國立交通大學

電機資訊國際學位學程

碩士論文

自我組織毫微蜂巢式基地台基於干擾之分群

Interference Based Clustering for Self-Organized Femtocells

研究生：Insya Mounavaraly,沐映喜

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Abstract

To achieve the goal of higher transmission rate and seamless internet access everywhere, femtocells are foreseen to be a key fixed-mobile convergence technology. As femtocells will be user-installed, self-organization techniques are required to automatically integrate themselves into the network and avoid co-femtocell interference, especially in urban dense deployment area. To cope with these challenges, a two-step femtocell-cooperation algorithm has been designed in this thesis. The first step is the clustering phase, during which femtocells will form groups with other femtocells according either to femtocell Base Station or to femtocell user interference measurements, thus setting two types of methods. Then, a frequency allocation scheme is proposed based on the grouping distribution; it corresponds to the tuning phase. The interference based clustering is the key part of this work; it has therefore been studied and evaluated according to several sets of parameters like power threshold or limit member per cluster. The results compare the performance of the two clustering methods with their parameters and show that the femtocell user SINR and the outage probability can be highly improved but at a capacity cost.

自我組織毫微蜂巢式基地台基於干擾之分群

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摘要

為了達到更高的傳輸速率及無痕的網路連接，超微型蜂巢式基地台(femtocells)被認為是固定式與移動式技術整合的關鍵。超微型蜂巢式基地台由使用者安裝，必須具備自我組織管理的能力，可以自動化將不同的基地台結合在一起，特別是在城市裡密集部署的地方，以避免使用相同通道造成的干擾。為因應上述問題，在本篇論文中將提出一個兩階段性超微型蜂巢式基地台協力的演算法。首先在分群方面，根據基地台或是使用者對干擾的量測，有兩種方法將其彼此分組。其次，根據群組的分布，設計出頻帶分配機制。在整個研究過程中，如何依據干擾來分群是最關鍵的部分，因此，多種參數例如，功率設置的門檻或是每個群組中基地台個數的限制等，都需要經過縝密的思考及計算。在模擬中，將比較兩種不同分群方式及其對應參數帶來的效能，結果顯示出超微型蜂巢式基地台使用者的 SINR 與中斷概率會有大幅顯著的進步，而代價只需犧牲一點點的系統容量。

Thanks

Since my arrival here in Taiwan, I must say that a lot of people, from Taiwan and my home country, offered me their support and their time to make my stay and my studies go smoothly. A single page will not be enough to express all my gratitude towards all these people. I want to thank all of those who recognize me because it means that somehow you cared. Having spent 18 months in Taiwan, discovering the country, its culture and its people has been a wonderful experience that I will always keep in mind.

First of all, I would like to thank Professor Huang and WINTECH laboratory for having accepted me in their team. It has been a pleasure to work and learn together as well as share ideas and opinions. Everyone tried to help me by lending me time, resource and support so that I could progress in my research and I really appreciate it.

I am also thankful to the EECS department and the International Service Center who handled a lot of issues with me and were always available to offer me many advice. In the same way, I would like to thank my home school, TELECOM SudParis, especially Professor Crespi, for having given me the opportunity to pursue my studies here in NCTU and helped me all the way long.

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To all of you, my success is a part of your success.

Insya Mounavaraly – 沐映喜

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Chapter 1 Introduction

Femtocell has recently emerged to be a leading next-generation-network technology base station capable of reaching the trend for higher throughput, enhanced coverage in indoor areas and larger range of services for end-user in wireless radio access network. Achieving these promising benefits have drawn a lot of attention in the research and industry community as many challenges need to be addressed before successfully deploying the femtocell network.

Among them is the femtocell to femtocell interference issue which turns out to be severe when a large amount of femtocells are deployed in a limited small area, for example in urban scenario. Besides, femtocells are installed by the subscribers themselves, therefore self-organization networks (SON) methods are developed to replace individual conventional planning and optimization procedures that are no longer conceivable for future wireless access networks. In this thesis, we will discuss these two issues and present a clustering algorithm to mitigate the co-femtocell interference in a self-organized manner.

The rest of this thesis is organized as follows: we will review the femtocell technology and the SON concepts respectively in chapter 2 and 3. In chapter 4, we will introduce the clustering algorithm based on femtocell BS or user measurements as a solution to interference mitigation and frequency allocation. The chapter 5 will describe the simulation scenario and platform that are used to provide the results shown and discussed in the chapter 6. Finally, conclusions and future work are summarized in chapter 7.

Chapter 2 Overview of Femtocells

2.1 Goal and Generalities

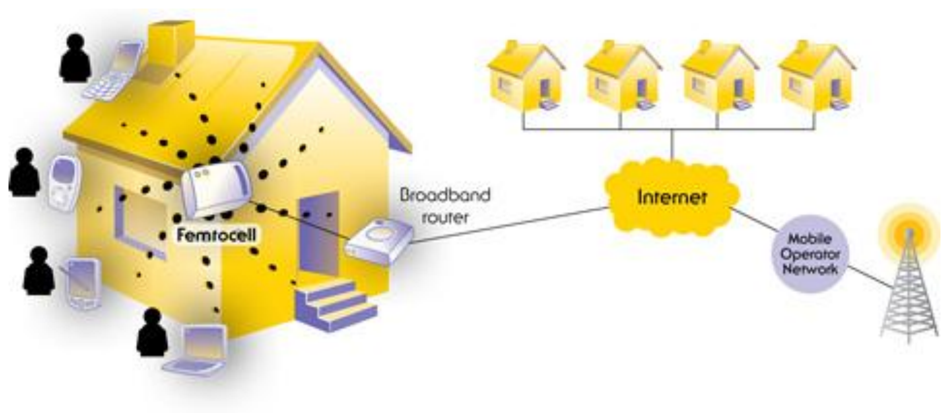


Figure 1 What is a Femtocell? [1]

A femtocell is a low-cost, low-power cellular indoor base station (BS) connected to a network operator through a backhaul link such as a Digital Subscriber Line (DSL) or an optical fiber [1]. End-customers can benefit from the coverage provided by the femtocells using a mobile network standard like Universal Mobile Telecommunications System (UMTS), Wireless Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE). Femtocell base station (fBS) is also known as home base station, home access point, or Home NodeB (HnB).

Deployed by the end-users themselves, femtocells are initially designed to extend operator's indoor coverage. Indeed, a survey [2] underlines that femtocells could benefit both end-users and network operators:

- From a user point of view, we can notice that more and more consumers use their mobile phones in the home or in the office even when there's a fixed line available. Therefore with a small indoor base station, the users may enjoy better signal qualities due to the reduced distance between the transmitter and the receiver. It also results in higher throughputs, longer handset battery lifetime and lower transmit power. Besides, the connection to the femtocell will be seamless without changing handsets or mode and at attractive lower prices for the end-users.

- For cellular operators with macrocell deployment, femtocell may work for extend high-rate data coverage. While operators are designed for suburban/rural coverage or in building, femtocell provides basic service coverage to home or enterprise. In the highly saturated operators, femtocell provides localized capacity to increase overall capacity. Moreover, femtocells also reduce the system cost, capital and operational expenditure, since they are purchased and maintained by the users.

2.2 Interference Mitigation

However, to accomplish these benefits, operators have to face some challenges in order to properly and successfully deploy femtocells into their existing network. Among these challenges is the interference management.

Indeed, a femtocell network will constitute a second layer on the top of the macrocell layer therefore creating interference to the macrocell, defined as cross-layer interference, as well as to femtocells, classified as co-layer interference. In the rest of this paper, we will use the term co-femtocell interference to designate femtocell to femtocell interference, in other words the interference undergone by a femtocell user from the other femtocells.

Besides, femtocells can be configured in two ways to restrict their access to limited and specific users. Thus, allowing femtocells to operate on the same channels as the macrocell – co-channel scenario - instead of separate channels – adjacent scenario – can severely degrade the overall network performance making the benefits mentioned non-feasible.

In addition to that, it is most likely that the owners of a femtocell BS will prefer not to share the access to every users but selected users – private and closed access – compared to letting anyone use their bandwidth – public and open access. This means that only users which are registered in the access list of a femtocell BS can access it. The mobile users who cannot connect to these closed access femtocells therefore suffer from large interference from these later.

Interference is even more important since the indoor-outdoor penetration loss is not enough to prevent signal leakage. This can lead to a dead zone scenario, i.e. a coverage hole where users cannot get a connection to their serving BS. The figure below illustrates all the possible interference cases.

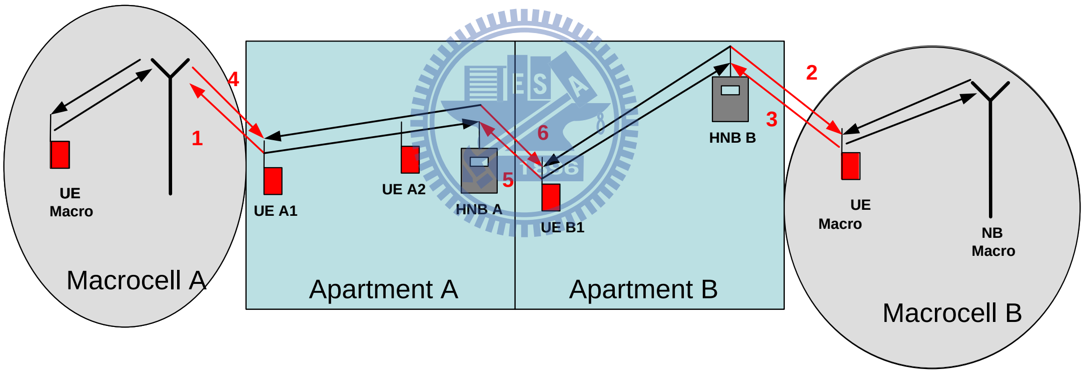


Figure 2 Interference scenarios [3]

If we further consider the femtocell to femtocell interference case in its worst scenario, a dense deployment in urban areas shows that the interference level may even be unacceptable for femtocell users themselves. The reason is that even if a femtocell user (UE) is receiving a better signal from another femtocell BS than its serving femtocell BS, handover from the serving to the new one will not be possible in private access femtocell case.

For all of these reasons, the femtocell to femtocell interference, referenced in this thesis as co-femtocell interference, occurring in this specific dense deployment scenario, has been chosen as the focused topic to study in this thesis.

Chapter 3 Overview of Self-Organization-Network

3.1 Introduction

The multiplication of wireless communication devices and technologies operating on the same or different carriers leads to multiple parameters with high inter-dependencies, multiple radio resource management techniques performed at different time and high complexity to achieve maximum utilization of these wireless access networks.

