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Thesis

混合式毫微微蜂巢式基地台網路之資源配置與分群方法

Clustering and Resource Allocation Schemes for Hybrid Femtocell Networks

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指導教授：方凱田 博士

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中　文　摘　要

為了提升住宅和企業內部環境的服務範圍和服務品質，毫微微型細胞 (femtocells) 已被視為一個解決方案，因為它可以提供低功率耗損且讓使用者自行佈署的特性。此外，毫微微型細胞可以被允許與巨細胞網路 (macro network) 使用相同的載波頻率或是不同的載波頻率。在一個具有高緻密毫微微型細胞佈署的傳輸環境中，資源配置和干擾管理是一個重要的研究議題，其中干擾主要來自於使用不同的存取模式的毫微微型細胞。若毫微微型細胞運作在封閉存取模式 (closed access mode) 指的是只允許擁有子載波使用權的使用者來和毫微微型細胞做連結; 而在開放存取模式 (open access mode) 指的是所有使用者皆可和毫微微型細胞來做連結。為了獲得毫微微型細胞在企業內部環境建置的好處，混合式存取模式 (hybrid access mode) 可以考慮被系統所採用，該模式可以同時服務封閉式用戶群組 (closed subscriber group) 毫微微型細胞內的使用者和非封閉式用戶群組 (Non-closed subscriber group) 毫微微型細胞內的使用者。此外，當毫微微型細胞運作在混合式存取模式，可以提供封閉和非封閉式使用者間不同的服務層級。在本論文中，我們考慮毫微微型細胞運作在混合式存取模式，且僅允許非封閉式使用者使用連結的毫微微型細胞的部分限制資源。為了最大化非封閉式用戶群的上鏈傳輸容量，本論文提出了一種集中式的功率配置方式，為非封閉式用戶群使用者進行資源的分配，其中使用了幾何規劃（geometric programming）和一種新穎的次佳化分群策略。此外，我們也考慮非封閉式使用者允入控制條件 (admission control condition) 的限制。本論文還提出一個在賽局理論架構下的分散式功率配置演算法。其中利用了非合作式的賽局（non-cooperative game）理論及其納什均衡（Nash equilibrium）的收斂特性。本論文針對在非合作式的賽局中，證明純策略（pure strategy）納什均衡的存在。我們所設計的功率配置演算法主要是根據毫微微型細胞與其服務的用戶之間的距離分配上鏈的功率，以最大化效益函數（utility function）。分析結果顯示，我們提出的資源與分群演算法能夠有效地改善系統的整體效能。

Clustering and Resource Allocation Schemes for Hybrid Femtocell Networks

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Abstract

To enhance indoor coverage and quality of service in both residential and enterprise environment, femtocells (FCs) have been proposed as a solution due to its low power consumption and being an end-user deployed base station. A FC can either share or be on a separate carrier from the macro-network. Due to high density of femto base station (fBSs), many challenges have not been sufficiently addressed such as resource allocation and interference management. The interference intensity mainly comes from the use of different access mode of fBS, which are closed access mode which permits only authorized subscribers to use the fBS and open access which allows all users to connect to the fBS. To gain the benefit of deployment of fBS for an enterprise environment, hybrid access mode has been selected to serve closed subscriber group (CSG) femto users and non-closed subscriber group (non-CSG) femto users. In this way the hybrid fBS may provide different service levels to femto users (FUEs) that are subscribers and non-subscribers. In this work we consider hybrid access mode which allows non-CSG users to connect to the fBS with limited resources. We propose a centralized power allocation (CPA) scheme where we perform resource allocation that reserves resources for non-subscribers using geometric programming (GP) and a novel sub-optimal clustering scheme in order to maximize the uplink (UL) capacity for non-CSG users. In addition, an admission control condition constraint is imposed on non-subscribers. Moreover, we propose a gaming-based distributed power allocation (GDPA) based on a non-cooperative game which converges to the Nash equilibrium (NE). We prove the existence of pure strategy Nash equilibrium of the non-cooperative game. The GDPA scheme tries to find the uplink power that will maximize the utility function based on the distance between the serving fBS and the FUE. Numerical results are presented and suggest the adoption of the proposed schemes.

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Words are often less to reveal one's deep regards. An understanding of work like this is never an outcome of a single person. I would like to take this opportunity to express my profound sense of gratitude and respect to all those who helped throughout the duration of this research.

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This work would not have been possible without the encouragement and able guidance of my supervisor Prof. Kai-Ten Feng. His enthusiasm and optimism made this experience both rewarding and enjoyable. Most of the novel ideas and solutions found in this thesis are the result of our numerous stimulating discussions. His feedback and editorial comments were also valuable for the whole of this research.

I would like to thank all the members of MINT Lab whose love had contributed to the completion of this work as i used to consult when i encounter problems while working on this document and they were willing to help where possible. I wish them all the best in their future attempt to achieve their goals.

Lastly, i would like to thank the admission committee for giving me a chance to come to National Chiao Tung University to pursue my graduate studies, not forgetting the staff at the institute of Electrical engineering and Computer Science (EECS) for their love and care while here. I appreciated all the funding they have provided throughout my stay and may they continue to provide such to other students in future.

狄天柏

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Table 1: Summary of Notations

Notations	Physical Meaning
γ_n^{th}	Resource percentage threshold(RPT) for non-CSG users in fBS_n
ρ_n	Resource percentage threshold(RPT) for CSG users in fBS_n
RPT	Threshold for resources reserved for non-CSG users
$\mathbf{N}$	Set of femtocells, $\{f_1, ..., f_N\}$
$\mathbf{J}$	Set of subcarriers
$\mathbf{K}$	Set of non-CSG FUE's, $\{U_1, ..., U_K\}$
β	System bandwidth (MHz)
λ_n	Total of non-CSG users being served by fBS_n
$\mathbf{M}_n^{neighbor}$	Set of FUEs served by neighboring fBSs of fBS_n
$\mathbf{M}_n$	Set of FUEs served by fBS_n
$C_{n,j,k}^{ncsg}$	Uplink capacity for non-CSG user k in subcarrier j
$\Gamma_{n,j,k}$	SINR experienced by user k in subcarrier j in fBS_n
Γ_0	Minimum SINR at the receiver, fBS_n
N_0	Gaussian Noise
d_{max}	Max distance between femto head (FH) and interfering fBS_{new}
d^{th}	Interference distance between FH and one-hop fBS_n
$\mathcal{M}_T$	Threshold for members per cluster
ϕ_n	Cluster of femtocells
M_{cnt}	Total number of current members in a cluster
fBS_{new}	Newly deployed femto base station
ψ_n	Admission probability for non-CSG users
α	Fixed parameter
χ	Fixed parameter
λ_p, λ_s	Arrival rate of subscribers and non-subscribers
$\mathbf{P}_{j,k}^*$	Nash Equilibrium UL transmission power point
G_{sm}	Supermodular game notation
$\mathbf{b}$	Price coefficient
t_T	Time between broadcast messages
τ_D	Timestamp for the deployed fBS
N_{csg}	Total number of CSG users being served by fBS_n

Chapter 1

Introduction

Femto base station (fBS) are wireless access point, which provides cost effective means of multi-connectivity in the next generation networks [1]. They are low powered, low cost, plug and play devices that are normally installed by the end user and they are connected to the network via a backhaul cable. They are administered by operators and make use of the licensed spectrums. The main goal behind the establishment of fBSs is to improve indoor coverage in current cellular systems due to increasing data demands from consumers [2].

With the explosive growth of mobile data traffic, the FC technology is one of the proper solutions to enhance mobile service quality and system capacity for cellular networks. However, the appeal for FCs gives rise to unsolved problems such as interference, coordination and resource allocation. In dense environment the interference becomes severe since they are deployed in a small area in large quantities, thus interference minimization remains a major challenge in femtocell operations [3], [4]. Since obtaining the optimal resource allocation in dense environment is a non-linear non-convex NP-Hard optimization problem [5], [6], most of the existing work focused on centralized heuristic resource allocation algorithms.

Furthermore, in [7] [8], different clustering sub-optimal heuristic algorithms have been proposed to mitigate inter-femtocells interference, however, they did not mention how the femto head (FH) is elected except for [9]. In our work we provide a new method for electing the FH using timestamp which avoids the frequent change of leadership expected in [9]. On the other hand research studies in [3], [4] did not overcome the challenges to design an effective hybrid access scheme to equilibrate the quality of services (QoS) of different users since they did not consider different types of users. In our work, an efficient hybrid access scheme is proposed to properly differentiate the requirements between closed subscriber group (CSG) and non-closed subscriber group (non-CSG).

