CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Electrical Engineering
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Estimation of Signal Level Evolution for Handover in Networks with Femtocells

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Declaration

I guarantee, that this thesis called "*Estimation of Signal Level Evolution for Handover in Networks with Femtocells*" made under the supervision of doc. Ing. Zdeněk Bečvář Ph.D. is my original work and only sources cited have been used.

Prague, 30.3.2015 …………………..

Acknowledgement

I want to thank all my family for giving me the possibility of studying this kind of career even when the situation was not the best one. Apart from that, without your support and the motivation that you have transmitted to me, it would have been impossible to achieve this goal.

Table of Content

Abstract:

The deployment of small cells is one of the solutions used by the operators in order to improve their coverage and the quality of service (QoS) offered in urban scenarios. However, an increase in the amount of available cell could represent a problem for the operators due to a higher number of performed handovers. Moreover, if we take into account that the density of femtocells deployed and the number of users in the same scenario could be high, the problem of performing handover becomes even more significant. An algorithm to decrease the number of performed handovers in a scenario with femtocells deployed densely is studied in this thesis. The proposed algorithm estimates the future signal level, which the user would receive if it performs the handover to the target cell. This estimates i exploited to evaluate if handover is going to be beneficial in terms of throughput or not. The performance is compared with the conventional handover technique and with selected competitive algorithms. The results show that the proposed algorithm decreases the number of performed handovers and, in addition, it maintains an acceptable level of SINR even for scenarios with high density of femtocells.

Keywords:

Femtocell, Handover, LTE, Small Cells, Throughput Gain.

List of Acronyms

GPS	Global Positioning System
eNB	eNode B
HeNB	Home eNode B
HetNet	Heterogeneous Network
UMTS	Universal Mobile Telecommunication System
LTE-A	Long Term Evolution - Advanced
MMM	Manhattan Mobility Model
PL	Path Loss
QoS	Quality of Service
SINR	Signal to Interference plus Noise Ratio
RSSI	Received Signal Strength Indicator
POI	Point of Interest
UE	User Equipment
RNC	Radio Network Controller
FAP	Femtocell Access Point
CSI	Channel State Information
CSG FAP	Closed Subscriber Group FAP
HO	Handover
ICIC	Inter-Cell Interference Coordination
RE	Range Expansion
CRAN	Cloud Radio Access Network
PDF	Probability Density Function
MH	Margin of Hysteresis

List of Tables

List of Figures

1 Introduction

Usage of mobile communication has become an important part of human life. The improvements of mobile communications and the deployment of high capacity networks around the world have changed the access to the information.

Since the deployment of the UMTS networks and the proliferation of UMTS devices, which enable UMTS connectivity, the amount of data has increased significantly. The paper [1] works shows that the worldwide mobile data usage has increased more than doubled on average from 2005 to 2010 (350% in West Europe and 400% in USA). The main reason of this growth is the availability of the UMTS connections.

However, the rise of the mobile communication in the last years makes necessary to improve the mobile networks constantly in order to offer a good service to the clients. For that reason, new technologies are applied in order to improve the performance of the network. Recently, LTE-(A) (often denoted as 4G) is being deployed and implemented. This new generation of mobile communications allows the users to have higher data rate and, at the same time, it offers lower latency than UMTS.. The data rate required for LTE-A networks [2] assures 100 Mbps while the user is moving. Moreover, this rate can reach 1 Gbps for static user. This obvious change permits the users to consume a big amount of data. Due to this improvement in the bitrates offered, the deployment of the LTE networks has introduced a dramatic increase on the cellular data usage, according to [3]. The study has taken into sample hundreds of thousands of worldwide smartphones. It has revealed that LTE users consume more data than UMTS users. For example, in January 2013, the average monthly usage of data with UMTS devices was 838 MB. At the same date, LTE devices reached 1.4 GB of mobile data usage. It means an increase of 68% of the monthly usage.

A big amount of the mobile data is generated at user's homes or offices. According to [1], in 2013, 45 percent of total mobile data traffic was offloaded onto the fixed network through Wi-Fi or femtocell. Furthermore, by 2018, it is expected that more than half of all traffic from mobile devices will be offloaded to the fixed network. The actual mobile networks could not satisfy every user with respect to above-mentioned statistics in growth of mobile network usage. The companies need to renew and improve their networks in order to offer their users a satisfactory quality of service (QoS). The solution to guarantee a good level of QoS adopted by the companies in the last years is to deploy femtocells in scenarios where the density of users is high. Using a network formed by femtocells allows the mobile operator to decrease the number of users being served by the main network. The femtocells use common Internet access for backhaul between the femtocells and the operator's infrastructure. However, the capacity of the femtocells in a residential scenario is limited. This kind of cells only supports four active phones being served at the same time. This number of users served increases if the femtocell is used in enterprises settings, reaching sixteen phones served at the same time.However, the femtocells are the small cells with less capacity and with less range. Microcells and picocells improve these two problems. Furthermore, due to the reduced number of phones which one femtocell can serve with residential settings, the operators use other kinds of small cells in the urban scenarios. With the small cells (femtocells, picocells or microcells) the operators can solve the problem of radio range or the problem of high density of users in urban scenarios, deploying each one of them depending on the scenario and the problem that has to be solved.

During these last years, the deployment of the fourth generation of the mobile communication is being accompanied for the deployment of the small cells in urban scenarios. These new kind of stations are the new solution adopted by the operators to improve their networks in scenarios where the number of users is high and the quality of the service is a problem to be solved. However, this solution also presents problems to be solved, as for example, the number of handovers. The amount of handovers performed by each user could be increased considerably in scenario with concentrated small cells.

Thus, in this thesis, we introduce a solution focused on reducing the number of handovers performed between the different stations deployed in one scenario composed by Macro Cells and Small Cells. We propose an algorithm focused on the estimation of the future signal level which each user will receive in order to improve the handover decision. Our goal is to estimate the future gain that the user will obtain before it performs the handover. With this information, we add more requirements to fulfill before the decision of performing the handover is done.

The rest of the thesis is organized as follows. The next section describes the works related with the improvement of the handover decision. Then, theory related with the work is explained. After that, the proposed algorithm is introduced in section 4. The scenario, the mobility movement used and the parameters are described in the next section. After that, the simulations are studied taking into account another algorithms in order to compare the performance of our proposed algorithm. Finally, the conclusion obtained after studying the results of the simulations is explained.

2 Related Works

The performance of handover is studied in a large amount of studies in order to improve the mobility management. The entire proposals have the same main goal: to increase the quality of the service offered to the UEs. The solutions presented intend to decrease the number of unnecessary handovers, improve the handover decisions to reduce the related latency and the amount of unnecessary data transmitted. Due to the long list of parameters that the network uses, the solutions to improve the performance of the UE in the network are very different. We have classified the potential solutions presented depending on the main parameter that each one uses. The papers focus on different parameters in order to improve the handover decision. As we explain in the next paragraphs, the articles use statistics provided by the behavior of the network. We can classify the proposed solution depending on the main parameter used. The first group uses the mobility pattern in combination with other parameters in order to achieve the goal of improving the handover decision. The estimation of the future base station or the knowledge of the time to perform the handover is used by other articles with the same goal. Path loss or changes in the way of calculate the neighbor cell list are also studied. After that, the articles which take into account the access modes that the small cells have, are explained. Then, the current load of each small cell is important for the behavior of the network and some articles focus on it in order to improve the handover decision. Next, the articles explained are focused on the usage of the parameter SINR. The next articles propose changes on the architecture in order to reduce the number of handover performed. Finally, some proposals focused on the LTE-A networks are explained, followed by articles which are focused on the location of the UE.

The prediction of handovers is one problem studied in all kinds of networks. In [4], the proposed algorithm uses parameters, which are already available at the RNC, in order to predict future switching of serving cells. For the same purpose, mobility pattern can be considered as demonstrated in [5]. Different ways to predict handovers can be used, but it just changes efficiency of the prediction while it does not mitigate redundant handovers. Moreover, using a combination of the prediction techniques could increase the reliability of the approach to reduce the rate of erroneous predictions. Prediction of user’s next serving cell can be exploited also for handover optimization. The mobility pattern could help in that prediction in many ways. In [6], the algorithm uses the mobility pattern and the mobility database of each UE in order to predict the next handover. Simple moving average and simple mobility pattern too are used in order to predict handovers in [7]. The mobility pattern combined with other parameters can improve the process as well as shown in [8]. It is integrated with an estimation of residence time in the next cell in order to evaluate if the throughput gain in the next cell is enough to perform the handover. This estimation is done using a defined probability density functions depending on the speed of mobile user. The estimation of throughput gain is used as well in [9] to initiate handover. This proposal introduces an algorithm to estimate the throughput gain, which the user will obtain if it performs the cell change. This estimation is compared with a predefined threshold level in order to evaluate if the FAP can offer a higher throughput to the UE than the serving eNB, that is, if the handover is going to be beneficial.

A prediction of the future base station using user's mobility history could increase the amount of successful handovers performed as is demonstrated in [10]. The proposed mobility predictor takes into account history of the user's mobility using Markov Chains to predict the movement of each user. With that prediction, the preparation of the next handover before it is required allows to increase the probability of success handover and to reduce the latency. The knowledge of the time when the user will perform the handover could reduce the latency as well, allowing the cell to prepare the handover, as in [11]. This solution takes into account the velocity and the direction of the UE and also the RSSI. With these parameters, the target cell and exact time to perform handover could be estimated. The paper [12] proposes a combination of the Channel State Information (CSI) with long-term handover information which could provide good results to the goal of predict the user's next cell even using a small vector of the CSI.

The path loss measurements can also be used in order to improve the handover decision. In [13] a new handover algorithm using the path loss measurement and the spatially path loss estimation using Kriging Interpolation is presented. With these, the number of unnecessary handovers is decreased and the new algorithm improves the handover decision.