The general idea of Self-Organization Network (SON) is to integrate network planning, configuration and optimisation into a single and mostly automated process, requiring minimal manual intervention [4].

Self Organizing Network can be divided into 3 main parts: self-configuration, self-optimization and self-healing that help maintain and optimize the network performance without human intervention.

Self-configuration is the initial process triggered at the network entry of a new site or a new service that requires the settings of the radio parameters, e.g. transmit powers, antenna gain and the detection of the surrounding environment. Continuous measurements of the radio channels, traffic and user mobility aspects are performed to collect valuable information for the self-optimization process. This latest will be in charge of deriving optimized parameters, including antenna parameters, power settings, scheduling and more to achieve better coverage, capacity or other specific objectives. In case of abnormal behaviour or failure of the BS, self-healing methods aim to resolve the loss of coverage/capacity induced in these cases by adjusting its parameters and report to the surrounding cells to recover the initial configuration.

These elements have been summarized in the picture below from [4].

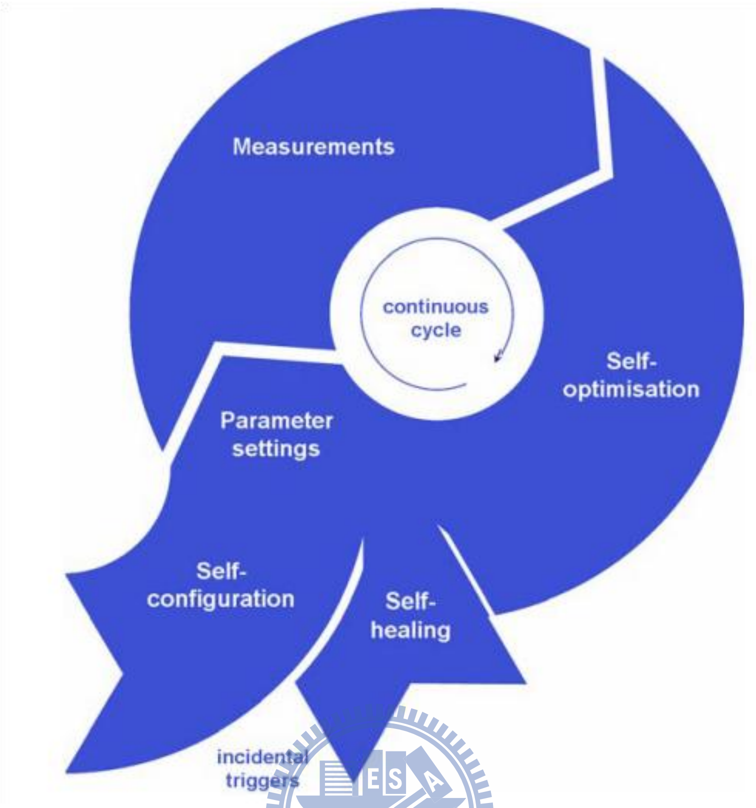


Figure 3 Self-Organization functions [4]

3.2 SON Femtocell

In WiMAX standard definition, SON functions are intended for BSs (e.g. Macro, Relay, Femtocell) to automate the configuration of BS parameters and to optimize network performance, coverage and capacity. The scope of SON is limited to the measurement and reporting of air interface performance metrics from MS/BS, and the subsequent adjustments of BS parameters [6].

These parameters can be related for instance to radio resource management, mobility management, interference mitigation, load balancing, coverage and capacity optimization.

Femtocell is regarded as a SON enabled device for several reasons. First, femtocell must be a Plug-&-Play and user-friendly device as it will be purchased, installed and maintained by the end-users. As a consequence, the operator doesn't have any control on the location of the femtocell and the common, one-by-one, network planning and optimization methods are not applicable. This also leads to the requirement of remote control capabilities of the femtocell through the network of the operator to address failed self-optimization attempts by keeping the operator cost of the network low. Lastly, many surveys expect femtocells number could reach hundreds per macrocell, in such kind of dense deployment, scalability is therefore a requirement.

As demonstrated above, SON functionalities need to be designed to deploy femtocells into the network. This same conclusion has also come up among different standard bodies like 3GPP (3rd Generation Partnership Project) [5], IEEE 802.16x [6], groups and international research projects like NGMN (Next Generation Mobile Networks) group [7] and the European project SOCRATES (Self-Optimisation and self-ConfiguRATion in wirelESs networks) [8]. These research groups are now working together to progress towards this goal not only for femtocell BS but for any type of BS. Thus, a list of SON use cases has been elaborated and is referenced below.

Table 1 Abstract of SON Use cases by NGMN group [7]

Use Case Examples	Short description
Radio Parameter Optimisation	
Neighbour Cell List Optimisation	Optimisation of existing neighbour cell list of a cell with all relevant neighbours and the associated parameterisation in the neighboured cell.
Interference Control	Optimize power and scheduling of sub-tone in downlink with minimal operational effort.
Handover Parameter Optimisation	Optimize handover parameter with minimal operational effort (related to neighbour cell list optimisation)
QoS related parameter Optimisation	Optimise RRM parameter impacting QoS with minimal operational effort
Radio Parameter related Optimization Scenarios with Home eNB	Due to unclear concept of Home eNB the consequences of Home eNB on optimisation is ffs.
Transport Parameter Optimisation	
Transport Parameter Optimisation	Optimize transport parameter with minimal operational effort
Routing Optimisation	Optimisation of data routing in a meshed network
Transport Parameter related Optimization Scenarios with Home eNB	Due to unclear concept of Home eNB the consequences of Home eNB on optimisation is ffs.

Research and industry have already looked into the problem and are still designing self-organization strategies for femtocells. For instance, we can quote:

[11] developed a downlink and uplink power control method, for co-channel femtocell deployment, that achieves a constant femtocell range. Each femtocell sets its power to a value that on average is equal to its closest macrocell received power at a target femtocell radius. It also ensures a low impact on the uplink performance of the macrocell network.

A coverage adaptation is proposed in [12] for UMTS network that uses information on mobility events of passing and indoor users. It optimizes the femtocell coverage in order to minimize the increase in core network mobility signalling.

In [13], a detailed system level performance evaluation for mobile WiMAX systems with self-organizing femtocells is reported and different frequency allocation scheme are proposed and compared. In their SON scheme, a femtocell network controller assigns the frequency segment to a femtocell BS based on its measurement reports and the frequency assignments that have been made in its adjacent femtocells. The schemes proposed are implemented in a centralized manner.

OFDMA Femtocells has also been subjected to self-organization study in [14] where they proposed two approaches to achieve frequency channel assignment. They make use of either messages broadcast by the femtocells or measurements reported by the users during the sensing phase, then in the tuning phase, they provide a solution for the frequency assignment problem.

Chapter 4 Algorithm design

4.1 Goal

The question we are trying to answer can be summarized as follows:

How to control co-femtocell interference in a dense deployment case using self-organization techniques?

In the literature and the standard bodies [14], we can find two types of approach.

- Ideally, to mitigate cross- and co-layer interference, there should be a central entity, usually a SON server that collects and stores the monitoring information of the different operator network elements in a huge database. It may also be in charge of intelligently telling each cell what parameters to use. Using the information collected, it should find an optimal or a good solution within a short period of time. However, since the number and position of the femtocells are initially unknown due to the individualistic nature of the femtocell BS, this approach poses some hard problems. The co-existence of increasing numbers of femtocells makes the optimization problem very complex and delay issues arise when trying to facilitate the femtocells communication with the central SON server through the backhaul. Besides, the network environment may change quite rapidly, therefore making centralized assignments obsolete.
- A second approach to deal with the same issue is to use a distributed method where each cell manages its own parameters. It is thus more suitable than the centralized method in order to achieve self-organization. In a non-cooperative solution, each femtocell would plan its parameters, for example its channels, so as to maximize the throughput and QoS for its users. Furthermore, this would be done independently of the effects that its allocation might cause to neighbouring

femtocells, even if it supposes a larger interference. On the other hand, in a cooperative approach, each femtocell BS gathers information about its neighbouring femtocells and may perform its allocation taking into account the effect it would cause to its neighbours. In this way, the average femtocells throughput and QoS, as well as their global performance can be locally optimized.

Thus, having many femtocells close to each other, we had the idea of using cooperation between femtocells as a possible method to solve our problem. In fact, femtocells BS can identify its neighbouring femtocell BS and macrocell BS either by sensing capabilities, user (UE) measurements reports or through the backhaul link. With this knowledge, each femtocell can analyze among its neighbours which ones are contributing the most to the interference it and its femtocell users are receiving. After identifying these target femtocells, they could start cooperating and communicating together. By creating these clusters of femtocell cooperation, we will show that co-femtocell interference and outage probability can be decreased by allocating different channels to the femtocells of a same cluster. In this proposed clustering methodology, it is important to set the correct thresholds and conditions that trigger the need of interference mitigation, as well as a maximum number of femtocells that can cooperate in a group in order to limit the communication between femtocells and maintain a reasonable capacity.

In the following parts, we will explain this clustering algorithm, paying special attention on how the femtocell BS does join a cluster of cooperation, under which conditions or constraints and what the resulted frequency allocation scheme designed is.

4.2 Scenario description

To investigate the femtocell to femtocell interference in dense deployment, we chose to consider the urban model referenced by 3GPP in their process of standardization for LTE.

This scenario, called dense-urban HNB modelling, has been specified as a possible model to study interference issues when deploying femtocells onto a macrocell layer.

In a dense-urban HNB modelling [10], a block represents two stripes of apartments, each stripe has 2 by N apartments (N = 10 in the example illustrated in Figure 4). Each apartment is a 10m X 10m square. There is a street between the two stripes of apartments, 10m wide.

We chose to analyze the worst case scenario, in which each apartment has a femtocell BS active with one active femtocell UE and a percentage of macrocell UE indoor.

