as a result of the proposed hybrid femto/macro rate-based offloading algorithm that includes RBO. Our algorithm essentially combines RBO with power control and OSFR for resource allocation. Simulation results showed that the proposed hybrid femto/macro rate-based offloading can effectively increase coverage and capacity by optimally assigning users to cell tiers and resources to users.

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