In order to provide an adequate signal quality for the signal of each FUE at the receiver without causing unnecessary interference to signals transmitted by other FUEs, an effective power control for FUEs is required. Power control extend the battery life of the terminal by ensuring that it transmit at the minimum power level necessary to achieve the required quality of service (QoS). In order to properly model the power allocation problem, different approaches based on game theory have been applied in femtocell networks using utility functions [10]. Authors in [11], proposed a hierarchical game where each macrocell and femtocell chooses its transmission power in order to selfishly maximize its utility function. They adopt the framework of a hierarchical game to the power allocation problem with a *leader-follower* approach. In this game macrocells are leaders and femtocells are followers. In [12], authors proposed a decentralized power control to determine the individual fBS transmission power and in [10], a CDMA system is studied to find the user optimal rate of transmission and allocates the power required to transmit. From our observation most of the studies focus more on fBS power allocation instead of femto users in hybrid cells. The idea behind game theory is to find the Nash Equilibrium (NE), of which is an action profile at which no player may gain by unilaterally deviating. In other words, a NE is a stable operating point where no user has no incentive for changing strategy [13].

Hybrid access mode allow fBSs to provide preferential access to fBS owners and subscribers while other public users can access fBSs with certain restriction [1], [2]. To the best of our knowledge, the problem of reserving resources for non-CSG users in hybrid cells and clustering of hybrid cells, which is studied in this paper, has not been well covered in literature. Therefore, the contribution of this work can be summarized as follows:

- We propose a centralized power allocation (CPA) scheme that performs resource allocation by reserving resources for non-CSG users taking into account the total number of CSG users being served using GP.

Our motivation stems from the fact that few studies (based on our own analysis) focused on resource allocation using GP in FCs that use hybrid access mode. In addition, an admission control condition is defined to maintain the number of non-CSG users that can be admitted while still guaranteeing the minimum data rate for CSG users.

- We also propose a sub-optimal hybrid femtocell clustering (HFC) for fBSs using hybrid access mode based on timestamp, distance and interference.

- Furthermore, we propose a gaming-based distributed power allocation (GDPA) scheme for FUEs using game theory. We prove that the proposed power game converges to the Nash Equilibrium.

- Using numerical analysis we demonstrate the efficiency of our resource allocation and clustering schemes. Comparing them with existing work [14].

The rest of our work is outlined as follows. The system model and problem formulation is presented in chapter II. Chapter III presents the centralized power allocation scheme, cluster formation scheme, and a gaming-based power allocation scheme for FUEs using a non-cooperative game approach, and performance evaluations are illustrated in chapter IV and lastly, chapter V concludes our study.

Chapter 2

System Model and Problem Formulation

2.1 Network Scenario

We consider the uplink (UL) of a dual-tier system, where a dense femtocell network system is overlaid on top of the macro cell, and the femtocell network employs frequency division duplexing (FDD) scheme. There are J subcarriers shared by non-CSG and CSG users for UL communications[1]. It is assumed that there are N femtocells, and there exists K users randomly distributed within each fBS. FC network takes the form of an enterprise deployment area where there is high density of femtocells, as shown in Fig. 2.1. We further assume that fBSs use hybrid access mode where non-CSG users can connect to a nearby fBS. We assume a split spectrum between FCs and macrocell thus eliminating interference between femto and macro users since interference between fBSs is our major concern in this work. Moreover, fBSs transmit at constant power and proportional fairness is adopted since it has been extensively utilized in practical wireless standards [15]. Two types of FUEs are considered: (i) CSG users (subscribers) who require fixed QoS guarantee in terms of data rate, and (ii) non-CSG users (non-subscribers) with no minimum guarantee. For example, CSG users can be the fBS's owner and subscribers; while non-CSG users are visitors.

We assume a full spatial reuse where all subchannels are utilized at each

[1]The structure of co-tier interference in the uplink is different from that in the downlink. Downlink anaylsis is left for our future work but the proposed schemes are applicable even in the downlink communication

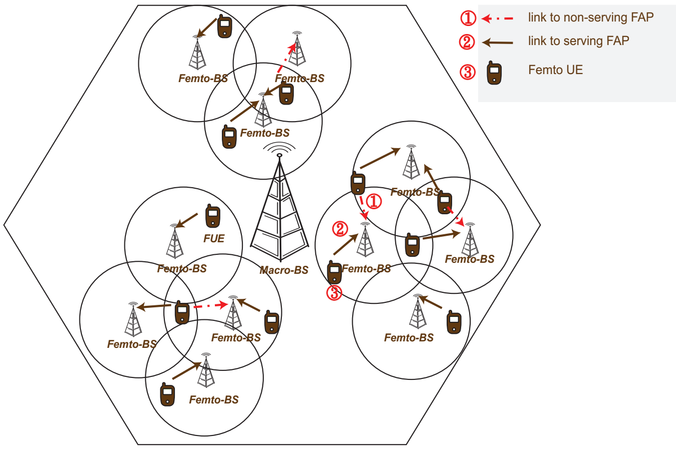

Figure 2.1: System diagram with femtocells in a Macrocell using hybrid access mode.

fBS. We assume that the UL connection requests of CSG and Non-CSG users, which follows Poisson process, arrive at a rate of λ_p and λ_s, respectively. Table I summarize the notations used in this work.

2.2 Problem Formulation

It is expected that there are high demands of available system resources in urban areas, especially during peak hours. Therefore, our main aim is to maximize the UL capacity for non-CSG users by dynamically reserving resources for non-CSG users, while still guaranteeing the required CSG users data rate. Also femto-to-femto interference will be mitigated by clustering FCs using hybrid access scheme. We maximize the UL capacity under the constraint of maximum transmission power of FUEs and guarantee data rate for CSG users per FC. What must be noted is that users closer to the fBS will need to lower their transmit power than users at the cell edge. As for the edge users, they will transmit at higher transmit power than center users since they suffer from high path loss. In such cases, users at the cell edge shall be allocated the least interfered channels. Note that the focus of this work is not on channel allocation since it has been studied in [16]. To achieve this, we formulate the power allocation problem as a single-objective optimization problem which can be formulated as:

$$\mathbf{P}^* = \arg\max_{\mathbf{P}} \sum_{n=1}^{N} \sum_{j=1}^{J} \sum_{k=1}^{K} C_{n,j,k}^{ncsg} \tag{2.1}$$

subject to:

$$C1: \sum_{j=1}^{J} P_{j,k} \leq P_{max}, \qquad \forall k \in \mathbf{K} \tag{2.2}$$

$$C2: \sum_{j=1}^{J} C_{n,j,k}^{csg} \geq C_{req}^{csg}, \qquad \forall k \in \mathbf{K} \tag{2.3}$$

where $P_{j,k}$ represent the UL transmission power for user k in subcarrier j and P_{max} is the maximum allowed UL power for each FUE in (2.2). $\mathbf{P}$ is the set of $P_{j,k}$. C_{req}^{csg} is the minimum data rate threshold to guarantee the data rate for CSG users and $C_{n,j,k}^{csg}$ is the data rate for CSG user k being served by fBS_n in subcarrier j. Equation (2.2) imposes a per FUE constraint on the maximum power, that is, UL transmission power must be lower than maximum power, and (2.3) denotes that the minimum required data rate for CSG users must be satisfied. The objective function in (2.1) can be obtained as:

$$C_{n,j,k}^{ncsg} = \frac{\beta \cdot \gamma_n^{th}}{\lambda_n} \log_2[1 + \Gamma_{n,j,k}] \tag{2.4}$$

where $C_{n,j,k}^{ncsg}$ represents the UL Shannon capacity for each FUE k in subcarrier j under fBS_n. The expression of the received signal to interference plus noise ratio (SINR), $\Gamma_{n,j,k}$, is as follows:

$$\Gamma_{n,j,k} = \frac{P_{j,k} \cdot L_{n,j,k}}{N_0 + \sum_{m \neq k, m \in \mathbf{K}} P_{j,m} \cdot L_{n,j,m}} \tag{2.5}$$

where N_0 in the denominator is the Gaussian noise power and the second term represents the total interference due to other FUEs. In the numerator, $P_{j,k}$ is the UL power for user k in subcarrier j and $L_{n,j,k}$ denotes the path loss between user k and fBS_n in subcarrier j. Note that we adopt the path loss model from 3GPP in [17].

Since a FC is in general located indoor, so interference occurs when adjacent FC use the same subcarriers. In order to mitigate femto-to-femto interference we therefore propose a sub-optimal heuristic algorithm for cluster formation. Here we use the Euclidean distance measure:

$$d(f_a, f_b) = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2} \tag{2.6}$$

where $d(f_a, f_b)$ is the distance between fBS f_a and fBS f_b which are located at (x_a, y_a) and (x_b, y_b), respectively and f_a is the femto head (FH), and f_b is the neighbor fBS within one-hop distance. Since the optimal clustering problem has been proved to be an NP-Hard in [18], therefore, we propose a sub-optimal clustering scheme for hybrid cells using timestamp, distance and interference. Also equation (2.1) is non-convex due to inter-cell interference, to solve it, we propose first to transform the problem into a linear one. We use the geometric programming approach to transform it into a convex function.