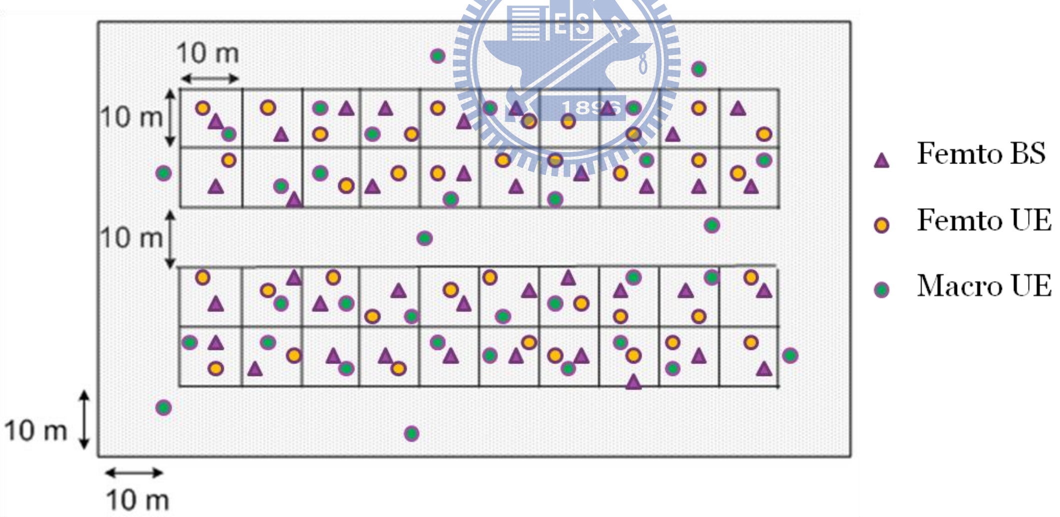


Figure 4 A femtocell block with femtocell BS and UEs

4.3 Femtocell BS & Femtocell UE based measurements

With this picture of the scenario, we designed a clustering algorithm based on different type of measurements. The femtocell BS measurement approach takes, as input information, the received power from each femtocell BS to each of the other femtocell BS. With its sensing capabilities, a femtocell can easily get this 1xN femtocell to femtocell received power matrix. Using this information we can identify which femtocell BS has its coverage overlapped with which other femtocell BS. We will reference this measurement as *femtocell based*.

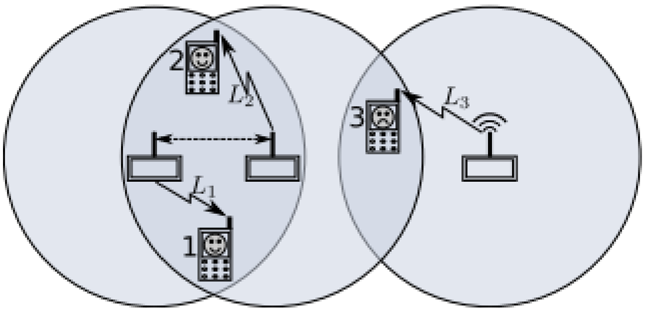


Figure 5 Sensing Problem in non-overlapping femtocells [14]

The drawback of this method is illustrated on the picture above. Indeed, two femtocells that do not overlap cannot detect each other, while the femtocell UE will be facing interference from this neighbour femtocell BS.

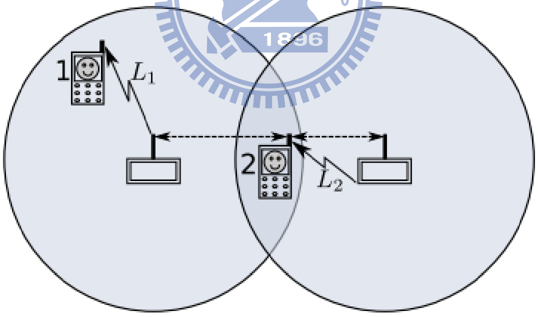


Figure 6 UE measurement report [14]

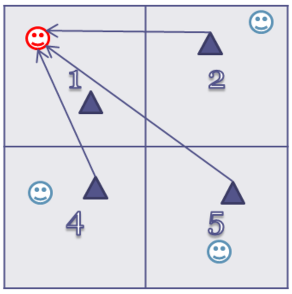
To cope with this issue, a second approach is to take this same information from the femtocell UE which is going to move in the indoor femtocell and report the signal strength from its serving femtocell and its neighbouring femtocells. We then can get from each femtocell UE a 1xN femtocell UE to femtocell BS Received Power matrix. This approach will be referenced as a *user based* one.

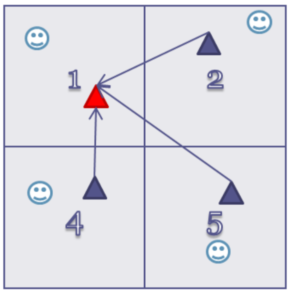
In this method, the user is subject to mobility and reporting measurements too frequently may increase the over-the-air traffic, compared to the previous method where the femtocell BS is not supposed to move in duty. That is why we will assume that the femtocell UE is not moving at high speed as he is in his home or office but at pedestrian speed.

A summary table of both measurements methods is introduced below:

Table 2 Femtocell and User based comparison

Femtocell UE based		**Femtocell BS based**	
Advantages	**Drawbacks**	**Advantages**	**Drawbacks**
Higher Information accuracy, real time	Femtocell user mobility issue	Low mobility of the femtocell BS	Less interference information accuracy
Detect overlapped and non overlapped femtocell BS	Increase air link messages	Less subject to information change	Detect only overlapped femtocell BS





4.4. Interference based clustering

In both proposed clustering methodology, it is important to set the correct thresholds and conditions that trigger the need of interference mitigation as well as a maximum number of femtocells that can cooperate per group in order to limit the communication between femtocells and maintain a reasonable capacity. Both clustering methods that will be introduced below create non-overlapping clusters, meaning that any femtocell BS belong to one and only one cluster at a given time. This is to simplify the parameters allocation process of the members of the clusters and limit the amount of information to be exchanged among the clusters.

4.4.1 Femtocell based clustering

The first method explained is based on the received power from each femtocell BS to each of its neighbouring femtocell BS. We will call this method *femtocell based clustering*.

To start with, we need a measurement matrix which gives us the basis to select for each femtocell BS its interfering neighbouring femtocell BS. Upon it, we build up an algorithm which groups interfering femtocell BS together to enable cooperation. We first notice that each femtocell BS have many candidates – N-1 potential candidates – to be in a group with, therefore we introduce two constraints to be able to select the candidates:

- A tuneable power threshold: for each femtocell, we only keep the femtocells BS that have a received power higher than the power threshold *MinPower*.
  - Formula: :

$$\begin{cases} \forall i \neq j \in N,\ if\ P_{femto}\,(i,j) \leq P_T\ , then\ P_{femto}\,(i,j) = -\infty \\ \forall i = j \in N, P_{femto}\,(i,j) = -\infty \end{cases}$$

  - P_T = *MinPower* = {- 30dBm, - 40dBm, -50dBm, ...}
  - When $P_{femto}\,(i,j) = -\infty$, it means that femtocell j doesn't interfere femtocell *i* and is therefore not a potential candidate.
- A maximum number of femtocells per group: this is to prevent having one big group with every femtocells BS cooperating with all the others which would not make any sense.
  - *MaxMember* = { 1, 2, 3, 4, ...}
  - Note: if *MaxMember* = 1, there is in fact no group.

Of course, these constraints will affect the results. We will therefore observe their influence by varying their values throughout the simulation.

With *MinPower*= -60dBm, the N*N matrix, named P_{femto}, is transformed as follows:

	1	2	3	4	5	6	7	8	9	10
1	-Inf	-49.5122	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
2	-49.5122	-Inf	-49.5111	-49.0439	-58.8999	-Inf	-Inf	-Inf	-Inf	-Inf
3	-Inf	-49.5111	-Inf	-38.7558	-52.4693	-Inf	-Inf	-Inf	-Inf	-Inf
4	-Inf	-49.0439	-38.7558	-Inf	-41.5909	-53.2277	-Inf	-Inf	-Inf	-Inf
5	-Inf	-58.8999	-52.4693	-41.5909	-Inf	-34.5842	-55.3495	-Inf	-Inf	-Inf
6	-Inf	-Inf	-Inf	-53.2277	-34.5842	-Inf	-42.5096	-Inf	-Inf	-Inf
7	-Inf	-Inf	-Inf	-Inf	-55.3495	-42.5096	-Inf	-38.0888	-47.6619	-Inf
8	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-38.0888	-Inf	-44.6286	-58.2853
9	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-47.6619	-44.6286	-Inf	-35.1448
10	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-58.2853	-35.1448	-Inf

Figure 7 P_{femto}: Femtocell BS to femtocell BS received power matrix

Having set these constraints, here is the clustering algorithm we proposed:

```
while n≠N
        if group (n) not full
                m=femto ID of the highest received power by n (0 if no)
                while m≠0
                        if nbr_members(group(n))+nbr_members(group(m)) > MaxMember or
                        group (n) = group (m)
                                P_femto(i,j) = −∞
                                m= femto ID of the next highest power received by n
                        else
                                All members of group (m) merge into group (n)
                                m=0
                        endif
                endwhile
        endif
        n=n+1
endwhile
```

'group' is a table that indicates in which group number each node is. By default, there are as many groups as femtocells BS. At initialization, there is one femtocell BS in each group, i.e. femtocell 1 in group 1, femtocell 2 in group 2 … femtocell j in group j.

Table 3 Group table

Femtocell ID	1	2	3	…	39	40
Group ID	1	2	3	…	39	40

'nb_members' refers to a table which registers the number of member for each group. Following from the previous one, at initialization, each group will only have one member and the table will be filled with value 1.

Table 4 Nb_members table

Group ID	1	2	3	...	39	40
Number of members	1	1	1	...	1	1

It is noteworthy to remind that this clustering method is used to enable femtocell BS that encounter interference from neighbouring femtocells to cooperate with them. By cooperation, the femtocells can mitigate interference by choosing specific radio frequency parameters, like different frequency bands. As a matter of fact, it is necessary to find out which femtocells could cooperate with which other. It is the purpose of this interference based clustering algorithm.

The series of pictures below describes the running of the algorithm:

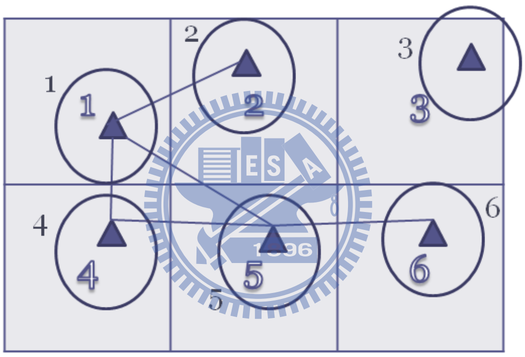


Figure 8 Femtocell based graph

In the following, we will designate femtocell BS by nodes. Let's say that we choose to browse the nodes in a fixed order, from node 1 to node 6, left to right, top to bottom. The measurement matrix can be represented with a non-oriented graph where node *i* and node *j* are linked if $P_{femto}\,(i,j) \neq -\infty$. In our example, we will choose *MaxMember* = 3 and *MinPower* = -60dBm. At the beginning, we have each node in its ID group so each group only has one member.