The big amount of femtocells which could be deployed indoor and the characteristics of the scenario where are placed introduce other ways to improve the performance of the UE in this kind of scenario. The optimization of the Neighbor Cell List (NCL) is one of the ways to do it. In [14] the optimization of the NCL allows the UE to increase his data transmission. This is due to the reduction of the amount of base station which the UE has to scan and this fact allows decreasing the signaling overhead and the time to scan everyone. The NCL could be also used in other ways to improve the handover performance. In order to achieve that, the division of the list in two categories is the solution which is proposed in [15]. The first one includes the FAPs whose the signal received is greater than a threshold level and the second one includes the FAPs with less signal than the threshold and the FAPs which are hidden (and also the FAPs with the same frequency than the serving FAP). In order to decide if one FAP is hidden for one user, the FAPs exchange information. With this new NCL the number of failed handover are reduced and, consequently, the handover decision is improved. Share information among the devices on the network is a useful mechanism to achieve the goal of improving the handover as is done in [16]. In this proposal the different users help each other in order to obtain a target cell. When one UE is losing his connection with the FAP and does not know an eNB to be connected, it will ask to another UE. The other UE will inform eNB that one user wants to be served and the eNB will send directly the message to establish the connection. This proposal achieves decreasing the latency and has more robust to radio link failures.

On the other hand, another kind of information could be used in order to prevent erroneous performs of handovers. Due to the different kinds of access modes of the FAPs, the failure handovers could be avoided. Two proposals which take it into account are the [17] and the [18]. The first one uses the information about the FAP's access mode to prevent the initiation of handover process to CSG FAP if the UE has not permission to access it. It permits to save radio resource and radio signaling to the network, and also, to avoid the failure of the handover due to the permission. This proposal proposes also a mechanism to reduce the interference produced by the eNB and the HeNB decreasing the signal power of the stations depending on the situation. The second proposal takes the received signal strength level, the access mode and the location of neighbor femtocells into consideration. Using the information about the access mode combined with the list of hidden FAPs allow decreasing the rate of failed handovers. The access control strategy is further addressed in [19]. This paper gives an overview of the 3GPP Releases and explains the different issues related with the femtocell access control.

The received signal to interference plus noise ratios (SINR) of UEs can be exploited to evaluate the performance of the network. For that reason, some proposals are focused on using this parameter to improve the network. The paper [20] introduces a solution to reduce the failure rate of HOs and the ping-pong HOs in a scenario with Macro Cells and Small Cells. The idea is to exploit SINR of each UE, the range expansion techniques (RE) and the inter-cell interference coordination (ICIC) to improve performance of the handover process. Different ICIC methods combined with the RE and with different handover types are evaluated in the proposal. Another paper, which uses the SINR parameter is [21]. It presents a way to predict the SINR level. If the SINR level is lower than a threshold, the algorithm searches the best candidate to perform a handover. The algorithm uses the SINR level, the user traffic cost, user preference and the available bandwidth of each station deployed on the scenario. A prediction algorithm is proposed in [22]. The proposed solution allows the eNBs to make potential handover decisions using the parameters reported by the UEs. The quality of the channel and relay-enhanced links are predicted using a Markov process. The proposal presents two different objectives: maximize the SINR and minimize the system energy consumption. Another proposal based on SINR is presented in [23]. In the paper, the cell association techniques in uplink Cloud Radio Access Networks (C-RAN) are studied. C-RAN are the proposed solution to increase the spectrum and the energy-efficiency in the next mobile generation (5G). Three received power based cell association techniques, namely the single best, N-best and N-th best, are presented and analyzed. The different techniques are based on the evaluation of the SINR and the PDF of the distance.

Furthermore of the access mode, other information useful of the FAPs to achieve the main goal of improving handovers is the information about his load. Some studies use it in order to improve the performance of the handover process. The proposal [24] uses the FAP's capacity and delay. These measurements are compared with the user's requirements and if the FAP is able to satisfy the user, the handover will be performed. The idea of [25] is to apply a call admission control with different priorities depending on the kind of user that wants to establish a connection with the femtocell. For that, it distinguishes two different kinds of user, CSG user and non-CSG user. The algorithm reserves a portion of the capacity only available for the CSG members in order to assure that a CSG user is always served. A solution to select the optimal target FAP using the measurement reports of the UE and access mode and also the current load of the FAP is presented in [26]. The system occupancy is also used in [27]. The proposal compares two ways to make a handover prediction. The work introduces two ways to do it: User's prediction and Cell prediction. The cell prediction takes into account the cell occupancy in each time and the user prediction is based on the user's movement.

There are solutions presented by some proposals which propose changes on the architecture of the network. In [28], architecture of femtocell network is presented to improve the management of the information. The way which the different networks share information is important to perform reliable handovers. Sharing information between macro cell and femtocell is necessary to perform its, so, with an efficient architecture is easier to do that. It also proposes an algorithm to reduce unnecessary handovers using RSSI, the duration of time that the UE maintain the level and the signal to interference level. Another proposal which focuses on the architecture is [29]. This proposal introduced a scheme to predict handovers with the Layer 3. The main objective of the proposal is to reduce the handover latency and it presents some modifications on the Layer 3 to achieve that.

The performance of the handover is always being discussed in order to find the better solution. The different techniques to perform a handover on the LTE-A networks are explained in [30]. The work also defends that using a combination of two different techniques improve the process in term of latency, outage probability and interruption time. The mobility management method has been optimized to be used in a macro cell scenario on the LTE-A networks. Due to the growth of the smallcell scenario, as is explained in [31], a new mobility management is necessary. The proposal presents a new mobility method to improve the performance in this kind of scenarios.

Due to the big deployment of femtocells on specific scenarios, the location of the UE has interesting applications. The amount of applications which uses the location of the UE is growing. For that reason, the knowledge of each UE location could be a problem for the networks because of the potential huge number of UE in a small scenario. The big amount of mobile phones could difficult the evaluation of the location. Despite of using GPS, there are interesting advantages of using a fingerprint positioning methods as is explained in [32]. Some of these advantages are less battery drain, non-GPS terminals could be integrated and indoor coverage. Furthermore, the save of the potential signaling could be used in transmission data. An algorithm to improve the indoor positioning is also proposed in [33] in order to know the location of each user in a WiFi network. The way to know the position use the RSSI values obtained from WiFi beacons.

3 Theory

This section introduces two important topics of the thesis. The handover is a very important process in the current networks and it is introduced in the next subsection. In addition, an introduction of the femtocell network is done in the second subsection.

3.1 *Process of Handover*

The handover procedure consists of changing the connection established with the network from one cell to another, as it showed at the Figure 1. That means, when one UE is losing his connection with the serving base station because of the cell cannot provide him the necessary level of signal, the UE must change the connection to one cell which is capable to offer him the required signal level in order to keep the service quality . In other words, when one UE is going out of the coverage of one cell and it is entering to other cell coverage, the connection has to be changed in order to guarantee the connection is not going to be lost.

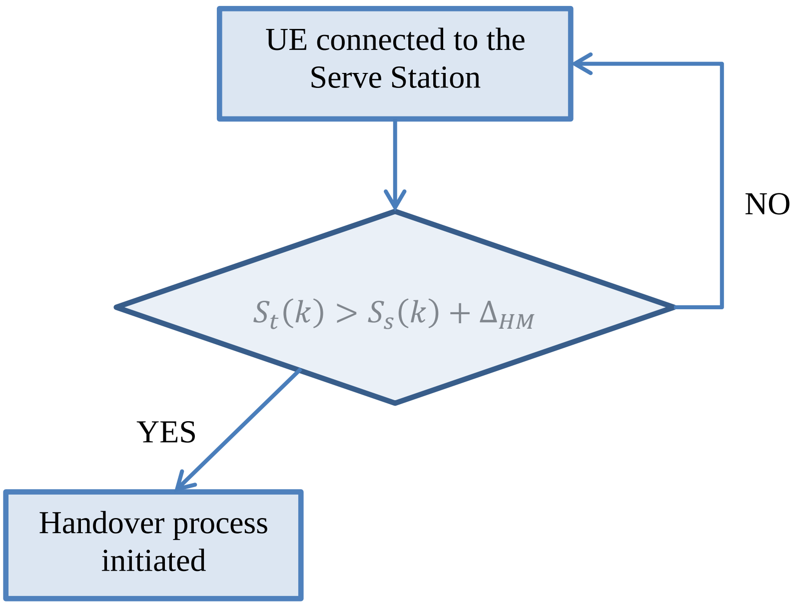

Figure 1. Handover Process

Focusing on the UMTS and LTE technologies, there are differences in the way to perform a handover in each generation. On UMTS there are two different main ways to do it, but only one in LTE. However, the technique used by LTE technology is used by UMTS as well, but UMTS uses another one technique in addition. The first one used by the UMTS technology is called Hard Handover. In this one, the UE is always using only a channel from one base station. In other words, the serving station will close the connection before new connection is established with other cell (denoted as target cell). . For that reason, the UE is disconnected during a short time of the network in case of the hard handover. This time is imperceptible by the user in almost all the cases. The handover interruption times should be since 27.5 ms to 60 ms, as we can see in [2]. The user cannot perceive the interruption if the process is performed in a normal way. In addition, usually, these intervals are lower than the specifications. The second handover technique is called Soft Handover. With this one, the UE remains connected to different cells at the same time. Several radio links with the different cells are active for one UE, so, when it loses the connection with one, it can change the principal link to other cell without losing the connection. In LTE technology, only hard handover is supported.

We can classify the handover as vertical handover and horizontal handover. Both of them have the same goal: maintain the on-going service through the network. However, the horizontal handover is performed when the UE performs handover between base stations with the same access technology. On the other hand, the vertical handover is performed when one UE changes communication technology.

3.2 *Femtocell Network*

Due to the need of improving the mobile network in scenarios where the density of users is high, the operators have chosen the solution of deploying small cells. Deploying this kind of station allows the operators to solve specific problem of coverage in specific areas. The characteristics of these stations facilitate to solve this kind of problem and the different kinds of small cells permit to adapt the solution depending on the problem presented.