Chapter 3

Power Allocation and Clustering Schemes

In this section, we divide our research work into sub-problems, that is, (i) Centralized power allocation - we perform resource allocation in a dense environment with an admission condition constraint considering interference in non-clustered FCs first and clustered FCs later. Power allocation is done using GP and (ii) Cluster formation - where we propose a different clustering method using the FH elected based on timestamp, and (iii) gaming-based power allocation for FUEs using game theory.

When a non-CSG FUE request an UL connection, the fBS has to check if by accepting the new non-CSG it will still meet its admission control condition. This can be done by calculating the new admission condition, $\beta_{new} = \frac{\beta \cdot \gamma_n^{th}}{\lambda_n + 1}$. The purpose of the admission control is to prevent fBS overloading resulting to low data rate. Here the total number of non-CSG users is increased by 1. Then, we compare the new admission condition with an admission bandwidth threshold, β_n^{ncsg}, which is the minimum equi-spaced channel per FUE of the width 180 KHz similar to 3GPP LTE definition [17]. Here we impose the following admission constraint to protect CSG users:

$$\beta_{new} \geq \beta_n^{ncsg}, \quad \forall n \in \mathbf{N} \tag{3.1}$$

The admission control probability can be illustrated as shown:

Lemma 1 (Admission control probability). Within the cluster the admission probability, ψ_n, is given by

$$\psi_n = \begin{cases} 1, & \beta_{new} \geq \beta_n^{ncsg} \\ 0, & otherwise \end{cases} \tag{3.2}$$

where $\beta_{new} = \frac{\beta \cdot \gamma_n^{th}}{\lambda_n + 1}, \forall n \in \mathbf{N}$

Proof 1. The total number of non-CSG FUEs attempting to connect to fBS_n is given by

$$\lambda_n = \frac{\beta \gamma_n^{th}}{\beta_{new}} - 1 = \beta \gamma_n^{th} (\beta_n^{ncsg})^{-1} \tag{3.3}$$

so if $0 \leq \lambda_n = \frac{\beta \cdot \gamma_n^{th}}{\beta_{new}} - 1 \leq \beta \cdot \gamma_n^{th} (\beta_n^{ncsg})^{-1}$, the fBS_n is under-loaded thus the admission probability equals 1. If $\frac{\beta \cdot \gamma_n^{th}}{\beta_{new}} - 1 \quad > \quad \beta \cdot \gamma_n^{th} (\beta_n^{ncsg})^{-1}$, the fBS_n is overloaded and the FUE that request UL connection is blocked or rejected, thus the admission probability equals $\frac{\beta \cdot \gamma_n^{th}}{\lambda_n + 1}$. ■

Therefore, non-CSG users can either be admitted or rejected. To balance the load over a cluster of FCs, the system can employ an immediate retry procedure, by which the rejected user attempt's to gain service from nearby fBS that still has available resources. Note that the admission constraint is only applicable to a newly arriving non-CSG user since they are secondary users in hybrid cells and they are allocated the remaining resources. At a departure instant of any connection, state transition occurs and no action is needed. Admission control can be performed separately in each hybrid cell and this enables it to be implemented in a distributed environment.

In addition to the admission control condition, the femto user SINR in (2.5) is supposed to meet the minimum SINR requirement at the receiver, Γ_0, in order to be accepted in case there are still resources available for non-CSGs. The SINR condition can be stated as follows:

$$\Gamma_{n,j,k} \geq \Gamma_0 \tag{3.4}$$

The admission control condition and the SINR condition will be used in our proposed schemes in the next sub-sections. The resource allocation model under consideration is illustrated in Fig. 3.1 and it's worth noting that we consider a dynamic network model where users come and leave the network with respect to time.

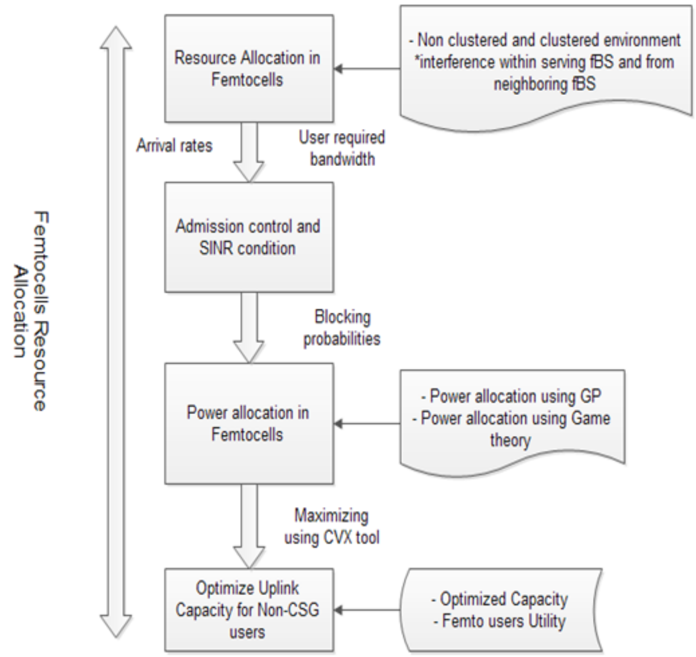

Figure 3.1: System diagram showing our proposed scheme.

3.1 Centralized Power Allocation (CPA) Scheme

We propose a centralized power allocation scheme where resources are dynamically allocated based on the number of CSG users that are currently being served by fBS_n. In order to manage the allocated resource block (RB) each fBS must define its own resource percentage threshold (RPT), that is, the percentage threshold for resources to be reserved for non-CSG users. In this way the QoS for CSG and non-CSG users can be improved without a negative impact on CSG users. This scheme guarantee's the data rate for CSG users first before allocating the remaining resources to non-CSG users. Furthermore, non-CSG users will be admitted only if they meet the admission control condition set in (3.1) and the SINR minimum requirement in (3.4). Each time a CSG FUE is admitted, the fBS has to compute the RPT currently dedicated for CSG users, ρ_n, based on the number of CSG users being served and the minimum required data rate for CSG users, C_{req}^{csg}. It must be made clear that we consider only the interference within the fBS since the environment we consider is non-clustered. Then, the fBS has to compute the RPT for non-CSG users, γ_n^{th}, where

$$\gamma_n^{th} = 1 - \rho_n \tag{3.5}$$

Algorithm 1: CPA Scheme

Input: $\beta, P_{max}, N_0, \beta_n^{ncsg}$
Output: $C_{n,j,k}^{ncsg}$

```
Each time a CSG FUE is admitted compute new ρ_n under the current SINRs
After that re-compute γ_n^th under the current SINR's of its associated FUEs
If non-CSG FUE request uplink then
   Compute new admission condition, β_new
   If (β_new ≥ β_n^ncsg) then
      accept non-CSG FUE
      compute path loss, L_{n,j,k}
      compute C_{n,j,k}^ncsg after lower bound and variable transformation.
      Then, Maximize C_{n,j,k}^ncsg.
   else
      block non-CSG FUE
   End if
End If
```

and,

$$\rho_n = \frac{C_{req}^{csg}}{\sum_{u=1}^{N_{csg}} \frac{\beta}{N_{csg}} \log_2(1 + \Gamma_{n,j,u})} \tag{3.6}$$

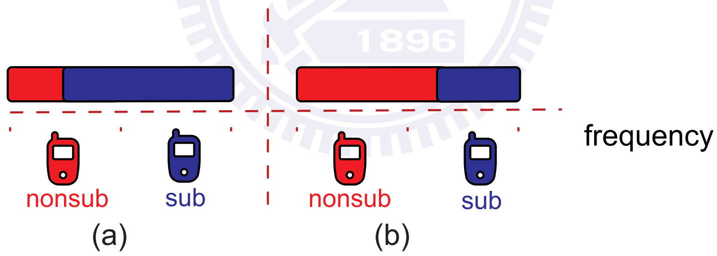

Figure 3.2: (a) The are many subscribers (CSGs) so $\gamma_n^{th} < \rho_n$ and (b) there are less subscribers so $\gamma_n^{th} > \rho_n$

Once the resources have been reserved, we then compute the optimized UL capacity for non-CSG user using GP after lower bound substitution and variable transformation, similar to [19],[20]. Here we use GP for power allocation. This can be further illustrated in Algorithm 1 and similar proof will be provided in subsubsection 3.2.1

The variation of resources reserved for non-CSG based on the number of CSG users currently being served can be illustrated using Fig. 3.2 where (a) shows that if the number of CSG (sub) users is greater than non-CSG (nonsub) users less resources can be available to non-CSGs and (b) the other way round. This shows that RPT always depends on the number of CSG users being served by the fBS and it must be noted that each fBS will have few subscribers at a time.