We start with node 1. We check the measurement table at $P_{femto}\,(1,j)\ \forall j$, and look if there is a non infinite value. This latest means that node 1 receives power from another node at a power higher than the power threshold. In other words, it means that this other node could be a potential threat and interference provider to node 1. In the illustration, node 1 has three potential candidates, namely nodes 2, 4 and 5. Node 1 will try to join the group of the node it receives the most power from among these 3 candidates nodes. Let's say it is node 4. Before accepting this merging request, two things have to be checked:

- ✓ if node 4 is not already in the same group as node 1,
- ✓ if the merging will not cause the sum of the members of both groups to exceed the limit number *MaxMember*:

$$\text{nbr\_members}(\text{group}(1)) + \text{nbr\_members}(\text{group}(4)) \leq MaxMember$$

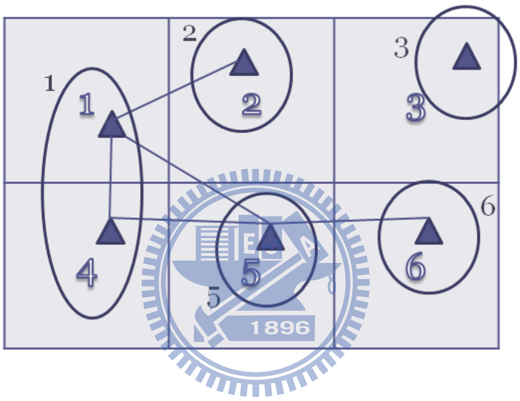


Figure 9 Femtocell based clustering - step 1

Here we have: node 4 belongs to group 4 which has only one member. Moreover, the sum of the number of elements from node 1 and 4's respective groups is below *MaxMember*, which is 3. The merging is therefore possible. Node 1 and node 4 are now in the same group, group 1. The merging is from the candidate node to the requesting node, so the candidate node moves from its original group to the new group.

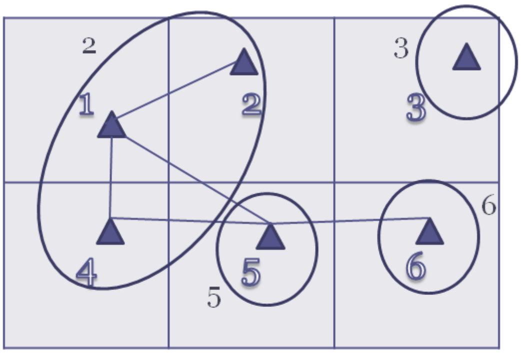


Figure 10 Femtocell based clustering – step 2

The next node is node 2. It only senses node 1. Node 1 belongs to group 1, which has two members. Since the sum of the members of group 2 and group 1 is still inferior to the maximum number of members allowed (*MaxMember*), the merging is acknowledged. Node 1 and node 4 join node 2 in group 2.

Node 3 doesn't sense any of its neighbours at a power higher than *MinPower*, it will therefore not engage any grouping procedure.

Node 4 cannot group with any other node as it is in a full group: group 2. Thus, we jump to the next node.

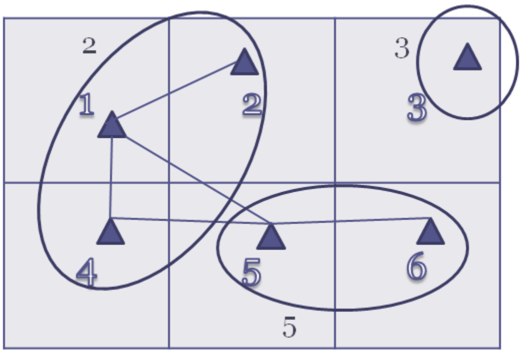


Figure 11 Femtocell based clustering - result

Node 5 senses node 6, and particularly node 4. Node 4 belongs to a full group already; node 5 cannot join its group. Node 5 will check its second candidate, node 6. As this latest has no constraint of member limit yet, they can form a group together.

Finally, node 1, 2 and 4 are in group 2, node 5 and 6 are in group 5 and node 3 is in group 3.

4.4.2 User based clustering

A second way to group the femtocell BS is to refer to the femtocell user information and interference sensitivity at its current location. With this method, we may have less and smaller groups.

Regarding this method, the measurement matrix is changed to the received power from each femtocell BS to each femtocell user, $P_{femtoUE}$. The power threshold is therefore changed to a power margin. The femtocell user will compare its serving femtocell BS received power to the signals it receives from the other femtocell BS within a power margin, *MarginPower*, of x dB. x spans from 5 to 15 dB.

- Formula:

$$\begin{cases} \forall i \neq j \in N,\ if\ P_{femtoUE}\ (i,j) \leq P_{femtoUE}\ (i,i) - M\ , then\ P_{femtoUE}\ (i,j) = -\infty \\ \forall i = j \in N, P_{femtoUE}\ (i,j) = -\infty \end{cases}$$

- M = *MarginPower* = {5 dB, 10 dB, 15 dB, ...}

The clustering algorithm is thus the same as the previous one but based on the femtocell user measurement matrix *MinPower* is changed to *MarginPower* whereas the *MaxMember* parameter remains unchanged.

The next picture shows the resulting matrix with *MarginPower* = 15 dB.

Femtocell BS

Femtocell UE	1	2	3	4	5	6	7	8	9	10
1	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
2	-56.493	-Inf	-43.9545	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
3	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
4	-Inf	-53.4793	-44.8955	-Inf	-54.8982	-Inf	-Inf	-Inf	-Inf	-Inf
5	-Inf	-Inf	-Inf	-42.9495	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
6	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
7	-Inf	-Inf	-Inf	-Inf	-Inf	-49.194	-Inf	-Inf	-Inf	-Inf
8	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf
9	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-50.1759	-Inf	-46.9125
10	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf	-Inf

Figure 12 Femtocell BS to femtocell user Received Power Matrix

Note that this matrix is a non symmetric matrix. Indeed, a femtocell user *i* may sense interference from femtocell BS *j* without having the opposite case for femtocell user *j* towards femtocell BS *i*.

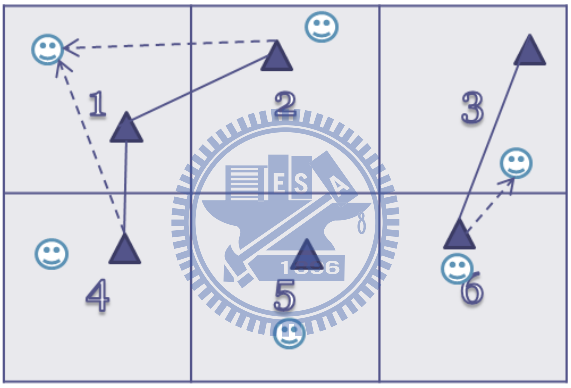


Figure 13 Femtocell user based graph

A noticeable feature of the user based scheme is that it may sometimes force cooperation. For instance on the figure 13, femtocell BS 2 may have to cooperate with femtocell BS 1 because femtocell user 1 is suffering interference from FBS 2, though femtocell user 2 is not having any interference issue. Nevertheless, it is a good solution to detect non-overlapping interfering femtocells and therefore to mitigate the interference received at the femtocell users instead of the femtocell BS.

Besides, since the user is moving inside the apartment, he may ask his serving femtocell BS to cooperate with another femtocell BS therefore changing the cluster configuration. It provides more real time and accurate information of the femtocell user interference level.

4.4.3 Clustering preliminary results

Before running any system performance simulation, we first tried out the two different clustering methods with the various parameters in the specific femtocell deployment, described earlier. The pathloss model applied is detailed later in section 5.31.

The better way to have a look at the clusters is to get some graphic results. The legend is as follows:

-each femtocell BS is represented by a circle,

-each femtocell user is represented by a cross,

-all femtocell BS in a same group are circled together and bear the same colour,

-the ID of the group is the upper number, beside the femtocell BS,

-the order in which the femtocell BS or the femtocell user (depending on the method implemented) triggered the algorithm is notified below the ID of the group.

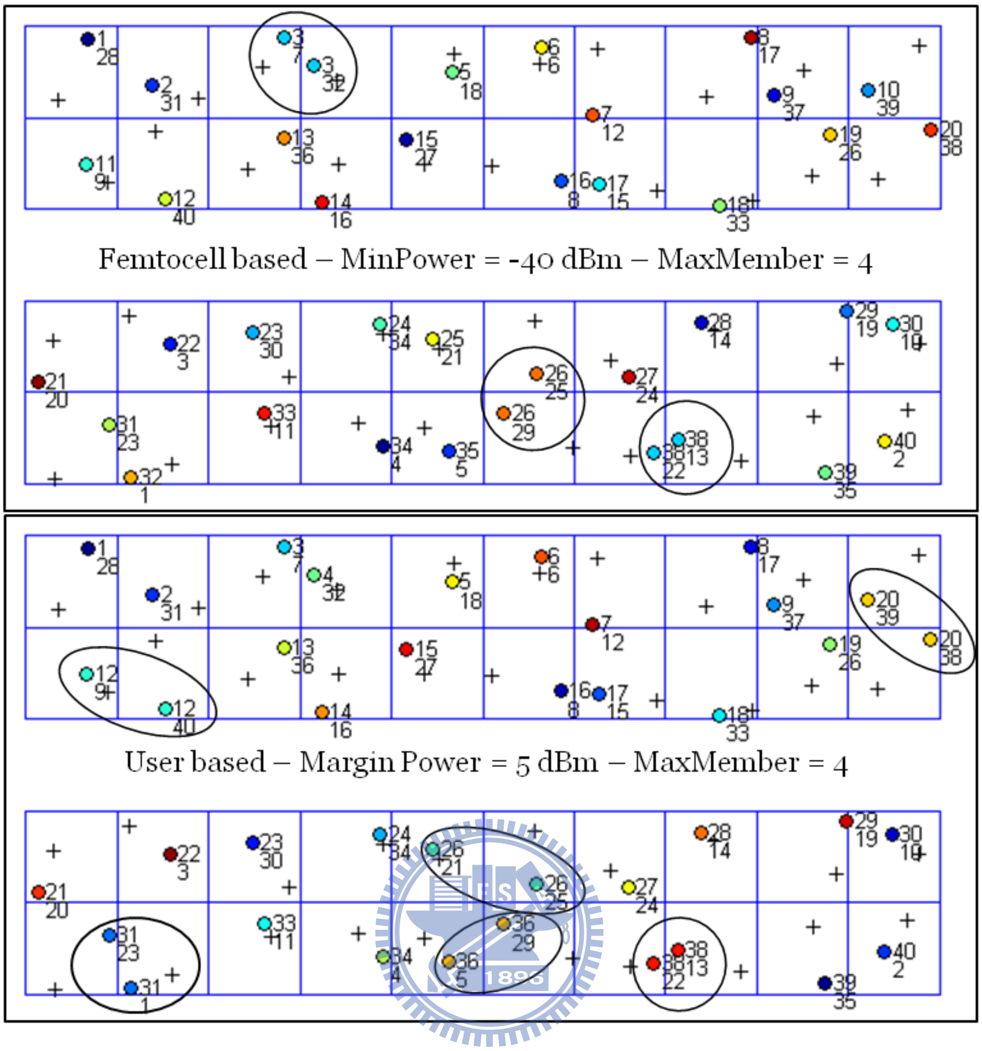


Figure 14 Femtocell based clustering versus user based clustering

As we can see, for the same browsing order of the clustering process and the same limit of members per cluster, the groups formed are different.