The small cell stations are base stations which transmit with low-power and create a short-range coverage. We can distinguish the small cells in three types: femtocells, picocells and microcells. The main difference between them is the coverage that they can cover and the number of users that they can serve. The microcell can cover, typically, less than two kilometers. On the other hand, picocells can cover two hundred meters as much, and femtocells more or less 10 meters.

Due to these kind of characteristics, the installation and the usage of this kind of stations is cheap. The operators use them in order to extend the coverage of mobile network or to improve the signal quality in specific locations. Particularly, the femtocell is a small base station designed for use at home or at office. The femtocells represent a good solution to improve the coverage in indoor scenarios or in places that the base station is not able to reach. Furthermore, the usage of them is a low cost solution in these cases for the mobile operators.

Another reason to deploy these stations is that the installation of the networks based on small cells allows improving the performance of the macro base station too. It is possible due to the usage of small cells, which permits to offload traffic from the main network. Consequently, the overload of the macro base station is reduced because of the reduction of potential mobile phones. Furthermore, this new kind of network is connected with the core network through a broadband internet connection. The network exchange information between the small cells and the core network using Internet. They do not use the resources of the network to exchange information about their state, for that reason, it represents a save of resources for the companies.

Nevertheless, due to the consumers who install femtocells in their own house or office, the access to them must be protected. For that reason, three types of access modes are defined: closed, open and hybrid. The closed one is the most restricted. In this kind of access, the UEs which can connect with the femtocell have to be identified before they use it . In other words, only the users which are subscribed to the femtocell's closed subscriber group (CSG) list are allowed to use it. On the other hand, the open access allows to use the femtocell to all the users. It represents an advantage for the mobile operator because they can offload more traffic from the core network and, due to that; they can reduce the overload of their main network. Finally, the hybrid access is a combination of the previous two accesses mentioned. One part of the capacity of the femtocell is dedicated to the users listed in CSG and the rest of capacity is opened to everyone.

The deployment of small cells in urban scenario does not only present advantages. One small cell network could help the main network because it allows decreasing the number of mobile phones connected to the main one. This solution could maintain or even improve the user connection to the network. Nevertheless, one of the main problems of the small cell deployment (more notorious in networks based on femtocells) is the increase of unnecessary handovers performed due to the constant movement of the users. In addition, unnecessary handovers reduce the system capacity and the quality of the signal. For that reason, the mechanism to perform the handover to this kind of stations should be controlled due to the characteristics of them. The radio range of the small cells is small and limited. For that reason, performing a handover to one of these cells is not always the best solution to improve the quality of the service. The scenarios where the small cells are deployed are different and changing the connection to one small cell could represent problems for the network. The handover process presents a computational cost to the network and the excess of it could make worse the performance of the mobile network.

4 Explanation of the algorithm

The principle of the proposed algorithm is to evaluate how much profitable was a previous handover between a serving station ($cell_s$) and a target station ($cell_t$) in order to decide if the future handover should be performed or not. The algorithm takes into account two different types of statistics: the information about the signal levels, which other UEs have received previously when they have performed the handovers between the same pair of cells, and the classification about whether the previous handover was profitable for the UE or not. The UE uses information on his own previous experienced signal quality and handover profitability as well.

The algorithm is used to evaluate the convenience of performing handover from a Macro Cell to a Small Cell or between two Small Cells. If the handover from the Small Cell to the Macro Cell or between two Macro Cells is performed, the algorithm takes into account only the comparison of the signals levels (including the hysteresis margin).

4.1 *Assumptions*

In order to make the proposal feasible, several reasonable assumptions are defined:

- Assumption I: The network can store the information about the signal level, which each UE observes while it is connected to any eNB of the network
- Assumption II: The network saves the information about the station which serves each UE.

4.2 *Algorithm*

The procedure of the proposed algorithm is explained in this section. The handover decision is based on a comparison of the signal levels received by the serving station and the target station. The signal levels are obtained by a periodic measurement and reporting of the signals transmitted by the different stations as it is done in conventional cellular networks. The signal level received by the UE is influenced by many factors such as the transmitting power of the Macro or Small Cells or path losses and other effects like fast fading or shadowing. The signal level received by the k-th UE from the small or macro cell is defined as:

$$\mathrm{S(k)} = \mathrm{P_{Tx}} - \mathrm{PL(k)} - \mathrm{u(k)} \qquad (1)$$

where $S(k)$ is the signal received by the user k, $\mathrm{P_{Tx}}$ the transmitting power of the base station, $PL(k)$ denotes the path loss, and $u(k)$ indicates the effects such as shadowing, fast fading, etc.

The conventional decision on handover is based on the comparison of the signal levels received by the different base stations, using also a hysteresis margin (denoted as Δ_{HM}). If we define $S_s(k)$ as the signal level received by the UE from the serving station and $S_t(k)$ from the target station, the conventional condition required to be met to perform a handover is:

$$S_t(k) > S_s(k) + \Delta_{HM} \qquad (2)$$

In our algorithm, the proposed idea is to add other requirements to approve the handover. The algorithm estimates the gain in signal level in order to evaluate if the handover is going to be profitable in terms of gain in signal quality over expected time spent by the user in the target cell. So, the algorithm evaluates the future signal level using the historical information of all the UEs, which have already stayed in the simulation of handover between the $cell_s$ and $cell_t$. The algorithm also checks if the previous handovers were profitable in terms of gain in signal quality or not. In conclusion, the algorithm evaluates how profitable is to perform the handover depending on how advantageous were the previous handovers and on the estimation of the signal quality experienced by the UE if the handover would be performed or not.

The procedure of the proposed algorithm is composed of several steps. First of all, the algorithm follows all steps considered in recent networks. It means the signal level received from the target cell is compared with the signal level of the serving station, including the hysteresis. Then, in addition to the conventional approach, the algorithm estimates the future signal power of the target cell and the one of the serving station. The next step of the algorithm is to evaluate if the previous handovers were beneficial for the UEs or not. The previous handovers, which the algorithm takes into account, are those performed by the UEs following the same or similar path as the investigated UE. In other words, the algorithm considers handovers when the UEs have been served by the same base station and have been trying to perform the handover to the same target cell. If the past handovers have not been profitable, the algorithm decides to keep the UE connected to the serving station, which means, not to perform the handover. If the past handovers have been profitable, the estimated signals are exploited for decision on whether the handover should be performed or not. The signals obtained on the previous steps are used now in order to evaluate the gain in signal level. The gain in signal level obtained by the UE depends on the estimated duration of the residence time in the small cell. Finally, if the estimated gain exceeds a threshold, the handover is performed. Otherwise, the UE stays connected to the serving cell.

4.3 ***Estimation of the future signal level***

In order to estimate the future signal level, the network has to save all the values of the signal level received by each user from the serving station and from the potential target stations. With the information about all the signal levels received from each station, the algorithm is able to estimate the future gain.

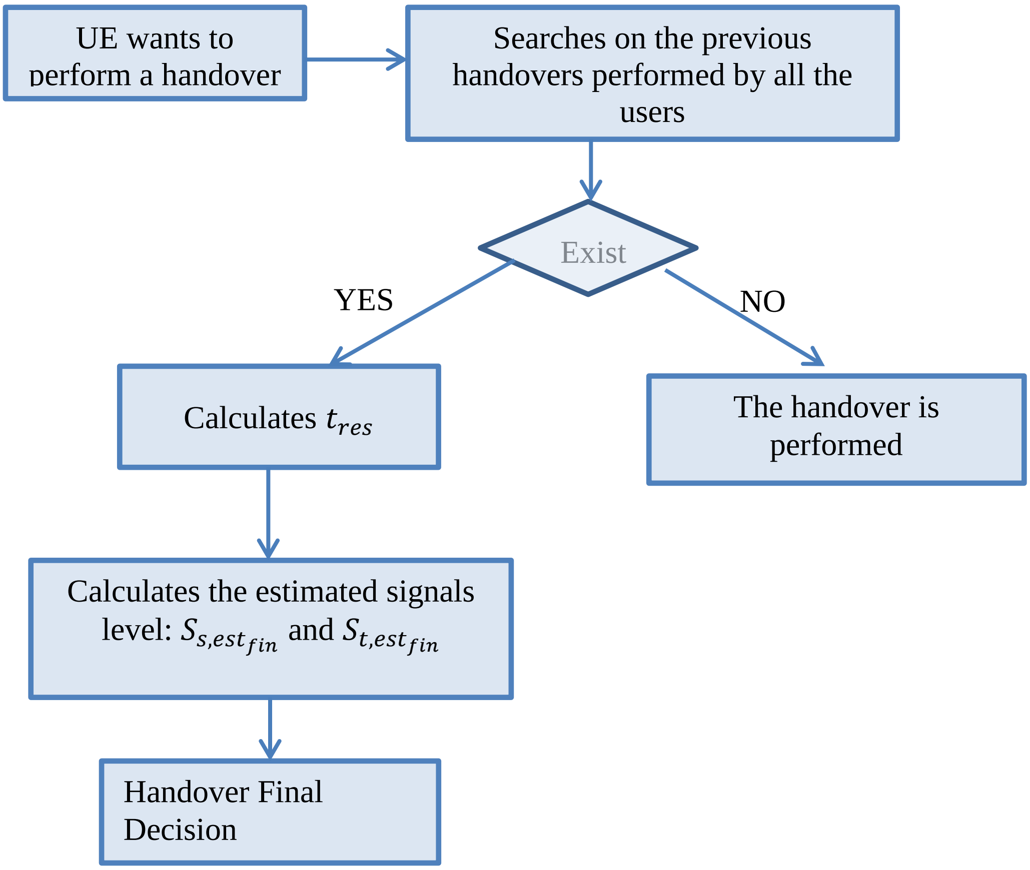

Figure 2. Estimation of the Signal Level

The part of the algorithm to estimate the future signal level is explained in Figure 2. For each user, the algorithm checks if has previously performed handover between the $cell_s$ and the $cell_t$ (or, as we will explain in the next subsection, they should have been performed). The proposed solution takes into account the time when the handover was initiated and the time that each handover lasted. Then, the algorithm calculates the mean time spent by the UE in the target cell. More specifically, the algorithm computes the mean time of residence in the target cell among all the handovers performed by all the users. The average time is computed giving a higher priority to the information related to the UE, which wants to perform the handover (denoted as $\mathrm{UE_h}$in the rest of the thesis). The mean time of residence in the target cell of the UE willing to perform the handover ($t_{res,UE}$) and of the other UEs ($t_{res,others}$) are computes as follows:

$$t_{res,UE}(i) = t_{final}(i) - t_{initial}(i) \qquad (3)$$

$$t_{res,others} = \frac{\sum_{u \neq \mathrm{UE_h}} \sum_{i=1}^{m(u)} \left(t_{res,u}(i)\right)}{\sum_{u \neq \mathrm{UE_h}} m(u)} \quad (4)$$

$$t_{res,\mathrm{UE_h}} = \frac{\sum_{u = \mathrm{UE_h}} \sum_{i=1}^{m(u)} \left(t_{res,u}(i)\right)}{\sum_{u = \mathrm{UE_h}} m(u)} \quad (5)$$

where u identifies the user, $m(u)$ represents the number of previous handovers between cell$_s$ and cell$_t$ performed by the user u , $\mathrm{t_{final}}$ is the time when the residence in the small cell of the user ends (handover from the cellt) and $\mathrm{t_{initial}}$ the time when the residence in the small cell of the user starts (handover to cellt).

The reason to separate the data obtained from the UE performing handover and data about handovers of other users is to give priority to the user-specific behavior as behavior of each user can be different. For that reason, the final value of the estimated residence time is defined as:

$$t_{res} = \alpha * t_{res,\mathrm{UE_h}} + (1 - \alpha) * t_{res,others} \quad (6)$$

where the parameter α is chosen to give more or less importance to the different information that the algorithm has. Note that for$\alpha = 0.5$, all the UEs are weighted equally with no priority for any user and for$\alpha = 1$; only the individual statistics of the UE performing handover are considered.

After computation of t_{res}, mean signal level of each UE is computed using the information that has been collected previously. In order to calculate it, the algorithm uses the initiated time of each handover and the estimated duration of them. If there is no past coincidence between the handover that the user wants to perform and the historical ones, the handover is always performed like in conventional handover decision to avoid a call drop. On the other hand, if there is past coincidence, the algorithm will obtain all the values of the signal levels, which the UEs have received during the residence in the target cell. Probably, one UE has performed more than one handover to this small cell. The estimated signal level of each user is represented by the mean of the signal levels experienced during past connections to the investigated cells, so the estimated signal level is defined as:

$$S_{s,est}(u) = \frac{\sum_{i=1}^{m(u)} \sum_{t=t_{initial}(i)}^{t_{initial}(i)+t_{res}} S_s(u,t)}{m(u)} \quad (7)$$

$$S_{t,est}(u) = \frac{\sum_{i=1}^{m(u)} \sum_{t=t_{initial}(i)}^{t_{initial}(i)+t_{res}} S_t(u,t)}{m(u)} \quad (8)$$

where $S_{s,est}(u)$ is the estimated signal of the cell$_s$ using the historical information of the user u, $S_{t,est}(u)$ is the estimated signal of the cell$_t$ using the historical information of the user u , $S_s(u,t)$ represents the value of the signal level received by the user u from the cell$_s$ at the time t and $S_t(u,t)$ is the value of the signal level received by the user u from the cell$_t$ at the time t.

Once the estimated signal levels are obtained, different importance to the data that have been obtained by different users is given in the similar way as for estimation of the target cell residence time. More specifically, in order to derive final estimates of the signals experienced by the UE in the future (estimated signal level of the $cell_s$ and estimated signal level of the $cell_t$), the algorithm gives more importance to the historical information about previous handover which $\mathrm{UE_h}$has experienced comparing to the other UEs. This prioritization is defined by the following equations:

$$S_{s,est_{fin}}(\mathrm{UE_h}) = \beta * S_{s,est}(\mathrm{UE_h}) + (1-\beta) * \sum_{u \neq \mathrm{UE_h}} S_{s,est}(u) \qquad (9)$$

$$S_{t,est_{fin}}(\mathrm{UE_h}) = \beta * S_{t,est}(\mathrm{UE_h}) + (1-\beta) * \sum_{u \neq \mathrm{UE_h}} S_{t,est}(u) \qquad (10)$$

where $S_{s,est_{fin}}(\mathrm{UE_h})$ is the final estimated signal level received of the serving cell by the user $\mathrm{UE_h}$, $S_{t,est_{fin}}(\mathrm{UE_h})$ is the final estimated signal level received of the target cell by the user $\mathrm{UE_h}$, and β is the coefficient used to give priority to the historical data of the user, which wants to perform the handover.

4.4 *Classification of previous handovers*

One of the most important parts of the algorithm is the determination of the beneficial handovers. When the management of the network finds previous handovers, the signals are used later to decide if the handover should be performed or not. Nevertheless, one of the conditions to performing the handovers is that the previous handovers were profitable for the UE, which performed it. For that reason, the algorithm will evaluate, after each handover, how beneficial the past handover was in order to classify it as profitable or not.

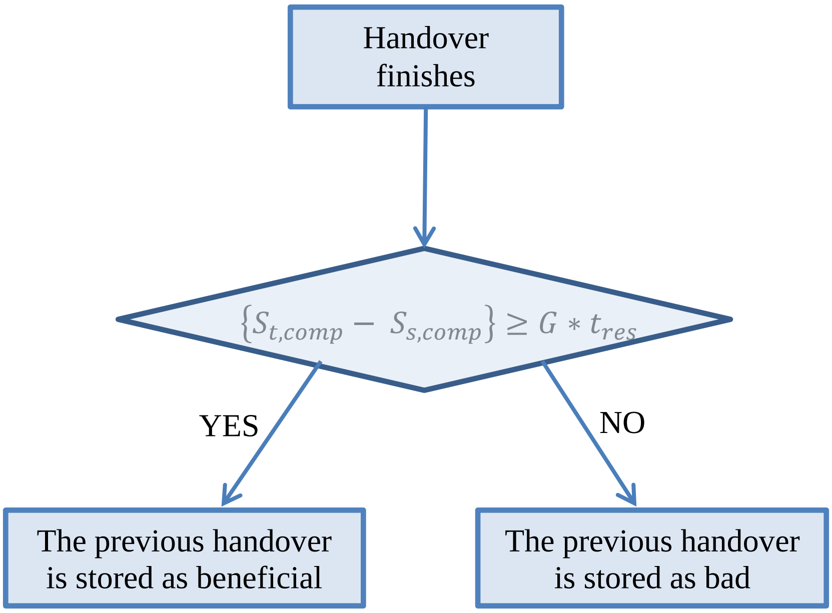

Figure 3. Classification of the previous handovers

The mechanism used to evaluate the previous handovers is explained in Figure 2. When the residence in the target station finishes, the network evaluates quality of the decision to perform handover to the target cell, i.e., if the handover to this cell was "good" or "bad" decision from the UE's perspective. For that evaluation, the real signals received by the user from the serving and the target cells are exploited. . In order to evaluate if the handover was beneficial or not, the network takes into account the proper part of the signal received by the UE. For that, the network uses the t_{res} and the amount of signal received is defined as:

$$S_{t,comp}(UE_h) = \sum_{t=i-t_{res}}^{i} S_t(UE_h, t) \qquad (11)$$

$$S_{s,comp}(UE_h) = \sum_{t=i-t_{res}}^{i} S_s(UE_h, t) \qquad (12)$$

where $S_t(UE_h, t)$ is the signal level received by the UE, which has performed the handover from the cell$_t$ at the time t , $S_s(UE_h, t)$ represents the signal level received by the UE, which has performed the handover from the cell$_s$ at the time t, $S_{t,comp}(UE_h)$

and $S_{s,comp}(UE_h)$ are the signal levels, which need to be compared with the threshold and i is the instant of time when the handover has finished.

Once the real signals levels received by the UE are obtained, the next step is to compare the difference between them in order to classify the previous handover decision as profitable or not. The comparison is denoted as:

$$\{S_{t,comp}(UE_h) - S_{s,comp}(UE_h)\} \geq G * t_{res} \qquad (13)$$

where G is the required gain (in dB) and t_{res} is the estimated residence time in the target cell

After the evaluation, the network stores the information about the convenience of each handover. This information contains the base station where the user equipment should have been connected in each instant of time, correcting the data if the previous handover was a bad decision from the UE’s point of view. More specifically, using the real signals received by each user, the algorithm is able to decide which base station was the best to be connected in order to obtain the best signal quality. The quality of decision is considered for evaluation of future handovers to improve further decisions.

4.5 *Handover final decision*

Once we have explained the process to obtain the estimated quality of signals received by the UE and we have explained the meaning of the variable which saves the historical correct handovers, the handover decision can be executed. The way to evaluate the final decision is explained as follows and represented in Figure 4.