3.2 Hybrid Femtocell Clustering (HFC) Scheme

Algorithm 2: Hybrid Femtocell Clustering (HFC) Algorithm

Assume the presence of n_0 as the FH (label (n)=$\mathcal{H}$) with no members
n_0 sets the d^{th} and $\mathcal{M}_T$ [measurements obtained from "fBS Sniffer"]
If a *new* fBS joins a network, i.e fBS_{new} is switched on within the area, and interfere with fBS n_0 **then**
  Find the max distance, d_{max}
  If ($d_{max} \leq d^{th}$) **then**
    If ($M_{cnt} \leq M_T$) **then**
      fBS_{new} becomes the member of the cluster, $fBS_{new} \in \phi$
      label(n)=M: the status update that node *new* is a member
      increase membership count, M_{cnt} +1
    else
      fBS_{new} becomes a new FH, $fBS_{new} \to \mathcal{H}$
    End If
  else
    fBS_{new} joins another FH ($fBS_{new} \to \mathcal{H}^{'}$, another cluster) or $fBS_{new} \to \mathcal{H}$
  End If
fBS n_0 updates membership list and share it
Wait for all members to respond
FH periodically checks its active members and if a member is not determined,status update becomes **X** (label (n) =**X**) and M_{cnt} is updated

Here we propose a sub-optimal heuristic algorithm for cluster formation in a dense environment to mitigate femto-to-femto interference based on distance, one-hop interference and timestamp, τ_D. Each cluster should have a femto head (FH) that is elected based on timestamp and we assume Over-The-Air (OTA) coordination. If FH becomes inactive another fBS is elected as the new FH based on the same criteria. The femto-gateway (F-GW) keeps records of newly deployed fBS and this includes deployment time and date. First, we assume an initially deployed fBS n_0 with no members. fBS n_0 sets the d^{th}, and $\mathcal{M}_T$ (measurements obtained through "fBS Sniffer"). If a *new* fBS is deployed and interferes with FH, the FH measures the maximum distance, d_{max}, the distance between FH and the interfering fBS. If $d_{max} \leq d^{th}$ and $M_{cnt} \leq \mathcal{M}_T$, then the new fBS joins the cluster, $fBS_{new} \in \phi$, else it may join another cluster or becomes a new FH. The duty of the FH is to form and maintain the cluster, that is, the FH keeps track of active and non-active members. The cluster formation can be described using pseudo-code as in Algorithm 2.

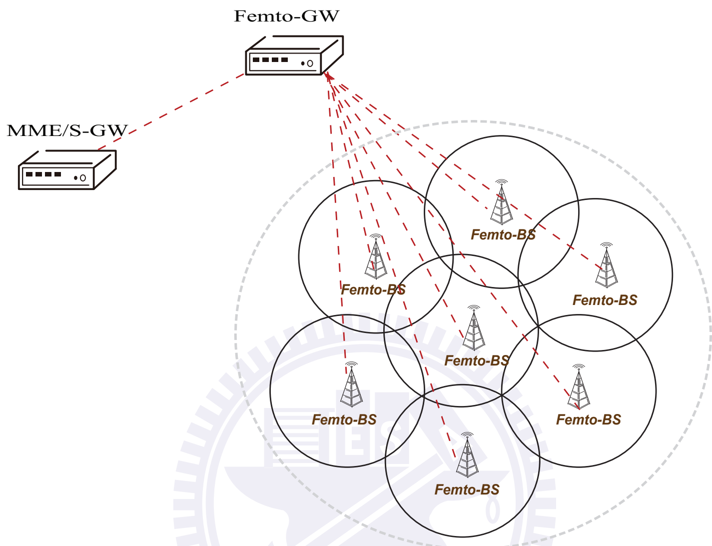

Figure 3.3: Simple architecture showing a cluster of femtocells connected to the gateway

To ensure the practicability of the proposed scheme, Fig. 3.3 show the architecture with a cluster of FC similar to a 3GPP architecture. For it to be practical, fBS will be deployed and join the FH elected based on timestamp. The femto-gateway will know the fBSs connected to it and the FH will have its own neighbor list or cluster membership list that will be shared with the femto-gateway, that is, by knowing the FH you can then know the cluster members. Therefore, any changes from the cluster will be updated and shared with the gateway. Moreover, the neighbor list consists of the physical ID of the neighbors fBSs and each fBS will have its own CSG list containing the CSG identities of users subscribed to use it.

An ideal FC network consists of FCs whose coverage area does not overlap with the coverage area of other FCs. So, clustering minimize same-tier interference in every cluster by assigning different subchannels to FCs in different clusters and to avoid collision between neighboring FC, they cannot use adjacent subcarriers. Examples of subchannel allocation schemes include fractional frequency reuse and partial frequency reuse [16]. Note that our clustering scheme is based on fBSs transmitting at a constant transmit power and also the coverage area is assumed to be constant for all fBS. Furthermore, fBSs use hybrid access mode since we are considering an enterprise environment.

3.2.1 CPA and HFC

We assume that the CPA scheme is being used by each fBS using hybrid access mode in a clustered environment [2] to effectively share the resources between subscribers and non-subscribers within each fBS. In a clustered environment, interference comes from neighboring fBs, therefore, in this case we consider the UL co-tier caused by neighboring FUEs, $m \in \mathbf{M}_n^{neighbor}$, at the receiver can be expressed as follows:

$$I_{n,j}^{inter} = \sum_{m \in \mathbf{M}_n^{neighbor}} P_{j,m} L_{n,j,m} \tag{3.7}$$

where $P_{j,m}$ is the UL transmission power of user m in subcarrier j and $L_{n,j,m}$ is the link gain from user m to fBS_n in subcarrier j. The conditions stated in (3.1) and (3.4) are adopted in this scenario. We consider that there are k users within the members that are one-hop from the serving fBS. Therefore, the overall SINR at the fBS_n is :

$$\Gamma_{n,j,k} = \frac{P_{j,k} L_{n,j,k}}{N_0 + \sum_{m \neq k, m \in \mathbf{M}_n} P_{j,m} L_{n,j,m} + I_{n,j}^{inter}} \tag{3.8}$$

The proposed scheme is named CPA + HFC, and its a combination of Algorithms 1 and 2. In order to transform the non-convex function into a convex function we use geometric programming (GP) as stated in subsection A without any proof. GP is based on successive approximation and we use GP for power allocation. Since we consider a clustered environment, our

[2] We consider an environment where FCs has been clustered using our proposed HFC scheme. The FH knows all its members and there is no member that belongs to two clusters. Our clusters are disjoint.

overall SINR equation at fBS changes. In this case we substitute (3.8) into (2.4). What can be noted is that after lower bound substitution, the function will still be non-convex. Therefore, the function can be further transformed into a convex by another substitution and observing the $log - sum - exp$ function which was proven to be convex in [5]. This can be achieved using similar work from [19],[20] and it can be illustrated as follows using Lemma 2 below:

Lemma 2. Our optimization problem is non-convex due to the presence of inter-cell interference. To transform (2.1) into a convex formulation we make use of the geometric programming concept where we use the relaxation approach similar to [19],[20]. In our problem we employ the following lower bound as

$$\alpha \cdot \log \Gamma_0 + \chi \leq \log(1 + \Gamma_0) \tag{3.9}$$

which is tight with equality at a chosen value Γ_0 when the approximation parameters are chosen as

$$\alpha = \frac{\Gamma_0}{1 + \Gamma_0} \tag{3.10}$$

$$\chi = \log(1 + \Gamma_0) - \frac{\Gamma_0}{1 + \Gamma_0} \log \Gamma_0 \tag{3.11}$$

where α and χ are fixed parameters. Therefore, equation (2.4) can be reformulated as

$$\hat{C}_{n,j,k}^{ncsg} = \frac{\beta \cdot \gamma_n^{th}}{\lambda_n} \cdot \alpha \cdot \log_2(\Gamma_{n,j,k}) + \chi \tag{3.12}$$

$\hat{C}_{n,j,k}^{ncsg}$ can be viewed as the lower bound of $C_{n,j,k}^{ncsg}$, therefore the original optimization problem can be transformed to maximize the UL capacity under the constraint of maximum power transmission of FUEs and guarantee data rate for CSG users per FC. Nevertheless, (3.12) is still non-convex which still requires further transformation into a convex function. The lower bound can be transformed into convex by letting $P_{j,k} = e^{(\hat{P}_{j,k})}$ in (3.12) and $\hat{P}_{j,k} = \ln(P_{j,k})$.