If we try to increase the level of the power threshold, we will indeed end with more clusters as we can see on the figure below.

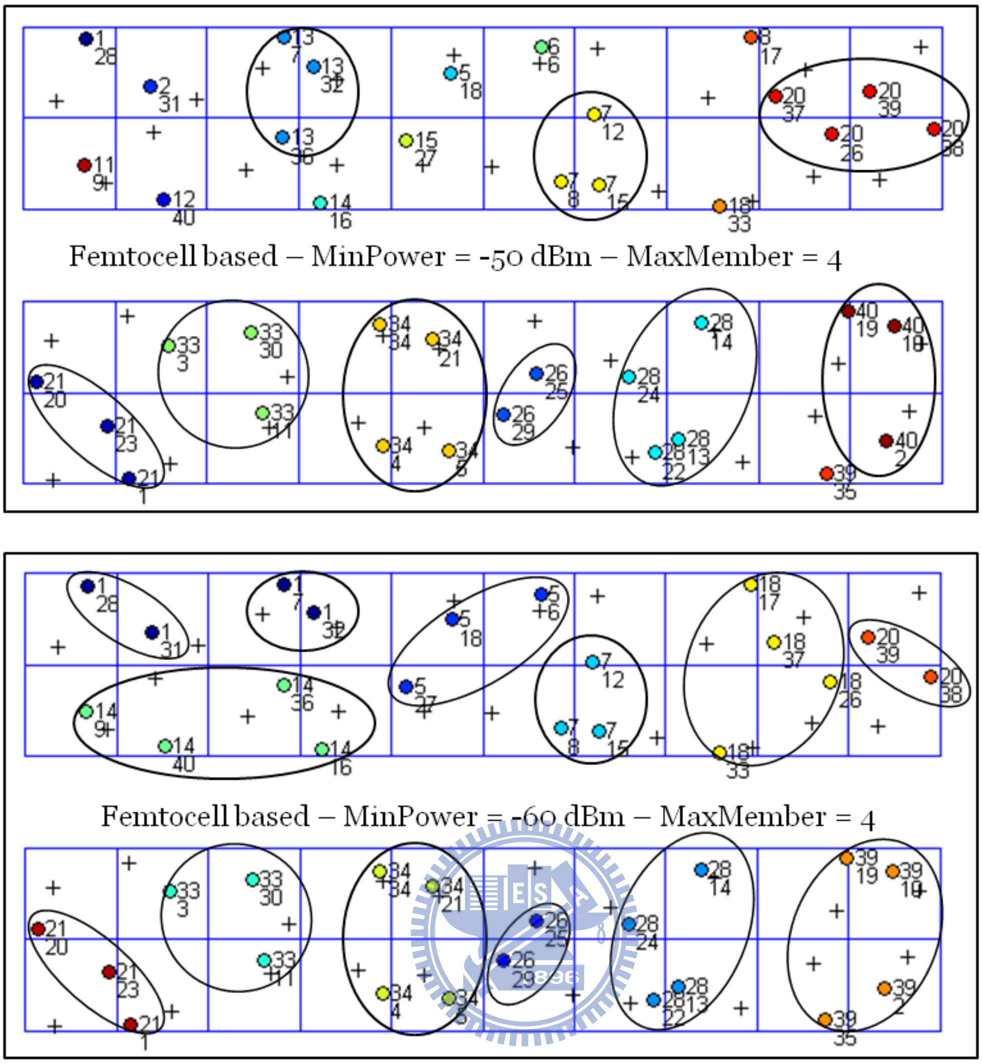


Figure 14 Example of femtocell based clustering result

4.5 Frequency allocation scheme

The frequency allocation scheme has been designed to allocate separate bandwidths to the members of a same group, which was created in the previous step. The easiest way to separate the bandwidth is to divide the spectrum by the number of members of each group. For example, for a group of two, we will allocate half of the bandwidth to each of the members. Nevertheless, when the group is getting bigger, 3 to 5 members, we may have nodes that do not sense high interference from all its other group members, in which case dividing the bandwidth by the number of members may affect the capacity for a small SINR gain.

We therefore tried to design a scheme to reuse the same frequency inside a group depending on the graph resulting from the measurement matrix. Thus, two nodes which are in the same group but are not connected by a branch in the graph may use the same bandwidth. This means that even if there are 4 or 5 members in a group, in some graph configurations, the bandwidth can be divided into 2 instead of, respectively, 4 or 5.

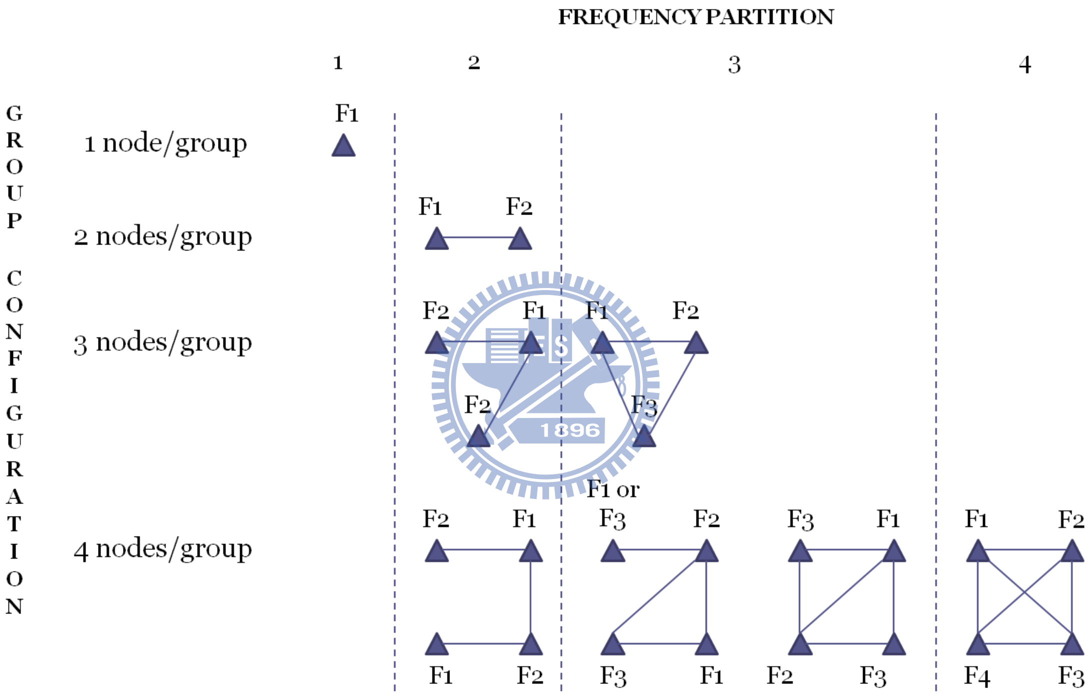


Figure 15 Group frequency allocation scheme example

The algorithm is Sudoku type logic and is related to the colouring problem. It is designed to compute what is the smallest frequency partition we can expect to assign a frequency to the member of a group according to the interference.

For each group, we build an interference connection graph which is the adjacency matrix of the elements of a group.

It is an *n* by *n* symmetric matrix, that we call *A*, where *n* is the number of vertices in the graph and therefore the number of members in a group. If some vertex *x* senses power higher than the power threshold or within the margin power from some vertex y, then the element $a_{x,y}$ is 1, otherwise it is 0.

In the case of the femtocell BS based clustering, we need to look back at the femtocell BS Received Power Matrix, P_{femto} .

$$a_{ij} = \begin{cases} 1 \; if \; P_{femto}\,(i,j) \neq 0 \\ 0 \; else \end{cases}$$

In the case of the user based clustering, we need to look at the femtocell UE Received Power Matrix, $P_{femtoUE}$. As this matrix is not a symmetric matrix, the formula is a little bit different.

$$a_{ij} = \begin{cases} 1 \; if \; P_{femtoUE}\,(i,j) \cap P_{femtoUE}\,(j,i) \neq 0 \\ 0 \; else \end{cases}$$

For each vertex of the graph of a group, we also need the number of connections of each vertex. It corresponds to the sum of each line/column of the adjacency matrix. In general this matrix is called degree matrix but we refer to it as SUM.

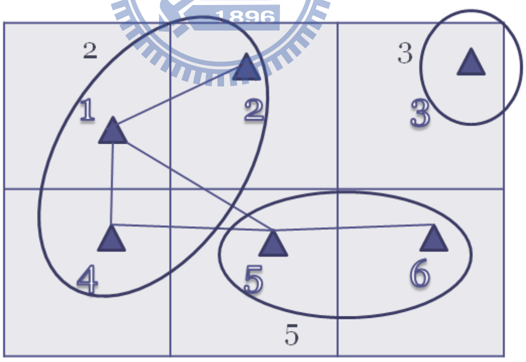


Figure 16 Graph for femtocell BS based clustering

Based on figure 11, we have the following adjacency matrices:

Table 5 Group Adjacency matrices

Group 2	1	2	4	SUM
1	0	1	1	2
2	1	0	0	1
4	1	0	0	1

Group 3	3	SUM
3	0	0

Group 5	5	6	SUM
5	0	1	1
6	1	0	1

For each adjacency matrix, we compute the sum of the links of each member of a group. Then, we list the possible frequencies that can be assigned to each node in a second matrix, called Combi, shorter name for combination. Indeed, in a graph of n nodes, we can give at most n different frequencies and colour with at least two frequencies. To each node can be assigned a frequency F1 to FN.

The combination matrices for the 3 groups above are:

Table 6 Combination matrices

Combi 2	1	2	4
1	1	2	3
2	1	2	3
4	1	2	3

Combi 3	3
3	1

Combi 5	5	6
5	1	2
6	1	2

If node *i* of group *j* selects frequency 1, we will therefore eliminate the possibility of choosing this frequency to the nodes connected to node *i*. This information is taken from the adjacency matrix and the reduction of the possibilities of the nodes is recorded in the combination matrix. To divide by the minimum number of frequencies, we need to start by assigning the frequencies from the node having the highest to the smallest number of connection, i.e., in descending order of the SUM matrix.