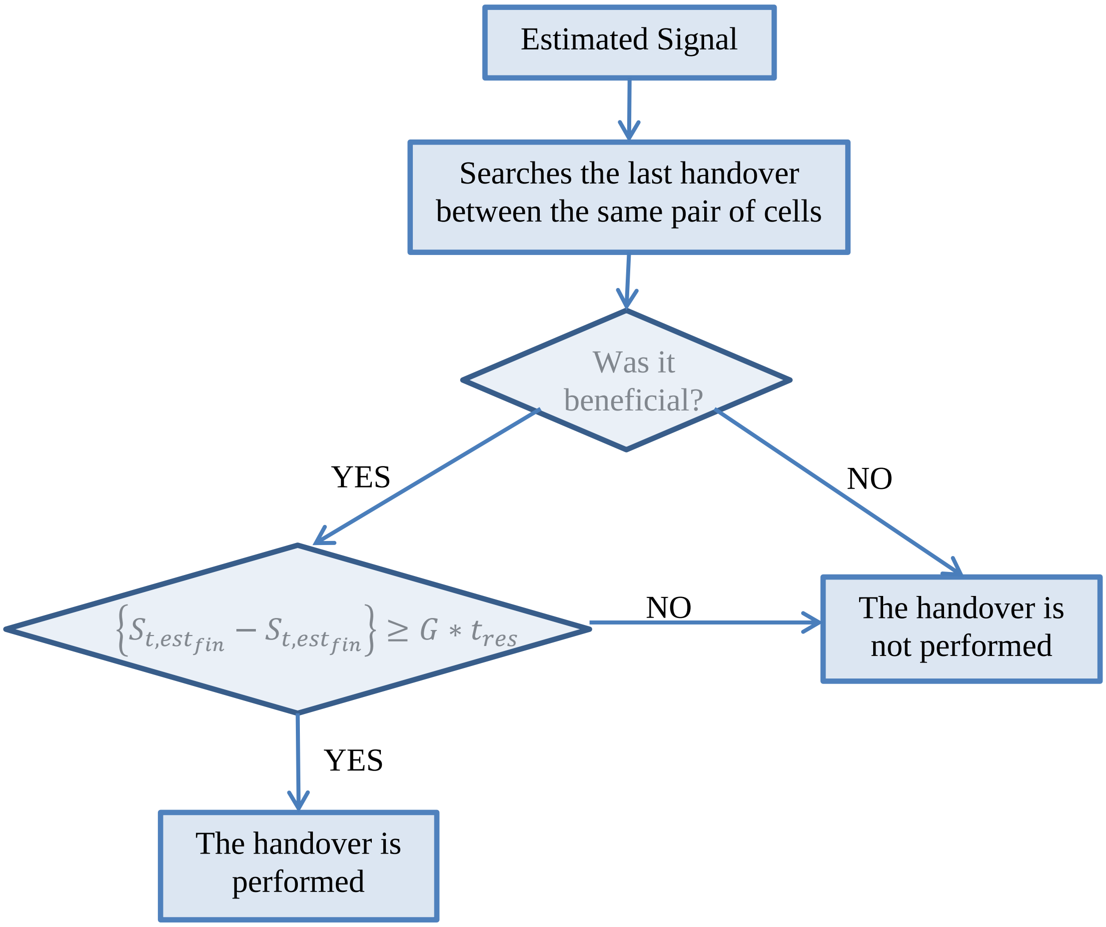

Figure 4. Handover Final Decision

After the final estimation of the signal, the algorithm checks the historical data of the user equipment, which wants to perform the handover. The procedure is to check the information about previous handovers and the information about the efficiency of performing the handover decision that has been previously evaluated. For that reason, the algorithm searches the last handover performed between the same pair of cells and it decides if it was a good decision taking into account the efficiency of this last handover. When the algorithm finds the last handover, it checks if to perform the last handover was a good or bad decision. If the decision was bad, the handover will not be performed. On the other hand, if the performance of the handover was a good decision, the algorithm continues to the next step.

In this new step, the algorithm has to compare the estimated signal levels of the target cell and the serving cell in order to evaluate the future gain. When the potential future gain is estimated, the algorithm compares it with the threshold calculated using the estimated residence time in the target cell and a pre-defined value:

$$\left\{\sum_{t=1}^{t_{res}} S_{t,est_{fin}}(UE\_h,t) - S_{t,est_{fin}}(UE\_h,t)\right\} \geq G * t_{res} \qquad (14)$$

where G is the required gain (in dB) and t_{res} is the estimated residence time in the target cell.

Finally, if the last condition is fulfilled, the handover will be performed.

5 Simulations and Results

In the next subsections we evaluate the algorithm in the scenario changing the different parameters to collect a big amount of results. In the first subsection we explain the scenario where the simulations are run, the mobility movement used and the parameters which are used on the simulation. After that, the results of the simulations are studied in order to compare the performance of the proposed solution with other algorithms.

5.1 *Scenario, models and parameters*

As we have previously mentioned, in the next subsection we explain the characteristics of the simulations. The section is organized by three subsections: a brief description of the scenario, an explanation of the mobility movement used and the list of parameters used during the simulations.

5.1.1 Scenario

The scenario where the simulations have been run is the same that is used in [14]. The urban scenario chosen for the evaluation of the algorithm is a real part of Prague, Czech Republic. This part of Prague is composed by five vertical streets and four horizontal streets. The scenario is a zone composed by different kinds of buildings. There are placed flats, shops, restaurants or offices. The buildings are of five floors height. To evaluate the algorithm, we need a scenario with Macro Cells and Small Cells. In this area, there are deployed four eNBs, in consonance with the real deployment of Vodafone mobile operator. About the deployment of the Small Cells, they are positioned randomly into the different existing buildings. The access mode of the Small Cells deployed are open or hybrid HeNBs. We assume that the closed HeNBs are removed automatically from the Neighbour Cell List of each UE. The simulation area is represented in the Figure 5.

Figure 5. Area of simulation in Prague, Czech Republic

The duration of each simulation run is 10000 seconds of real time. Out of this period, the first 500 seconds are a monitoring period used for collect information about the handover behavior. The monitoring period is set in order to collect information about the handovers. This information is used then by the algorithm, which requires this kind of information. For each simulation, 60 UEs are set up into the scenario with different mobility behavior, as we explain in the next section.

For the derivation of the signal propagation from the base station to the UEs, the models recommended by the Small Cells Forum are used. We have used the Okumura-Hata model for deriving the signal propagation of the eNBs and the ITU-R P.1238 for the HeNBs. The rest of the transmission characteristics are summarized in the next table:

Parameter	Value
Carrier frequency [GHz]	2
Transmitting power of eNBs/HeNBs [dBm]	27/15
Height of eNBs/HeNBs/UE [m]	32/10/1.5
Std. dev. Of Sadhowing (eNBs/HeNBs) [dBm]	8/4
Number of eNBs/HeNBs/UEs	4/0-90/60
Duration of simulation step [s]	1
Monitoring period [s]	500
Simulation real-time [s]	10000

Table 1. Transmission Characteristics

5.1.2 **Mobility model**

The mobility model used for simulations follows the model defined in [14]. The model used is based on the movement of users in urban areas. The mobility model used is based on Manhattan mobility model (MMM) supplemented with points of interest (POIs), as restaurants, shops, work or home. The mobility model used is explained in the appendix.

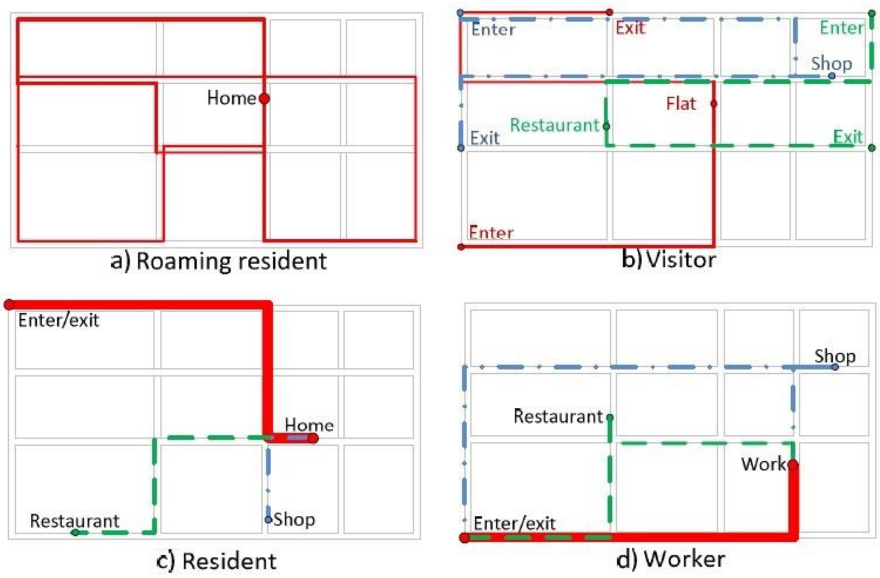

Figure 6. Examples of the users' movement

5.1.3 **Parameters**

The different parameters that we test in order to compare the performance in the simulations are the four following ones: Margin of hysteresis, BIAS, Required Gain and Number of femtocells deployed.

5.1.3.1 Margin of Hysteresis

The both values selected to evaluate the algorithm presented are 0 dB and 3 dB.

With the first one value, the number of handovers performed will be higher due to the relatively ease to fulfill the condition based on the comparison of the signal levels received. With the margin of hysteresis fixed in 0 dB, when one cell provides more signal level to one UE, the UE will initiate the procedure to perform the handover. Testing this value permits us to evaluate our algorithm when there are a lot of attempts to perform handover between the different cells deployed on the scenario.

On the other hand, the usage of 3 dB as a value of the margin of hysteresis reduces the total number of handovers performed. This is due to the probability to fulfill the conventional comparison of the signal level has been reduced because of the usage of this high value. With this margin of hysteresis, we can study how the algorithm behaves when the number of handovers performed is not high.

5.1.3.2 BIAS

The parameter BIAS is used in the simulation in order to increase the residence time that the UEs remain connected to the small cell network. One of our goals is to offload the main network (composed by macro cells) and to increase the time that the UEs remain connected to the small cells. With the parameter BIAS we force the UE to stay connected to the small cell network. The different values of BIAS that we simulate are BIAS=[0,5,10] dB. We explain what means each value in the next sections.

5.1.3.2.1 BIAS=0 dB

When the parameter BIAS takes this value, it means that the algorithm uses the conventional comparison of the received signal level in order to evaluate the performance of the handover. For that reason, the comparison follows the next equation:

$$S_t(k) > S_s(k) + \Delta_{HM}$$

Where the $S_t(k)$ is the target station of the user equipment k, $S_s(k)$ is the serving station of the user equipment k, and Δ_{HM} represents the margin of hysteresis.