Proof 2. Then we have (3.12) as,

$$Z_{n,j,k} = \frac{\alpha}{\ln(2)} \left[\ln(L_{n,j,k}) + \hat{P}_{j,k} - \varphi \right] + \chi \tag{3.13}$$

where

$\varphi = \ln(\sum_{m \neq k} e^{(\hat{P}_{j,m})} L_{n,j,m} + N_0 + \eta)$

$\eta = \sum_{m \in \mathbf{M}_n^{neighbor}} e^{(\hat{P}_{j,m})} L_{n,j,m})$.

Observing (3.13), we find a *log-sum-exp* function which has been proven to be convex in [5]. ■

After lower bound variable transformation and approximation, our initial optimization problem in (2.1) can be reformulated as

$$\mathbf{P}^* = \arg\max_{\mathbf{P}} \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{k=1}^{K} \tilde{C}_{n,j,k}^{ncsg}, \tag{3.14}$$

subject to:

$$C1 : \sum_{j=1}^{J} P_{j,k} \leq P_{max}, \qquad \forall k \in \mathbf{K}, \tag{3.15}$$

$$C2 : \sum_{j=1}^{J} \tilde{C}_{n,j,k}^{csg} \geq C_{req}^{csg}, \qquad \forall k \in \mathbf{K},$$

where

$$\tilde{C}_{n,j,k}^{ncsg} = \hat{C}_{n,j,k}^{ncsg}(e^{\hat{P}_{j,k}}; \alpha, \chi) \tag{3.16}$$

3.3 Gaming-based Distributed Power Allocation (GDPA) Scheme

If FUEs can control their transmission power, interference can be reduced thus in turn improves the user performance within FCs. The goal of each FUE is to adapt its transmitted power in a distributed manner. We introduce a non-cooperative game [3] formulation for our power allocation problem and further prove the existence of a stable point (i.e Nash Equilibrium). Therefore, we propose the GDPA scheme for FUEs so that they can adjust their UL transmission power to $\mathbf{P}^*_{j,k}$ that will maximize the utility function. It must be pointed out that we are still maintaining our objective of maximizing the UL capacity for non-CSG users. Based on [21], [22], the following game can be defined to formulate a non-cooperative game.

Definition 1 (General Form of a Strategic Game). *Considering the scenario in Fig. 3.4, the strategic game G_{sm} can be expressed as follows:*

$$\langle \aleph, (P_k)_{k\in\aleph}, (u_k)_{k\in\aleph} \rangle \tag{3.17}$$

where $\aleph = \{1, ..., K\}$ is a set finite set of players, i.e, the set of non-subscribers

[3] Game theory is an appropriate tool to solve some problems in communication systems since it deals with distributed optimization [13]

$\in R$, and K denotes the number of players. $(P_k)_{k\in\aleph}$ represents the set of pure strategies, where P_k is the non-empty set of actions for player k. Our strategy is such that $P_k = \{\mathbf{p} : P_{j,k} \geq 0, \forall k, \sum_{j=1}^{J} P_{j,k} \leq P_{max}\}$. $(u_k)_{k\in\aleph}$ indicates the set of utility functions.

The utility function for each non-CSG user can be expressed as follows assuming proportional fairness amongst FUEs:

$$u_k(p_k, p_{-k}) = \log(C_{n,j,k}^{ncsg}) \tag{3.18}$$

where p_{-k} denotes the power vector of elements of $\mathbf{p}$ without the k^{th} element. The objective of each user is to adapt its transmitted power in a distributed manner such that its corresponding utility is maximized. In our case, the utility function reflects the FUEs performance per fBS.

In our game we consider the scenario in Fig. 3.4 where players are the FUEs, subscribers and non-subscribers.

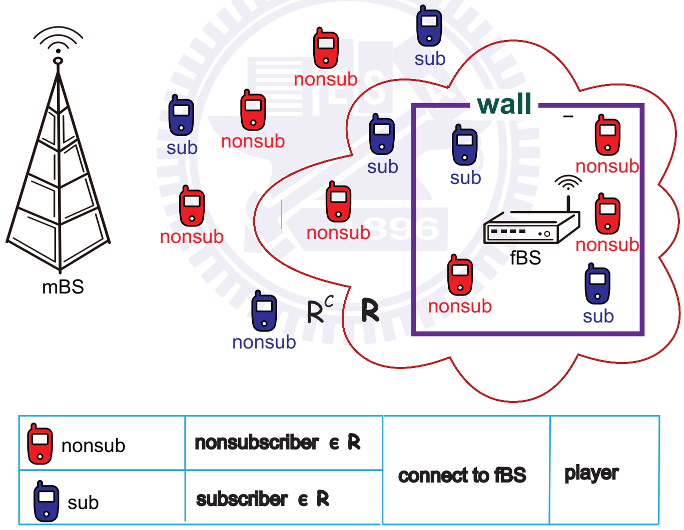

Figure 3.4: Our Non-Cooperative Game Model

We let the fBS to be passive, that is, the only communication between the fBS and the non-CSG user is only a broadcast message from the fBS at time, t_T. We adopt the open loop power control standard and players are power constrained, i.e, $P_{j,k} = [0, P_{max}]$. A player can only drop in the game if she or he becomes inactive. The broadcast message from fBS consists of the received power from all players and their SINR status. By SINR status we mean an indicator that shows that user k transmission power meets the minimum required SINR at the receiver, fBS_n. Let "0" and "1" define the SINR status for not meeting the SINR minimum requirement and the other for meeting the SINR minimun requirement, $\Gamma_{n,j,k} \geq \Gamma_0$.

3.3.1 Existence of Nash Equilibrium (NE)

To prove the existence of NE we use the Supermodular game approach because supermodular games have several remarkable properties [22]. We make use of the similar work done in [12] and the following conditions: (i) P_k is a compact subset of $\mathbf{R}$ which represent a set of real numbers and (ii) the utility function $u_k(\cdot)$ is continuous and is twice continuously differentiable, (iii) $\frac{\partial^2 U(P_k)}{\partial P_k \partial P_m} > 0$ for all $P_k, P_m \in [0, P_{max}]$.

An NE in transmitted powers is defined formally as

Definition 2. *A power vector* $\mathbf{p} = (p_1, ..., p_K)$ *is a NE of the game* $G_{sm} = \langle \aleph, (P_k)_{k\in\aleph}, (u_k)_{k\in\aleph} \rangle$ *if for every* $k \in \aleph, u_k(p_k^*, p_{-k}^*) \geq u_k(p_k, p_{-k}^*)$*, for all* $p_k^* \in P_k$.

Theorem 1. An NE equilibrium in UL transmission powers for the pure strategy game $G_{sm} = \langle \aleph, (P_k)_{k\in\aleph}, (u_k)_{k\in\aleph} \rangle$ exists and its unique.

Proof 3. Our proposed game model can be shown as a supermodular type of game. This can be done by using the partial derivative test to check if $\frac{\partial^2 U(P_k)}{\partial P_k \partial P_m} > 0$ for all $P_k, P_m \in [0, P_{max}]$ or not. The capacity per user in the n^{th} fBS can be expressed as in (2.4) and the SINR is similar to (2.5) and the utility function is given in (3.18). Substituting (2.4) into (3.18) we have

$$u_k(p_k, p_{-k}) = \log\{\frac{\beta \cdot \gamma_n^{th}}{\lambda_n} \log[1 + \Gamma_{n,j,k}]\} \tag{3.19}$$

Let $A = \frac{\beta \cdot \gamma_n^{th}}{\lambda_n}$ and $S = N_0 + \sum_{m \neq k, m \in \mathbf{K}} P_{j,m} \cdot L_{n,j,m}$, then we have

$$\frac{\partial U(P_k)}{\partial P_k} = \frac{L_{n,j,k}}{(S + P_{j,k} \cdot L_{n,j,k}) A \log(1 + \frac{P_{j,k} \cdot L_{n,j,k}}{S})} \tag{3.20}$$

Let $\mu = (S + P_{j,k} \cdot L_{n,j,k}) A \log(1 + \frac{P_{j,k} \cdot L_{n,j,k}}{S})$, then we have the partial differential as

$$\frac{\partial^2 U(P_k)}{\partial P_k \partial P_m} = \frac{-A \cdot L_{n,j,k} \cdot L_{n,j,m}[\log(1 + \frac{P_{j,k} \cdot L_{n,j,k}}{S}) - \frac{P_{j,k} \cdot L_{n,j,k}}{S}]}{\mu^2}, \tag{3.21}$$

For the range $0 \leq P_k \leq P_{max}$ the utility function is continuous and P_k is a compact subset of $\mathbf{R}$ since $[0, P_{max}]$ is a compact set. Therefore, (i) and (ii) are satisfied.