The algorithm is described in the flowcharts below:

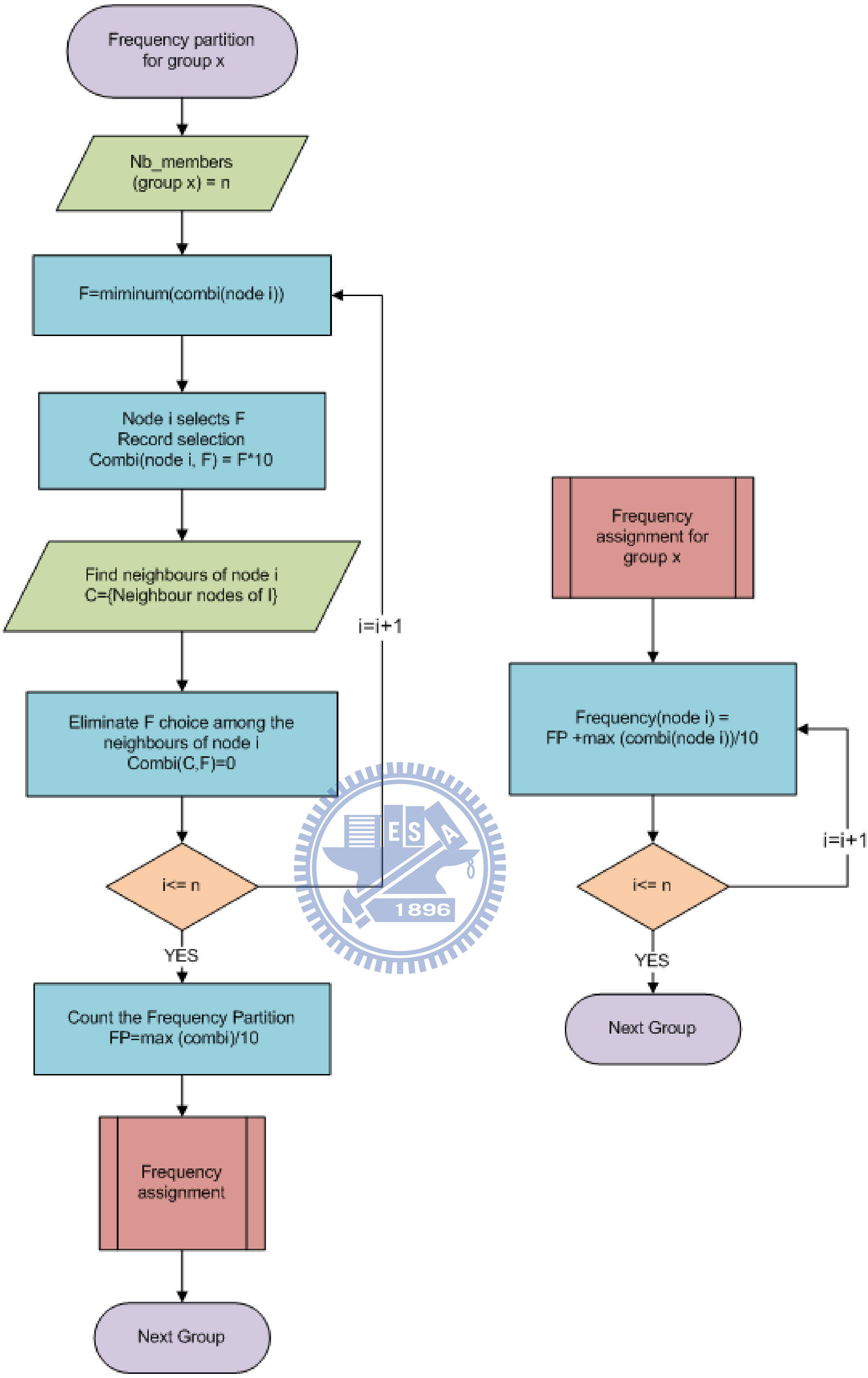


Figure 17 Group Frequency Reuse Scheme

At the end of the group frequency assignment scheme, we have the Frequency Assignment Matrix (FAM).

Table 7 Frequency Assignment Matrix

Femtocell ID	1	2	3	…	39	40
FAM	11	21	22	…	21	22

The possible values of FAM are: {11, 21, 22, 31, 32, 33, 41, 42, 43, 44, 51, 52, 53, 54, 55…}. If a node is assigned to the frequency band 11, it will use all the bandwidth. If a node is assigned to the band 21, it will use the first half of the total bandwidth and so 22 will be assigned to the second half of the total bandwidth. By the same token, we can get the meaning of each value of the FAM matrix.

Table 8 Frequency assignment values

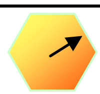
<table>
<tr><th colspan="12">Total Bandwidth</th></tr>
<tr><td colspan="12">11</td></tr>
<tr><td colspan="6">21</td><td colspan="6">22</td></tr>
<tr><td colspan="4">31</td><td colspan="4">32</td><td colspan="4">33</td></tr>
<tr><td colspan="3">41</td><td colspan="3">42</td><td colspan="3">43</td><td colspan="3">44</td></tr>
</table>

Chapter 5 Simulation Platform

We chose to do the simulation for LTE femtocells. We followed the simulation assumptions given in [10] for dense HeNB deployment modelling with each BS parameters, the detailed pathloss model for the dual-stripe apartment scenario and the shadowing models.

5.1 Macrocell parameters

Table 9 Macrocell BS Parameter [10]

Parameter		Assumption
Cellular Layout		Hexagonal grid, 3 sectors per site, reuse 1.
Inter-site distance		500 m or 1732 m
Number sites		19 (=57 cells) or 7 (=21 cells) with optional wrap-around.
Carrier Frequency		2000 MHz
Distance-dependent path loss		See section 5.2
Shadowing standard deviation		8 dB (see section 5.3)
Shadowing correlation	Between cells	0.5 (fixed, see section 5.3)
	Between sectors	1.0 (see section 5.3)
Penetration Loss (assumes UEs are indoors)		10dB (see section 5.2)
Antenna pattern (horizontal) (3-sector cell sites with fixed antenna patterns)		See section 5.2.1
BS antenna gain after cable loss		14 dBi
BS noise figure		5 dB
Number of BS antennas		2 Rx, 2 Tx
UE Antenna gain		0 dBi
UE Noise Figure		9 dB
Number of UE antennas		2 Rx, 1 Tx
Total BS TX power (Ptotal)		46 dBm
UE power class		23 dBm (200 mW)
Inter-cell Interference Modelling		Explicit modeling (all cells occupied by UEs)
Antenna Bore-sight points toward flat side of cell (for 3-sector sites with fixed antenna patterns)		
Traffic model		Full buffer
UE distribution		UEs dropped with uniform density within the indoors/outdoors macro coverage area, subject to a minimum separation to macro and HeNBs. The probability of a macro UE being indoors is a parameter
Minimum distance between UE and cell		>= 35 m
UE speeds of interest		3 km/h
DL Receiver Type		MRC (single stream)

In our case, one femtocell block will be randomly dropped in the sector 1 of the central macrocell as pointed on the picture below.

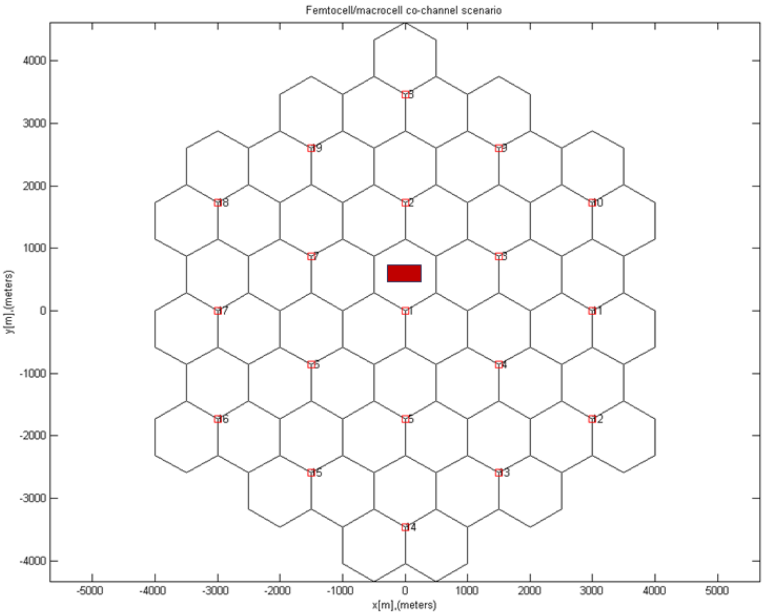


Figure 18 Femto block deployment

50% of macrocell UEs are assumed to be indoors. Macrocell UEs are dropped uniformly and randomly throughout the indoors/outdoors macrocell coverage area. It's possible that some Macrocell UEs will be dropped into the femtocell area. It is assumed that there is one femtocell UE per femtocell, which is dropped randomly in the active femtocell. The femtocell BS is also randomly placed in each femtocell.

5.2 Femtocell parameters

Table 10 Femtocell BS parameters [10]

Parameter	Assumption
HeNB Frequency Channel	Same frequency and same bandwidth as macro layer –co-channel
Min separation UE to HeNB	20 cm
Number Tx antennas HeNB	1
Number Rx antennas HeNB	2
HeNB antenna gain	0 dBi or 3 dBi or 5 dBi
Exterior wall penetration loss	10 or 20 dB (See section 5.2.2)
Interior path loss model	See section 5.2.2
Interior to Exterior path loss model	See section 5.2.2
Exterior path loss model HeNB to UE	See section 5.2.2
Log-normal shadowing standard deviation	4 dB
Noise figure HeNB	8 dB
Min/Max Tx power HeNB	0/20 dBm
Carrier bandwidth	10 MHz

5.2.1 Antenna pattern

The azimuth antenna pattern of the macro is modelled as:

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3\,dB}}\right)^2, A_m\right]$$

where θ_{3dB} = 70 degrees, A_m = 20 dB.

The azimuth antenna patterns for UEs and femtocell BS are assumed to be omnidirectional.