5.1.3.2.2 BIAS=5,10 dB

Contrary to the last section with BIAS=0 dB, now, the new value of this parameter take importance to the simulation. The new requirement to fulfill in order to perform the handover is expressed by:

$$S_t(k) + \beta_t > S_s(k) + \beta_s + \Delta_{HM}$$

Where the $S_t(k)$ is the target station of the user equipment k, $S_s(k)$ is the serving station of the user equipment k, and Δ_{HM} represents the margin of hysteresis, the parameter β represents BIAS and it takes the value BIAS=0 when the target or the serving station is one macro cell or takes BIAS=5 when the target or the serving station is one small cell.
With this parameter, the main objective is to maintain the UEs connected to small cells stations, allowing the core network offloaded. As higher is the value of BIAS, the UEs remain more time connected to the small cell network.

5.1.3.3 Required Gain

The required gain is one parameter that the algorithm uses in order to decide if the handover has to be performed or not. This parameter is used as a condition after the estimation of the future signal level that the UE will receive if he performs the handover to the cell. For that reason, the algorithm is simulated with 6 different values of the required gain in order to study the performance of the algorithm in each case.

The values selected for the simulations are [-1, 0, 1, 2, 5, 7] dB. With these ones, we can study the different behavior of the algorithm depending on the required gain selected, comparing the reduction of handovers performed, the residence time in each network or the SINR level received, among others statistics collected.

5.1.3.4 Number of Small Cells

The number of small cells deployed on the scenario is an important parameter in order to study the performance of the algorithm. The deployment of the small cells and the density that they have in one scenario is important to evaluate the different statistics that we obtain during the simulations. In this case, we have simulated the algorithm for 0, 30, 60 and 90 small cells deployed. For each amount of small cells deployed, we have run the simulations combined with the other three parameters.

5.2 *Simulations*

This part of the thesis is divided in two sections: „Handover Decision with Throughput Estimation and Learning“ and „Comparison with other algorithms“. In the first one, we present the results obtained in the simulations done to test the performance of our proposed algorithm. The parameters that we change in order to observe the results are the number of femtocells deployed on the scenario that the simulations are done and the value of the threshold (G). The idea is to evaluate the algorithm with different values of the threshold in the same scenario. With these changes, we want to evaluate the different results that we obtain and how the algorithm improves the handover performance.

5.2.1 **Handover Decision with Throughput Estimation and Learning**

5.2.1.1 Zero Femtocells Deployed

The first scenario where we want to test the performance of our algorithm is in the scenario with 0 femtocells deployed. We want to study if the algorithm behaves in the same way in the case that no one small cell is deployed.

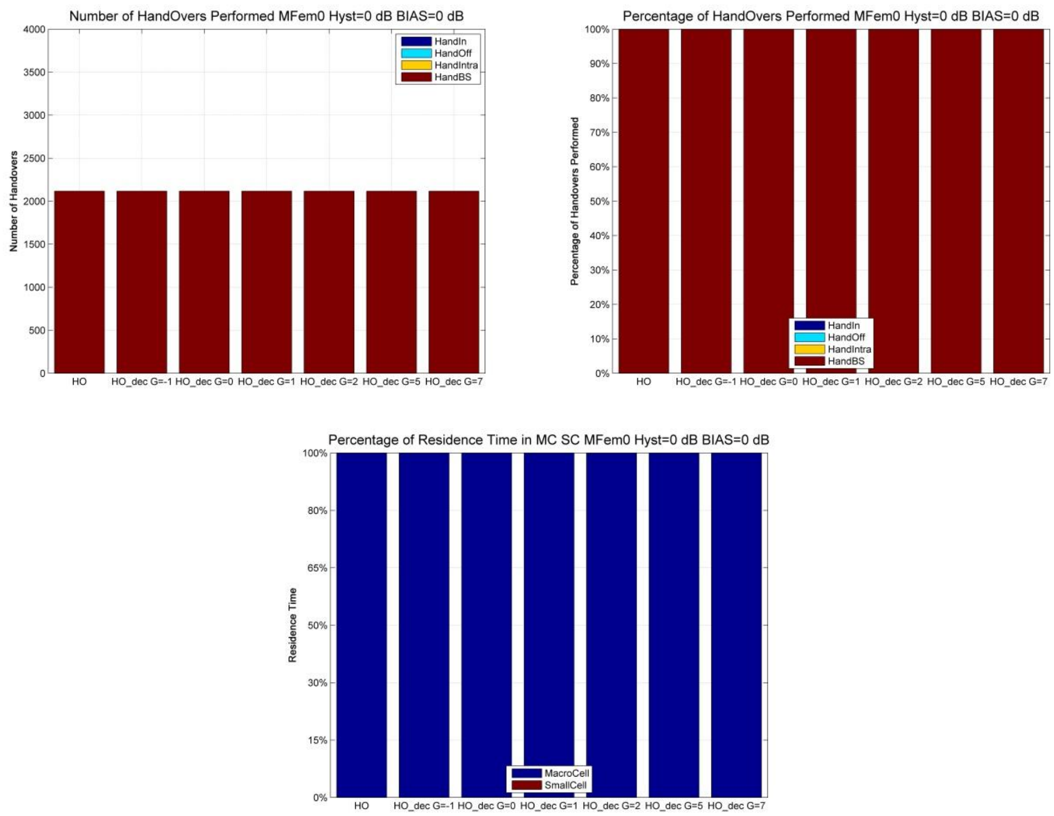

Figure 7. Results of NumFem=0 and MH=0 dB

As we can see in the figures showed above, the statistics do not change when we evaluate our algorithm. The statistics are exactly the same than the statistics provided by the conventional handover technique. The number of handovers performed is the same in every simulation, the percentage of handovers performed are always between macro cells and all the time the UEs are connected to the macro cell network. In addition, the number of redundant handover performed is the same in all the cases.

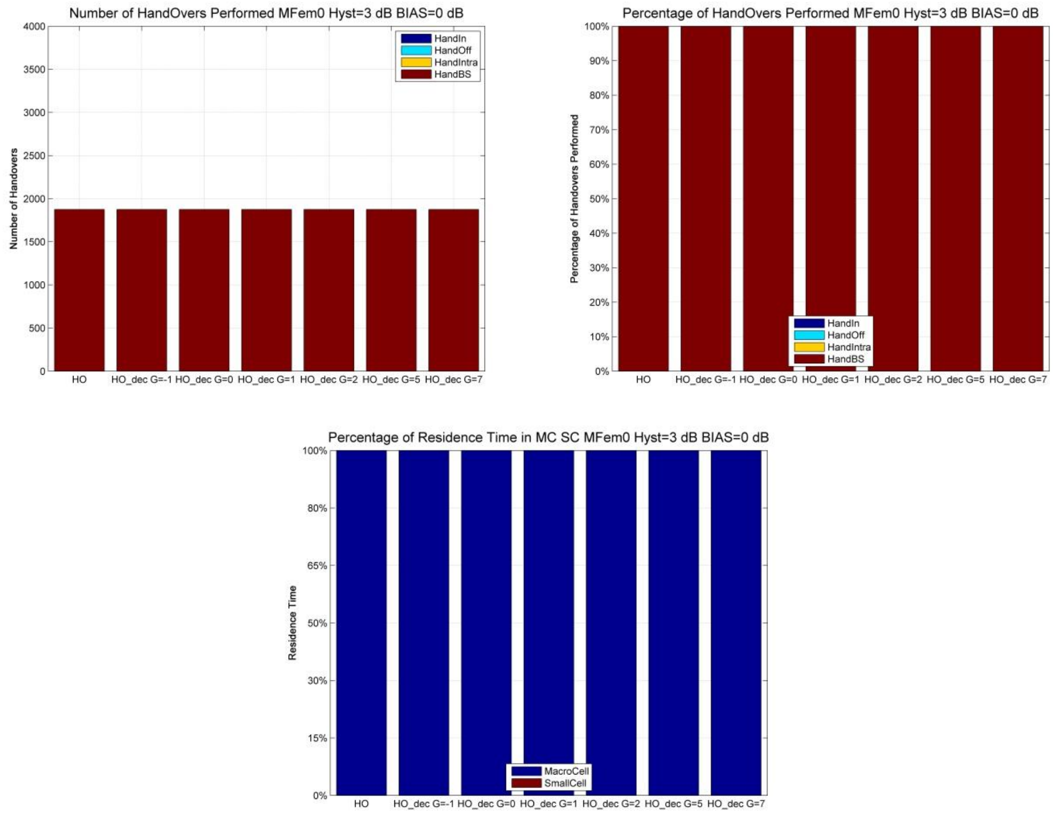

Figure 8. Results of NumFem=0 and MH=3 dB

In the simulation using as a margin of hysteresis the value of 3 dB, the performance in all the simulations is exactly the same. All the statistics have the same value, as it happens with the margin of hysteresis fixed in 0 dB.

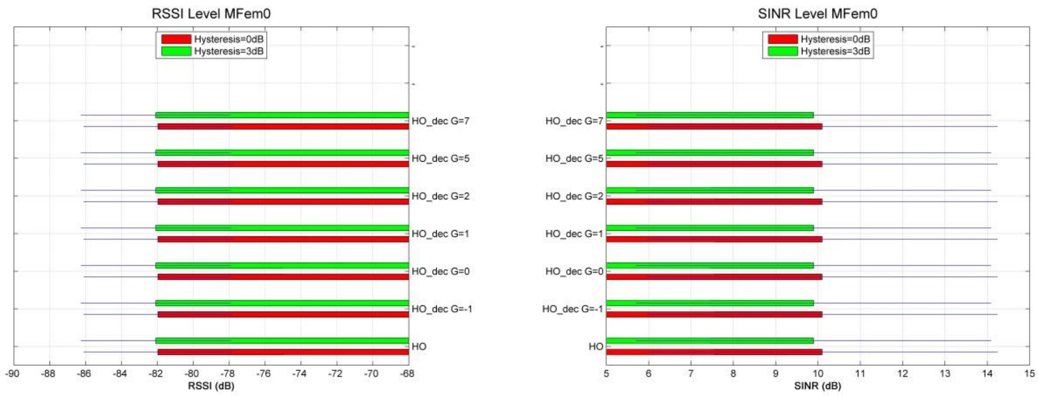

Figure 9. RSSI and SINR Level NumFem=0

The RSSI level and the SINR level is the same in every simulation as well. There are not differences among the evaluations in comparison with the conventional handover technique. In the next table we can see the SINR level more in detail, the SINR level has more importance in order to evaluate if the performance of each simulation is valid or not, because a big loss in that parameter mean the loss of quality of the signal and, due to that, the connection with the network.