Using log properties we can analyze (3.21). We can observe that $\log(1+x) < x$ for all $x > 0$ and $\frac{P_{j,k} \cdot L_{n,j,k}}{S} > 0$. Therefore, we can conclude that $\frac{\partial^2 U(P_k)}{\partial P_k \partial P_m} > 0$ and our game is a supermodular game.

As for uniqueness we did not prove it but we assume that each strategy to be employed by each FUE will be unique, that is, in the broadcast message there won't be any duplicate $\mathbf{P}^*_{j,k}$.

3.3.2 Proposed GDPA

In order to properly model the power allocation problem, we propose a distributed power control for FUEs. Here each FUE adjust its transmission power such that its corresponding utility function is maximized, that is, the best response leads to an equilibrium irrespective of the starting point of the transmission power of the FUE. Similar to [11], we define two user functions: the Reward function which depends on user's SINR, and the Penalty function which depends on user's transmission power. In our case we use formula's similar to capacitor transient state, that is, the charging and discharging state of the capacitor. We define the Reward function $R(\Gamma_{n,j,k}, \Gamma_0)$ and Penalty function $D_{p_k,p_{-k}}$ on the j^{th} subcarrier as follows:

$$R(\Gamma_{n,j,k}, \Gamma_0) = p_k(1 - e^{-b(\Gamma_{n,j,k} - \Gamma_0)}) \tag{3.22}$$

$$D(p_k, p_{-k}) = -p_k e^{-b(\Gamma_{n,j,k} - \Gamma_0)} \tag{3.23}$$

where p_k is the previous transmitted FUE UL power in the frequency slot assuming every user knows the received power of all transmissions in the previous frequency slot, Γ_0 is the minimum target SINR for FUEs at fBS_n and $\Gamma_{n,j,k}$ is the SINR for user k attached to fBS_n in subcarrier j. The constant $\mathbf{b}$ ($\mathbf{b} > 0$) is the *price* coefficient to adjust the influence of the reward and penalty function over the power allocation. In our case, $\mathbf{b}$ is the distance between the FUE and the serving fBS which can be easily obtained from the path loss.

If we increase the power level, we also increase the interference levels. Then, if we adjust the power levels the quality of service would be improved. In distributed networks, power allocation algorithms should minimize power with good convergence. The convergence of transmission power property can

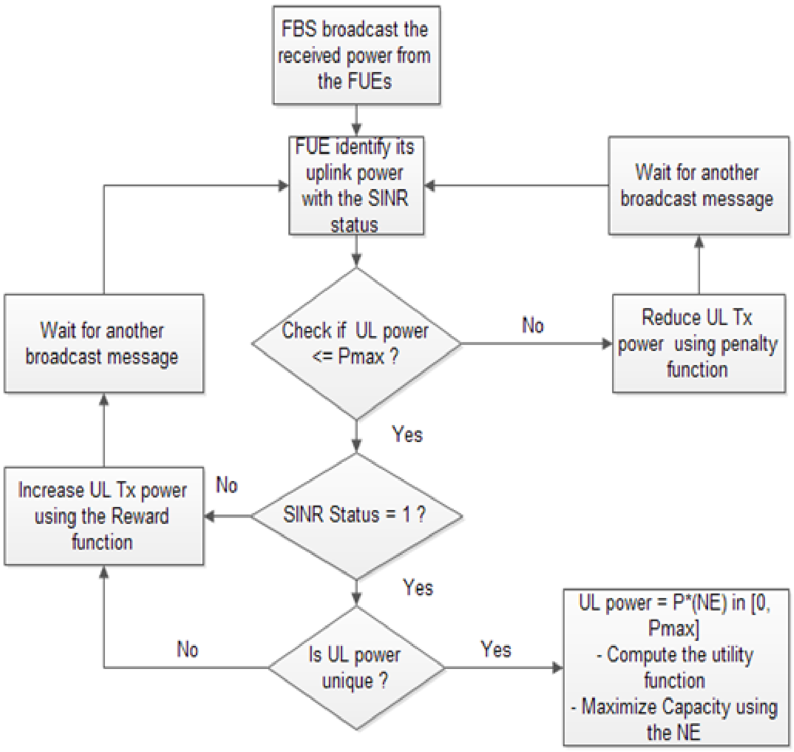

Figure 3.5: Gaming-based Distributed Power Allocation Flow Chart

be applied to practical implementation where each FUE tries to find the optimal value of transmission power to maximize its utility function expressed in (3.18) and uses the optimal transmission power to maximize its UL capacity. After some search iterations, the power of the FUE will reach the equilibrium. In this way we can define a power allocation algorithm converging to NE.

Fig. 3.5 summarized our proposed distributed power allocation scheme. In our proposed power allocation algorithm (Algorithm 3), each FUE tries to find the best response, that is, tries to decide which strategy for getting the best transmission power and this depends on the distance between the serving fBS and the FUE, and the SINR minimum requirement. Terminals can decide on any value between $[0, P_{max}]$. If every FUE performs the same procedure many times, then the power of the FUE will converge to an NE.

Algorithm 3: Gaming-based Distributed Power Allocation (GDPA)

01: Initialization: Each fBS calculates the admission control for Non-CSGs as presented in (3.1) and runs the CPA scheme for reserving resources for Non-CSG users.
02: Initialize a power vector $\mathbf{p}$ randomly at time t_0.(Assume this as a broadcast message from fBS_n, i.e, $p_{j,k} = (p_{j,1}\{0\}, p_{j,2}\{1\}, ..., p_{j,k}\{\cdot\}), \{\cdot\} \rightarrow$ SINR status)
03: **Repeat**
04:     **If** FUE meets the admission condition check if $P_{j,k} \leq P_{max}$ **then**
05:         condition = true
06:     **Else**
07:         Update uplink TX power using (3.23)
08:         Wait for the next broadcast message time t_T
09:         goto 4
10:     **End If**
11:     **If** condition = true **then**
12:         **If** SINR status = 1 **then**
13:             Check for uniqueness of $\mathbf{P}_{j,k}$ in the broadcast message (no duplicate)
14:             **If** $P_{j,k}$ is unique **then**
15:                 $P_{j,k} = \mathbf{P}^*_{j,k} \in P_k$
16:                 Substitute $\mathbf{P}^*_{j,k}$ into (3.18)
17:                 Substitute $\mathbf{P}^*_{j,k}$ into (2.4)
18:             **Else**
19:                 Update uplink TX power using (3.22)
20:                 Wait for the next broadcast message time t_T
21:                 goto 4
22:             **End If**
22:         **Else**
23:             Update uplink TX power using (3.22)
24:             Wait for the next broadcast message time t_T
25:             goto 4
26:         **End If**
27:     **End If**
28: **Until** convergence to NE

Chapter 4

Performance Evaluation

In this section, we present our numerical results of our proposed schemes considering FCs using hybrid access mode, assuming a stationery FUE, with a system bandwidth of 10 MHz. Evaluation results are based on how each proposed scheme maximizes the UL capacity of non-CSG per user per fBS and its utility function. We apply the FDD system level simulation assumptions and parameters given in 3GPP specification [17] as summarized in Table II. Here we used a static simulator, $MATLAB^{TM}$, where we make use of the CVX tool [23] to solve the NP-Hard optimization problem, equation (2.1).

Table 4.1: Simulations Parameters

System Parameters	**Value**
Femtocell Radius, d_n	10 m
Max No. of CSG FUEs per fBS	13
Members per Cluster	30
Shadowing, ω	4 dB
Wall loss, η	20 dB
Rayleigh fading, ξ	8 dB
fBS transmit power	20 dBm
FUE min. transmit power, P_{min}	0 dBm
FUE Max. transmit power, P_{max}	18 dBm
Channel width, β_f^{ncsg}	180 KHz
Max FUE-fBS distance, D	5 m
Thermal Noise density , N_0	-174 dBm
Minimum SINR, Γ_0	15 dB
Minimum data rate for CSGs, C_{req}^{csg}	1 Mbit/s
House size	10m x 10m

Considering our proposed cluster formation scheme (HFC); In our work we provide a better method for electing the FH using timestamp which avoids the frequent change of leadership expected in [9] and the close proximity of cluster members saves energy if OTA coordination is used. HFC overcomes the limitations of other schemes by considering how the FH can be more effectively elected, by having the FH setting d_{max} and by setting the cardinality of cluster members. This scheme is suitable for clustering fBS in a dense environment where fBSs use hybrid access mode.