5.2.2 Pathloss model

The path loss models for dense femtocell deployment are as follows:

Table 11 Pathloss model [10]

Cases		Path Loss (dB)
UE to macro BS	(1) UE is outside	PL (dB) =15.3 + 37.6$\log_{10}$R
	(2) UE is inside an apt	PL (dB) =15.3 + 37.6$\log_{10}$R + L_{ow}
UE to HeNB	(3) UE is inside the same apt stripe as HeNB	PL (dB) = 38.46 + 20 $\log_{10}$R + 0.7$d_{2D,indoor}$+ 18.3 $n^{((n+2)/(n+1)-0.46)}$ + q*L_{iw} n is the number of penetrated floors q is the number of walls separating apartments between UE and HeNB In case of a single-floor apt, the last term is not needed
	(4) UE is outside the apt stripe	PL (dB) = max(15.3 + 37.6$\log_{10}$R, 38.46 + 20$\log_{10}$R) + 0.7$d_{2D,indoor}$ + 18.3 $n^{((n+2)/(n+1)-0.46)}$ + q*L_{iw} + L_{ow}
	(5) UE is inside a different apt stripe	PL(dB) = max(15.3 + 37.6$\log_{10}$R, 38.46 + 20$\log_{10}$R) + 0.7$d_{2D,indoor}$ + 18.3 $n^{((n+2)/(n+1)-0.46)}$ + q*L_{iw} + $L_{ow,1}$ + $L_{ow,2}$

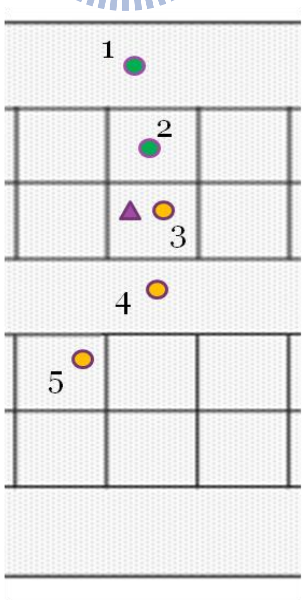


Figure 19 Pathloss model illustration

R is the Tx-Rx separation in meters

L_{ow} is the penetration loss of an outdoor wall, which is 10dB or 20dB.

L_{iw} is the penetration loss of the wall separating apartments, which is 5dB.

The term $0.7d_{2D,indoor}$, in meters, takes into account of the penetration loss due to walls inside an apartment.

In Case (3), the path loss is modeled by free space loss, penetration loss due to internal walls and floors. The loss due to internal walls is modeled as a log-linear value, equal to 0.7dB/m.

In Case (4), the path loss modeling takes into account of (2) and (3).

To simplify the simulation we do not consider the existence of other floors therefore n=0.

5.2.3 Shadowing model

Log-normal shadowing applies to all links. For links between a HeNB and a UE served by this BS, the standard deviation is assumed to be 4dB. Otherwise for all other links (including interference links) the standard deviation is 8dB.

Correlated shadowing is applied. The baseline models the shadowing correlation from one UE to multiple BS, and assumes no shadowing correlation from one BS to multiple UEs no matter how close the UEs are located.

Chapter 6 Results

In this section, we will discuss and confront the results from the different clustering scenarios.

We will first confront the two clustering methods: femtocell BS based and femtocell user based.

The simulation scenario is as described in the previous chapter. The femtocell block is randomly placed in the sector 1 of the centre macrocell. The simulation is run 100 times with fixed location of the femtocell block and the femtocell BS inside the block. Only the users are thrown differently and randomly 100 times. To better stick to the reality the browsing order for the clustering decision is set as random. The simulation is only evaluating the downlink performance. The results we will show will only focus on the femtocell BS and femtocell user performance, especially the femtocell outage probability, the average SINR of the femtocell user and the average capacity of the femtocell. The effect of the clustering strategies on the performance of the macrocell is therefore not covered in this thesis.

For each user in the centre cell, we compute the signal-to-interference plus noise ratio (SINR) and the corresponding spectral efficiency (SE). The SE is mapped with the Modulation Coding Scheme (MCS) table.

Table 12 Modulation Coding Scheme table [13]

Modulation	Code Rate	Receiver SINR (dB)	Spectrum efficiency (b/s/Hz)
QPSK	1/2	3.50	1.00
QPSK	3/4	6.50	1.50
16QAM	1/2	9.00	2.00
16QAM	3/4	12.50	3.00
64QAM	1/2	14.50	3.00
64QAM	2/3	16.50	4.00
64QAM	3/4	18.50	4.50

When the SINR is below 3.5 dB, the corresponding user is in outage. This minimum SINR value is therefore used to compute the outage probability.

The other important metric is the average system capacity. For each user, the SINR of each of the channels he has been assigned to is mapped to the correct coding rate and spectrum efficiency. We multiply MCS-based SE by the total bandwidth allocated to each user. The average system capacity of the femtocell layer is given by the sum of the mean data rate of all the femtocell users accumulated during the simulation time.

The parameters of the two clustering algorithms and their tested values are reviewed here:

- Femtocell BS based: $MinPower = \{-40\ dBm, -50\ dBm, -60\ dBm\}$
- Femtocell User based: $Power\ Margin = \{5\ dB, 10\ dB, 15\ dB\}$
- For both, the maximum members per cluster: $MaxMember = \{1,2,3,4,5,6,7\}$

In all the different results, the comparison basis is made with MaxMember = l, which means that each femtocell is cooperating with itself as if there were no group. It is then referred to the original case, without any collaborative algorithm implemented.

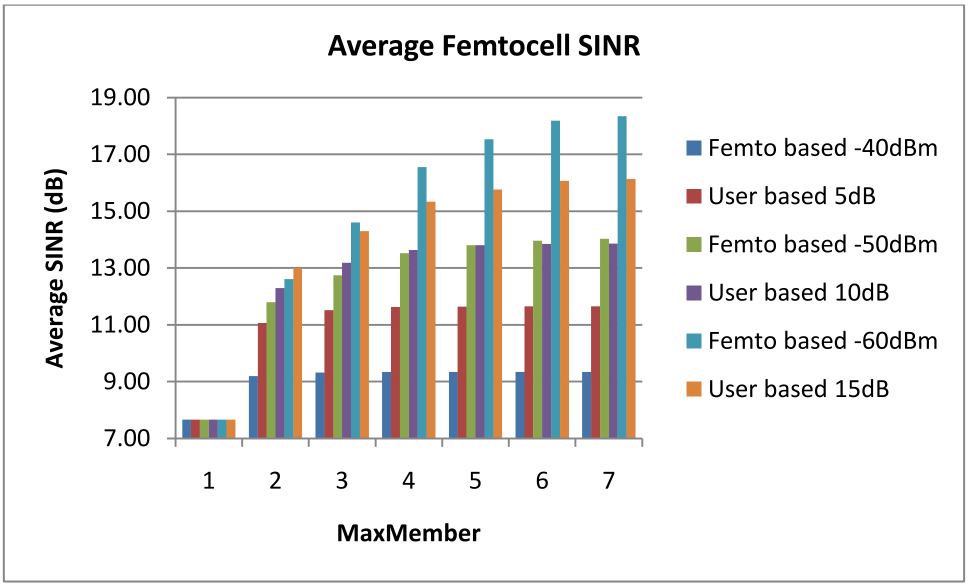


Figure 20 Average Femtocell SINR with group frequency reuse

Table 13 Femtocell average SINR with group frequency reuse scheme

Average SINR + Group frequency reuse scheme	MaxMember						
Clustering scenario	1	2	3	4	5	6	7
Femto based -40dBm	7.66	9.20	9.32	9.34	9.35	9.35	9.35
User based 5dB	7.66	11.06	11.52	11.62	11.64	11.65	11.65
Femto based -50dBm	7.66	11.79	12.74	13.52	13.81	13.96	14.02
User based 10dB	7.66	12.29	13.18	13.63	13.80	13.85	13.86
Femto based -60dBm	7.66	12.61	14.61	16.55	17.53	18.18	18.35
User based 15dB	7.66	13.00	14.30	15.34	15.77	16.06	16.14

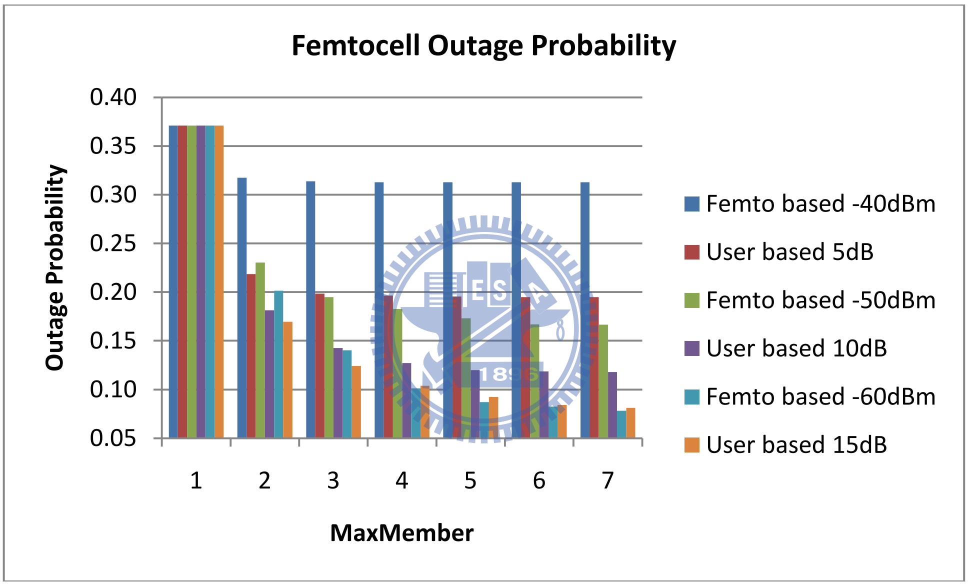


Figure 21 Femtocell outage probability with group frequency reuse

Table 14 Femtocell outage probability in percentage with group frequency reuse

Outage probability + Group frequency reuse scheme	MaxMember						
Clustering scenario	1	2	3	4	5	6	7
Femto based -40dBm	37%	32%	31%	31%	31%	31%	31%
User based 5dB	37%	22%	20%	20%	20%	19%	19%
Femto based -50dBm	37%	23%	19%	18%	17%	17%	17%
User based 10dB	37%	18%	14%	13%	12%	12%	12%
Femto based -60dBm	37%	20%	14%	10%	9%	8%	8%
User based 15dB	37%	17%	12%	10%	9%	8%	8%

The outage probability is decreasing significantly for all the clustering schemes. It gets smaller when MaxMember and the power threshold are increasing.

The two previous graphs give quite good results for both schemes and particularly when they are at their less restrictive parameter values. But this is at a capacity trade-off, as we can see on the next plot.