	HOver	HO G=-1	HO G=0	HO G=1	HO G=2	HO G=5	HO G=7
Hyst=0dB	10.1	10.1	10.1	10.1	10.1	10.1	10.1
Hyst=3dB	9.8963	9.8963	9.8963	9.8963	9.8963	9.8963	9.8963

Table 2. SINR level received NumFem= 0

As could be expected, the SINR level does not change in the different simulations due to the performance is the same in every one of them.

5.2.1.2 Thirty Femtocells Deployed

In this scenario we simulate our algorithm if 30 femtocells are deployed in the investigated area. The goal is to test if our algorithm can reduce the number of handovers performed in comparison with the conventional handover technique and how it makes it, taking into account another statistics, not only the amount of handovers performed.

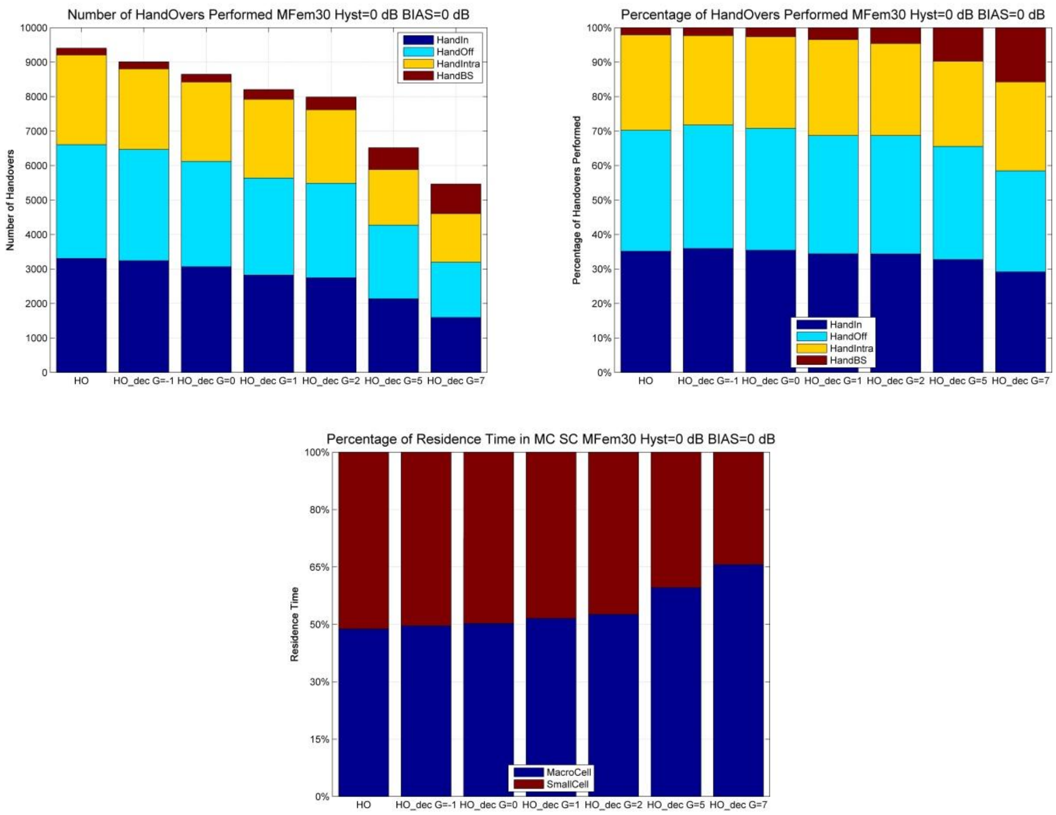

Figure 10. Results of NumFem=30 and MH=0 dB

The statistics showed above are the statistics obtained from the simulations done when the margin of hysteresis takes the value of 0 dB. As we can see in the Figure 10, the number of handovers performed decrease as the threshold (G) increases. As the threshold is increasing, the total number of handovers performed decreases, but if we observe more in detail the statistics, we can observe that the amount of handovers performed between macro cells is increasing in each step. For that reason, if we focus now in the residence time spent in each mobile network, the percentages remain more or less constant until the threshold takes the value of G=2.

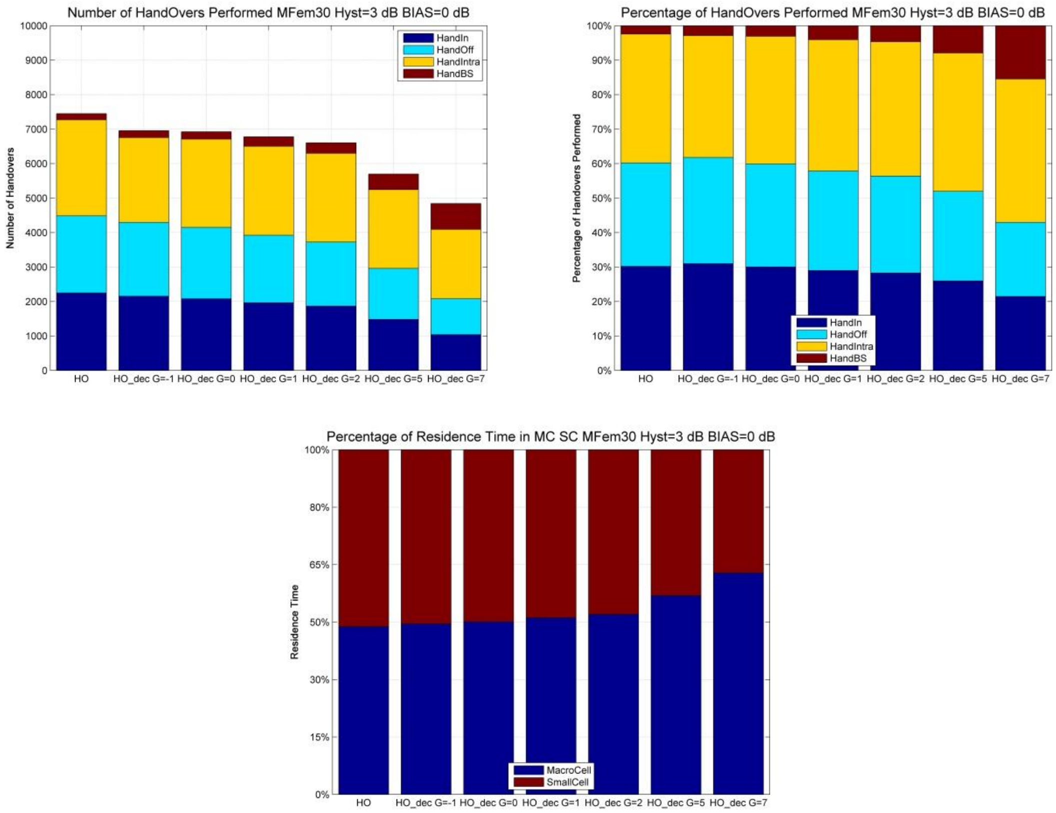

Figure 11. Results of NumFem=30 and MH=3 dB

When the margin of hysteresis takes the value of 3 dB, the behavior of our algorithm is the same than when it takes the value of 0 dB. The number of handovers performed is decreased in each step, as the value of the threshold is increasing. However, the reduction now is less effective. The explanation about why the reduction is less effective with the simulation when the margin of hysteresis takes the value of 3 dB is that the requirement of performing the handovers is more difficult to fulfill. The thresholds simulated is G=[-1,0,1,2,5,7]. If the margin of hysteresis is 3 dB, when appears one possible handover (more specifically, when the condition between the signal of the target station and the signal of the serving station taking into account the margin of hysteresis is fulfilled), the probability to fulfill the requirements, which uses the value of the threshold, is easier, due to the margin of hysteresis is higher than the thresholds simulated. For that reason, in the simulations that we can really notice the difference on the amount of handover performed is when the threshold is higher than the hysteresis value.

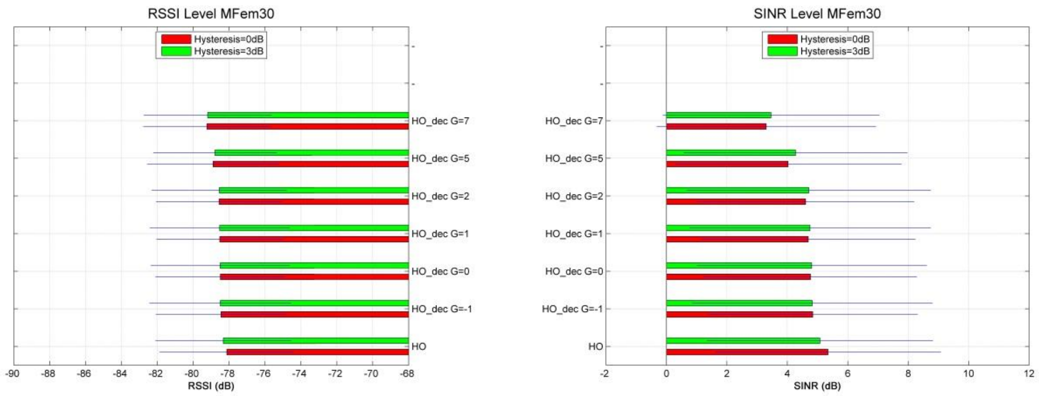

Figure 12. RSSI and SINR Level NumFem=30

	HOver	HO G=-1	HO G=0	HO G=1	HO G=2	HO G=5	HO G=7
Hyst=0dB	5.3496	4.8422	4.7679	4.6928	4.6051	4.0244	3.3042
Hyst=3dB	5.0801	4.8212	4.8066	4.75	4.7103	4.2713	3.4596

Table 3. SINR level received NumFem=30

Finally, we focus on the RSSI level and on the SINR level. The values received in the simulations of our algorithm decrease as much higher is the value of the threshold. The number of handovers avoided increases in each simulation and the UE is not always connected to the best station. For that reason the quality of the signal decreases when the threshold is high. This is more remarkable in the simulation that uses the values of G=5 and G=7 for the threshold. The SINR level suffers a significant decrease. We can check the SINR levels obtained by each simulation in the table. The SINR level suffers a significant drop due to the reduction of handovers performed.