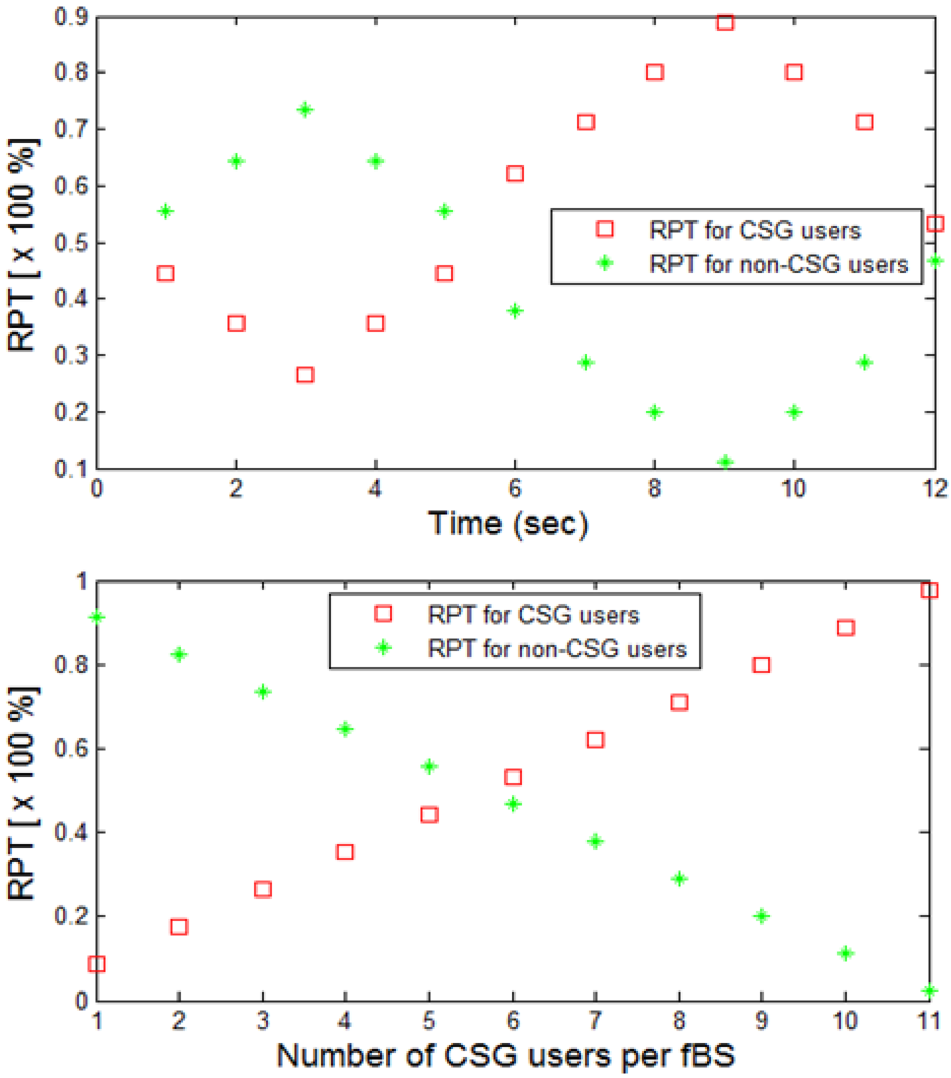

Figure 4.1: (a) Resource Percentage Threshold (RPT) variation for CSG and non-CSG users with respect to time per fBS and (b) Comparison of RPT for non-CSG and CSG users by varying only the subscribers

In Fig. 4.1 (a) we show the variation of the resources being shared by non-CSG and CSG users per fBS with respect to time. For instance, at time

= 3 sec 26.68 % of the resources are dedicated to CSG users and 73.32 % is reserved for non-CSG users. This is observed when the fBS is serving 3 CSG users as shown in (b). However, at 9 sec more resources are dedicated for CSG users as shown by the RPT value of 88.93 %. What can be deduced here is that at any time instant the will be a variation of resources reserved for non-CSG users or resources dedicated for CSG users since reserving resources always depends on the number of CSG users currently being served by the fBS at time t. As it can be noted in Fig. 4.1 (b), the fBS cannot reserve resources for non-CSG users if there are more than 11 CSG users at time t. Fig. 4.1 (b) illustrates the variation between the values of γ_n^{th} and ρ_n as the number of admitted CSG users increases. What can be observed is that as fBS_n keeps on admitting CSG users, the value of γ_n^{th} decreases to $\gamma_n^{th} \leq 0$ when users are greater than 11. Nevertheless, the possibility of having an overloaded fBS (a mass of CSG users) might not be common in a dense environment when the fBSs use hybrid access mode.

Fig. 4.2 illustrates the performance of our CPA + GP and CPA + HFC + GP schemes compared with the modeling scheme used in [14] based on UL capacity per non-CSG user in fBS_n. Both proposed schemes use GP for power allocation, CPA + HFC + GP and CPA + GP. In [14], the UL capacity was analyzed by using Conventional fBS, single user detector (SUD), to determine co-channel interference as well as received SINR and a closed loop power control.

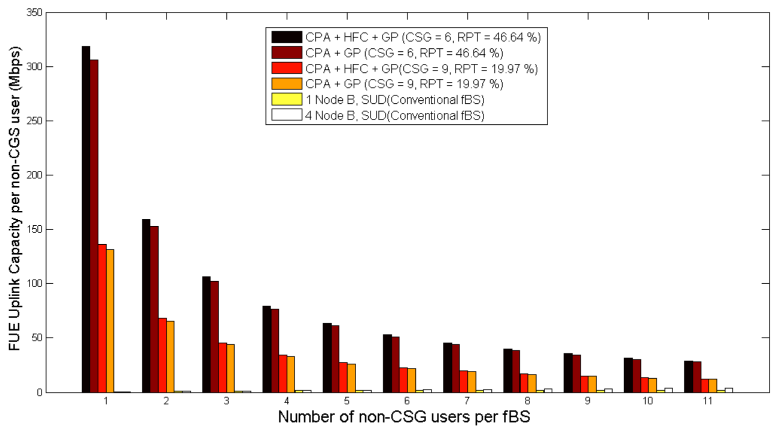

Figure 4.2: FUE Uplink Capacity per non-CSG user per fBS

From our proposed schemes it is observed that the achievable UL capac-

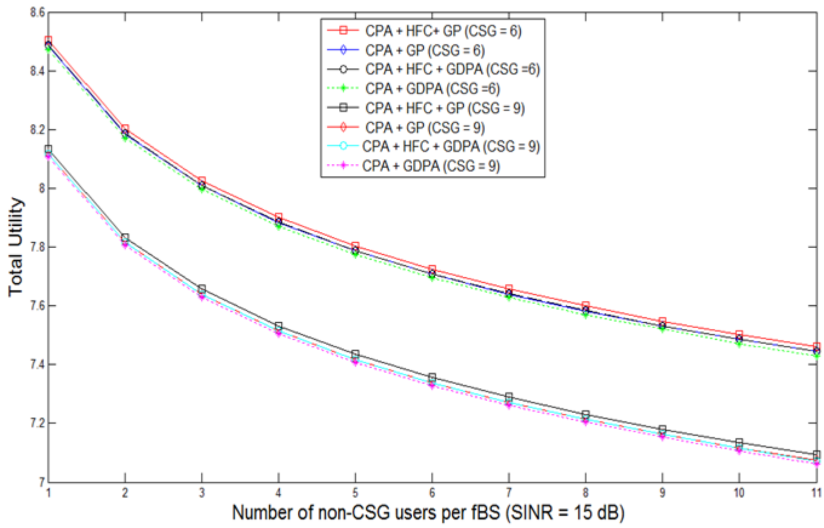

Figure 4.3: Total Utility for non-CSGs (subscriber(CSG) = 6 and 9) at SINR = 15 dB and FUEs use GDPA to adapt their uplink transmission power.

ity for non-CSG users decreases with increase in the number of non-CSG users being served suggesting that FUEs performance is limited by interference from other FUEs. However, by combining clustering with our proposed power allocation scheme, CPA +GP, the UL capacity can be greatly improved as clustering reduces the interference impact among FCs. The CPA + HFC + GP outperforms the other schemes and enables the ability to serve a large number of non-CSG users while still serving CSG users. For example, when the fBS is serving 9 CSG users (note: CSG = 6 and CSG = 9 were randomly selected), the resources reserved for Non-CSG users is 19.97 % and this results to about 11 non-CSG users being served concurrently with an UL capacity of more than 10 Mbps. The poor performance for conventional fBSs results from noise saturation at the receiver due to the increase in the number of accepted FUEs. On another note, their simulation environment was based on 5MHz bandwidth and they assume that there were no internal walls while in our case we did consider wall penetration loss and shadowing.