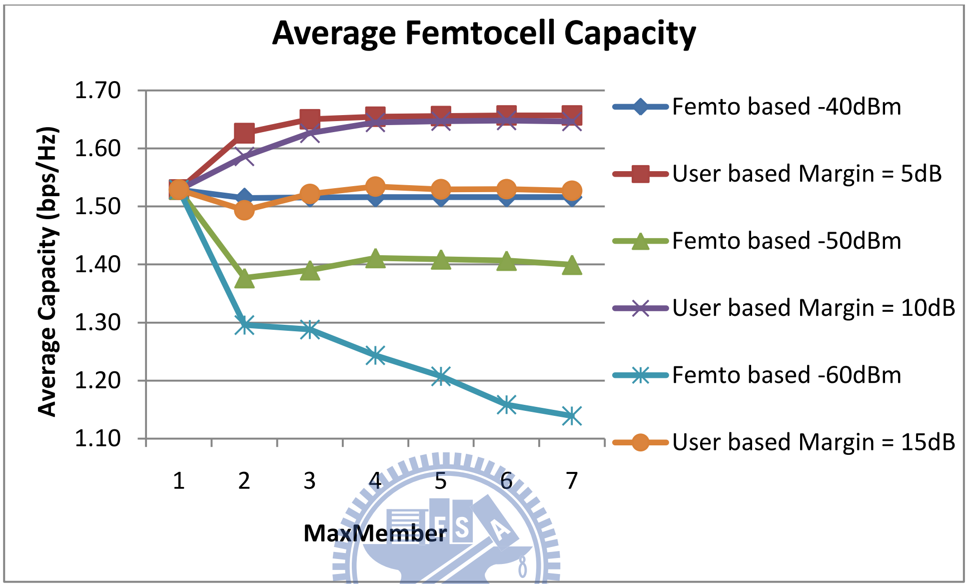


Figure 22 Average Femtocell Capacity with group frequency reuse

From the graph above and the associated table below, we can see that the user based clustering can keep the capacity stable or increase it up to 8% whereas the Femtocell BS based decreases the capacity.

Table 15 Average Femtocell Capacity in percentage with group frequency reuse

Average Femtocell Capacity + Group frequency reuse scheme	MaxMember						
Clustering scenario	1	2	3	4	5	6	7
Femto based -40dBm	100%	99%	99%	99%	99%	99%	99%
User based 5dB	100%	106%	108%	108%	108%	108%	108%
Femto based -50dBm	100%	90%	91%	92%	92%	92%	92%
User based 10dB	100%	104%	106%	108%	108%	108%	108%
Femto based -60dBm	100%	85%	84%	81%	79%	76%	74%
User based 15dB	100%	98%	100%	100%	100%	100%	100%

The values is in this table are confronted to the original and reference case (the case without any group).

This last result can help us better compare the two clustering schemes. For example, we can compare the femtocell based at -60 dBm and the user based at 15 dB as these two schemes achieve with at most 3 points difference, the same outage probability for all the MaxMember values. If we take a look at the average capacity results, for MaxMember >3, the outage probabilities being almost equal, we notice that the capacity provided by the user based method is 35% higher than the capacity provided by the femtocell based method. This conclusion is also true for the other schemes if we compare them two by two: femtocell based -40 dBm and user based at -5 dB, femtocell based -50 dBm and user based 10 dB.

Moreover, for the femtocell based -40 dBm and the user based 5 dB, the number of groups that are formed are quite few as the power threshold is very selective. Thus increasing the number of allowed members in a cluster doesn't further improve the outage probability and the average SINR.

To choose among these clustering scenarios and the different parameters, we have settled a metric. In fact, the goal is to decrease the co-layer interference, which means to decrease the femtocell outage probability or increase the femtocell coverage, under the constraint of a non-decreasing capacity. The metric introduced is

$$\begin{aligned} M\ (\%) &= (1 - Outage\ Probability(\%)) * Average\ capacity(\%) \\ &= Coverage\ (\%) * Average\ capacity(\%) \end{aligned}$$

Table 16 Outage – Capacity Trade-Off with group frequency reuse

Metric : M	**MaxMember**						
Clustering scenario	1	2	3	4	5	6	7
Femto based -40dBm	96%	103%	104%	104%	104%	104%	104%
User based 5dB	96%	127%	131%	132%	132%	133%	133%
Femto based -50dBm	96%	106%	108%	106%	102%	100%	100%
User based 10dB	96%	130%	137%	138%	137%	137%	137%
Femto based -60dBm	96%	103%	100%	93%	86%	77%	73%
User based 15dB	96%	124%	127%	125%	121%	120%	119%

This table shows that we can improve the capacity and the outage probability at the same time if we use the user based clustering scheme.

Also, from this table, we can advice to use the user based scheme with MaxMember = 4 and a Margin Power equals to 10 dB. Indeed, with this scheme, we can maximize our gain on the interference and the capacity level. Increasing the maximum number of members per group is saturating the performance as well as increasing the number of information to be transmitted between collaborating members of a group, it is therefore increasing the overhead and the complexity.

Then, it is important to analyze the performance of the group frequency reuse scheme. It has been to confronted to a no frequency reuse scheme, i.e. an algorithm assigning to the n members each a group 1/n of the total bandwidth, having therefore completely separate and orthogonal channels.

The same scenario as before has been run to compute the femtocell average capacity, outage probability and average SINR in the case of the frequency reuse scheme, in order to compare the performance differences with the no frequency reuse scheme.

To better confront the results between the two schemes, we will put in the tables the results of the *capacity comparator* and the *outage comparator* which are defined thereafter, instead of the simple raw data from the simulation.

For the average femtocell capacity, the comparison measure is as follows:

$$\text{Capacity comparator} = \frac{(Value\ \ for\ the\ No\ Reuse\ Scheme - Value\ \ for\ the\ \ Reuse\ Scheme\ )}{Value\ \ for\ the\ Reuse\ Scheme}$$

If this indicator is negative then the performance of the no-reuse scheme is worse than the group frequency reuse one.

Table 17 Average capacity relative comparison group frequency reuse VS no reuse

Average Femtocell Capacity Comparison	MaxMember						
Clustering scenario	1	2	3	4	5	6	7
Femto based -40dBm	0%	0%	0%	-1%	-1%	-1%	-1%
User based 5dB	0%	0%	-1%	-2%	-2%	-2%	-2%
Femto based -50dBm	0%	0%	-6%	-13%	-16%	-18%	-19%
User based 10dB	0%	0%	-3%	-6%	-7%	-8%	-8%
Femto based -60dBm	0%	0%	-11%	-19%	-24%	-31%	-33%
User based 15dB	0%	0%	-6%	-12%	-15%	-17%	-17%

For the femtocell outage probability, the comparison measure is as follows:

$$\text{Outage comparator} = \frac{(Value\ \ for\ the\ \ Reuse\ Scheme\ - Value\ \ for\ the\ No\ Reuse\ Scheme\ )}{Value\ \ for\ the\ Reuse\ Scheme}$$

If this indicator is positive then the performance of the no-reuse scheme is better than the group frequency reuse one.

Table 18 Outage probability relative comparison group frequency reuse VS no reuse

Femtocell Outage Probability Comparison	MaxMember						
Clustering scenario	1	2	3	4	5	6	7
Femto based -40dBm	0%	0%	1%	1%	1%	1%	1%
User based 5dB	0%	0%	3%	5%	5%	5%	5%
Femto based -50dBm	0%	0%	12%	23%	24%	24%	24%
User based 10dB	0%	0%	11%	16%	17%	18%	18%
Femto based -60dBm	0%	0%	13%	22%	35%	43%	50%
User based 15dB	0%	0%	14%	30%	29%	31%	32%

The conclusion is quite obvious, reusing the frequency inside groups is better as the loss of capacity is reduced for certain cases even if the outage probability is not as good as it is for the no reuse of the frequency. It is the trade-off between capacity and outage.

Chapter 7 Conclusion

In this thesis, we have studied whether the concept of clustering neighbouring femtocell Base Station which suffers interference is achievable. The clustering algorithm designed is either based on interference information collected by the femtocell Base Station themselves or reported by the femtocell users. We have shown here that the user based clustering can achieve better performance in terms of capacity with the same outage probability than the femtocell based. We have also discussed the effects of the different parameters - like the maximum members per cluster and the power threshold that were introduced to control the clusters. Our future work is to further improve the clustering algorithm, design the message format to make the cooperation between femtocells practical and evaluate the effect of these additional messages on a time based system performance. Moreover, we would like to further implement Self Organization functionalities by designing other algorithms to set the optimized parameters for femtocell network.

References

[1] Femto Forum, 'What is femtocell?'

[2] V. Chandrasekhar and J. G. Andrews, 'Femtocell networks: A survey', IEEE Communication Magazine, 46(9):59–67, September 2008

[3] 3GPP, 'TR 25.820 V8.2.0 3G Home NodeB Study Item Technical report', Technical Specification Group Radio Access Networks, September 2008

[4] A.G. Spilling,1 A.R. Nix, M.A. Beach, and T.J. Harrold, 'Self-Organization in Future Mobile Communication Networks', Electronics & Communications Engineering Journal, Vol. 12, Issue 3, June 2000

[5] 3GPP, 'TR 32.581,2,3 V.8.0.0 - Home NodeB Operations, Administration, Maintenance and Provisioning (OAM&P)', Technical Specification Group Services and System Aspects, March 2009

[6] IEEE 802.16, 'IEEE 802.16m System Requirements Document (SRD)', January 2009

[7] NGMN, 'NGMN Use cases related to Self Organizing Networks – Overall description', May 2007

[8] SOCRATES Project, 'Use cases for self-organising networks', 2008

[9] Femto Forum, 'Interference management in UMTS femtocells', Technical report, Femto Forum, December 2008

[10] 3GPP, 'R4-092042', Technical Specification Group Radio Access Networks WG4, May 2009

[11] H. Claussen, L. T. W. Ho, and L. G. Samuel, 'An overview of the femtocell concept', Bell Labs Technical Journal - Wiley, 3(1):221–245, May 2008

[12] H. Claussen, L. T. W. Ho, and L. G. Samuel, 'Self-optimization coverage for femtocell deployments', in Wireless Telecommunications Symposium, 24-26, pages 278 – 285, April 2008

[13] H. Zeng, C. Zhu and W. Chen, ‘System Performance of Self-Organizing Network Algorithm in WiMAX Femtocells’, Invited paper in WICON’08, Fujitsu Laboratories of America, November 2008

[14] D Lopez-Perez, A. Valcarce, G. de la Roche and J. Zhang, ‘OFDMA femtocells: a roadmap to interference avoidance’, in IEEE Communications Magazine, June 2009