We compare our non-cooperative game with a centralized scheme in different scenarios, that is, an environment where fBS have not been clustered and where fBS have been clustered assuming all the fBS are using our proposed power allocation scheme, CPA and FUE use our proposed GDPA scheme. We use the same system parameters as given in Table II and [17]. Our comparison is based on how the total utility is affected by the increase of non-subscribers per fBS at different SINR values and varying subscribers at

fBS_n. In this case, the utility represents how the FUEs compete fairly for resources trying to maximize their UL capacity using open loop power control standard.

In Fig. 4.3, 4.4 and 4.5, CPA + HFC + GP and CPA + GP represents the scenario where FUEs use a centralized power allocation scheme in a clustered and non-clustered environment. CPA + HFC + GDPA and CPA + GDPA represents the scenario where FUEs use our proposed distributed power allocation scheme in a clustered and non-clustered environment. Intuitively, we expect our proposed GDPA scheme to work similar to the centralized power control in an environment where FCs are not clustered.

In Fig. 4.3, we compare the utility of our proposed schemes when the

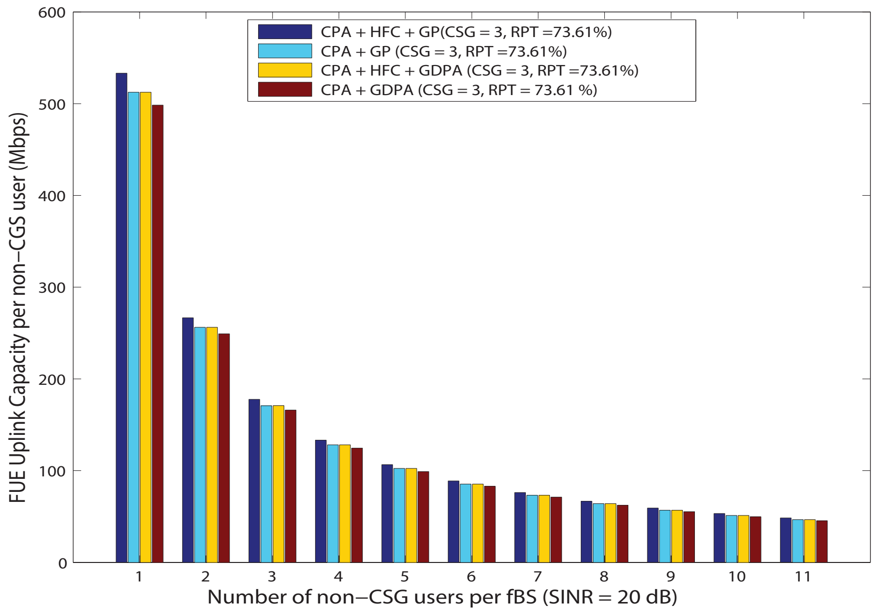

Figure 4.4: FUE Uplink Capacity for non-subscribers (subscriber(CSG) = 3) at SINR = 20 dB and FUEs use GDPA to adapt their uplink transmission power.

fBS serve 6 and 9 CSG users at SINR = 15 dB. From the total utility results we can observe that when FUEs use our proposed GDPA scheme to try and find the UL transmission power that will maximize their UL capacity, users using our proposed scheme cannot perform better than users using the centralized power allocation scheme in a clustered environment due to limited information exchange between users and serving fBS. The total utility drops as the number of CSG increase (CSG = 9) due to the fact that as the number of CSG increases, the reserved resources for non-CSG users are reduced as

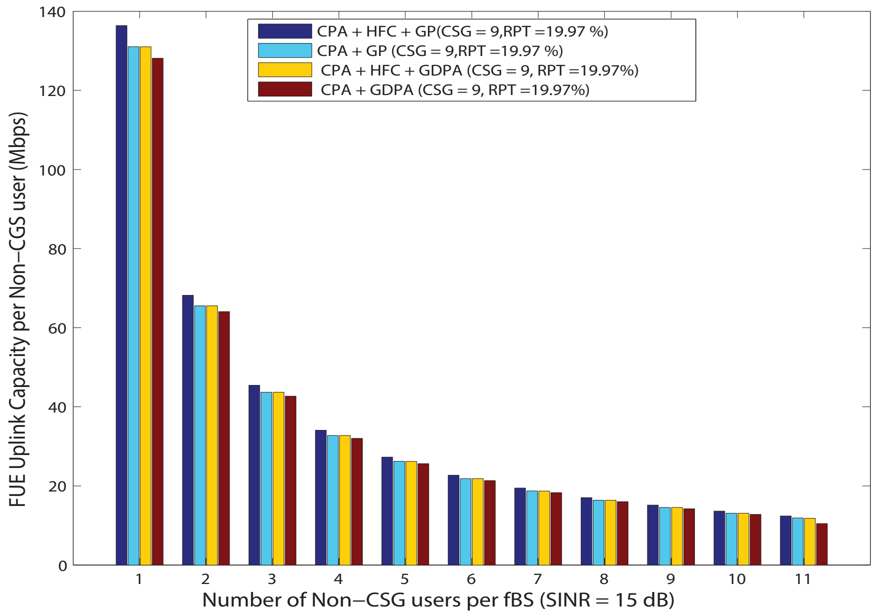

Figure 4.5: FUE uplink Capacity for non-subscribers (subscriber(CSG) = 9) at SINR = 15 dB and FUEs use GDPA to adapt their uplink transmission power.

they are secondary users.

In order to confirm our expectations, we further consider different environment with varying SINR values and subscribers being served by the fBS. In Fig. 4.4 and 4.5 we compare the UL capacity at different SINR values and at different CSG users. In Fig. 4.4, we consider an environment where the fBS serve 3 CSG users at 20 dB. In this case more resources are reserved for non-CSG users compared to Fig. 4.5 where less resources are available for non-CSG users. What we can observe is that, at different SINR and CSG we still obtain similar results between non-CSG users in a clustered environment using our GDPA scheme (CPA + HFC + GDPA) compared with non-CSG users using a centralized power allocation scheme (CPA + GP) in a non-clustered environment. The obtained UL capacity is almost the same. What can be observed is that the margin difference between CPA + HFC + GP and CPA + GP is 3.8 %, CPA + GP and CPA + HFC + GDPA is almost the same, and CPA + HFC + GDPA and CPA + GDPA is 7.4 % as observed when the fBS serve 9, 10, 11 non-CSG users. Our proposed distributed power allocation scheme performs a little bit worse compared to the centralized case which has optimal performance, CPA + HFC + GP, the scheme where FUEs use a centralized power control in a clustered environment. This is due to limited information exchange, reduction of resources reserved for non-CSG users as the number of CSG users being served increases. Since our proposed scheme can be realized by a decentralized power allocation algorithm, it shows meaningful results compared with the centralized case.

Chapter 5

Conclusion

In this work, a centralized power allocation (CPA) scheme that reserves resources for non-CSG users is proposed and a novel sub-optimal clustering scheme for hybrid cells where the femto head elected on timestamp forms the cluster has also been proposed. Simulation results gives us evidence to conclude that the proposed schemes can maximize the uplink capacity for non-CSG while also increasing the number of non-CSG users being served, that is, the centralized scheme can be used for resource allocation in hybrid cells where femtocells have been clustered using the proposed hybrid femtocell clustering (HFC) scheme. By allocating more resources to more users and less resources to fewer users we maximize the fairness. However, the number of non-CSG users that can be served simultaneously with CSG users is limited when the fBS is serving more CSG users at a time. Nevertheless, hybrid cells allows both CSG and non-CSG users to connect to any fBS with a strong signal strength. The advantage of the proposed schemes is that it overcome the challenges of how to design an effective hybrid access scheme to equilibrate the quality of service for non CSG and CSG users thus optimizing non-CSG users uplink capacity, and it also guarantees the CSG minimum data rate such that fBSs are not affected by sharing the resources with non-CSG users and it is suitable for a distributed environment similar to an enterprise environment since each fBS will run the CPA algorithm on its own as they are uncoordinated. Furthermore, a distributed power allocation scheme is proposed where femto users try to adjust their uplink transmission power trying to find the optimum power that will maximize their utility function. Under feasible assumptions, the channel capacity can show the existence of the pure strategy Nash Equilibrium. It allows femto users to have full control of their transmission power and in that way able to maximize their utility function. In addition, it reduces the latency at the fBS such few messages can be exchange between the FUE and fBS. The numerical results presented here suggests the adoption of the proposed centralized power allocation scheme and the clustering scheme.

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Biography

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