5.2.1.3 Sixty Femtocells Deployed

The number of femtocells deployed in the scenario simulated is increased again. We want to test our algorithm with a higher amount of small cells. The goal is to simulate the algorithm with a higher deployment of femtocells to check the results and compare the results with the ones obtained with lower density of small cells.

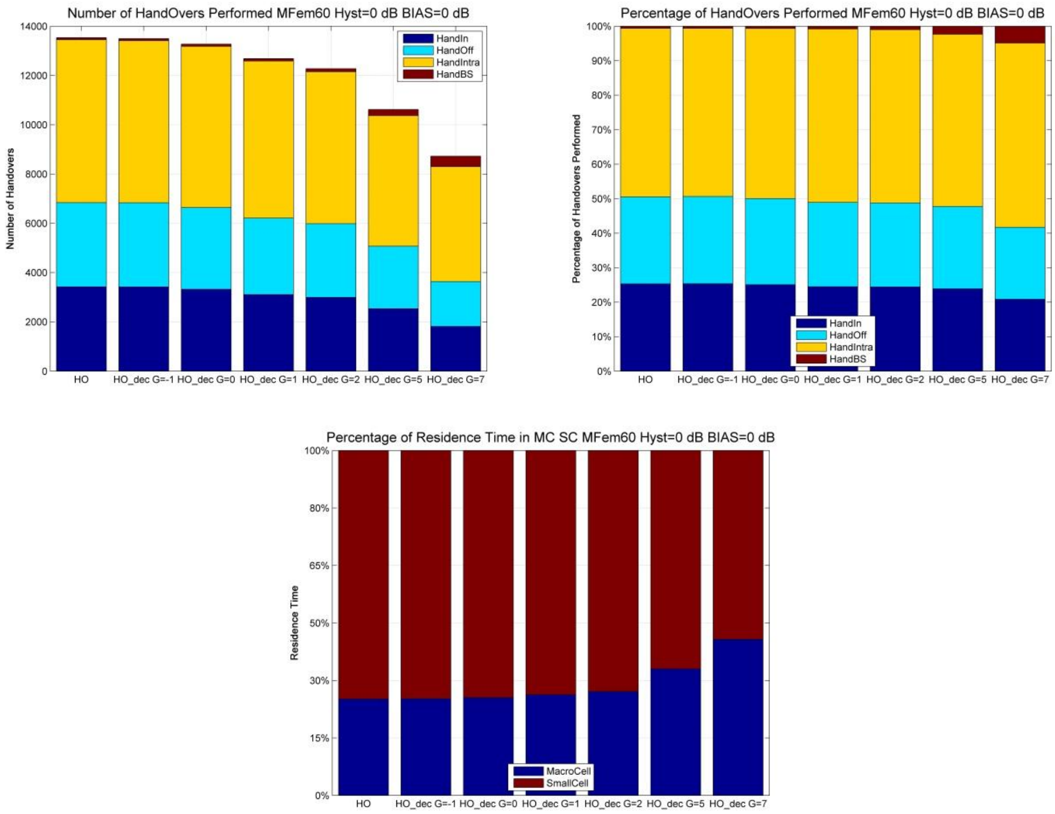

Figure 13. Results of NumFem=60 and MH=0 dB

The number of femtocells deployed in the scenario increases and, for that reason, the total number of handover performed increases as well. Specifically, the type of handover that more increases is the handover between femtocells (HandIntra). We can see that in the figures. The number of handovers increases and the percentage of this kind of handover takes more prominence in the results. Again, the total number of handovers performed decreases in each step of the simulation of our algorithm. As we have previously mentioned, the number of HandIntra performed increases. That fact allows to offload the main network (composed by Macro Cell). For that reason, the percentage of residence time on small cells increases in these simulations (respect the simulations with 30 femtocells), despite of it decreases in each step due to the reduction of handovers performed and the increase of handovers between Macro Cells. Even in the last simulation, with takes the value G=7 of the threshold, the percentage of residence time in the small cell network overtakes the 50%.

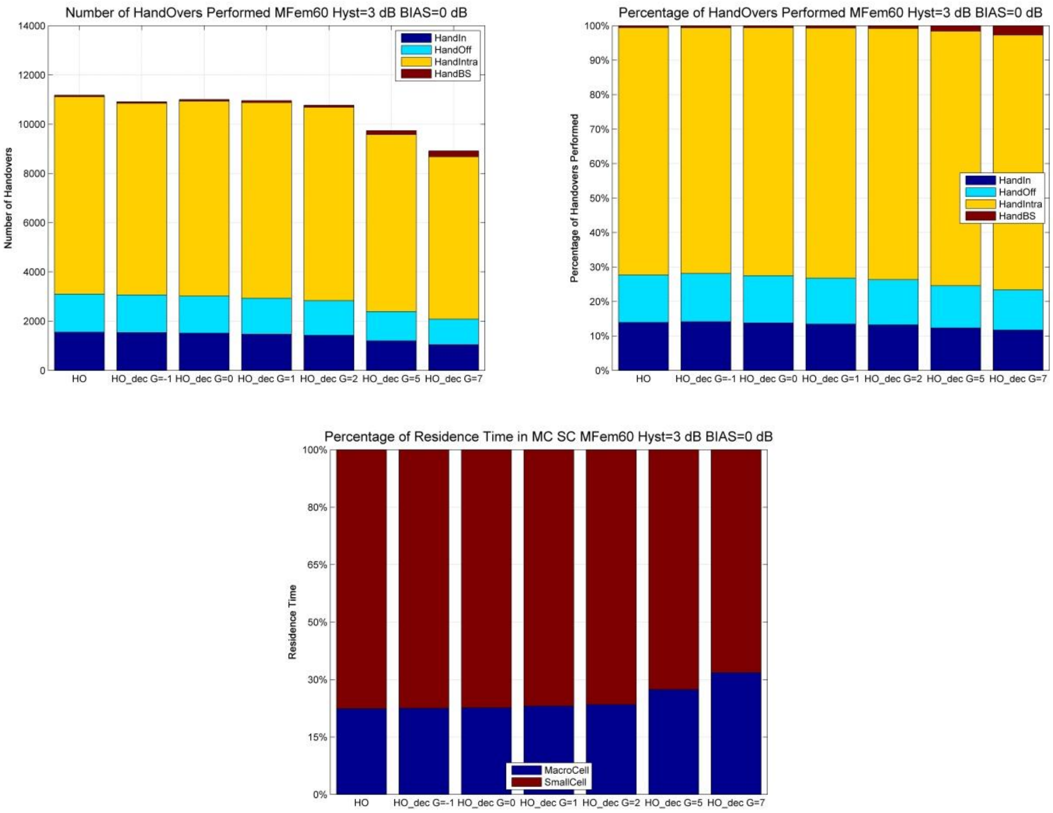

Figure 14. Results of NumFem=60 and MH=3 dB

The performance when the margin of hysteresis takes the value of 3 dB is similar to the previous one. The number of handovers performed is reduces as the threshold increases, but the decrement is less effective in this case again, as we have previously explained.

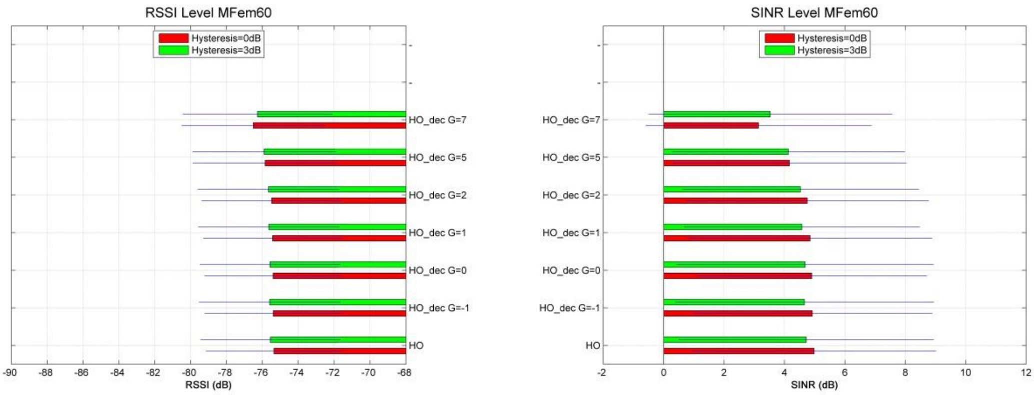

Figure 15. RSSI and SINR Level NumFem=60

However, the problem of the SINR level received remains. The level of the SINR decreases when the value of G (threshold) increases, and this remains remarkable mainly in the simulations with G=5 and G=7. However, the results which provides the simulation with the threshold G=2 have a good SINR level, the level just drop 0.2 dB in comparison with the original SINR level. When the simulations takes the threshold G=5, the drop is more significant, it drops 0.8 dB, but the reduction on the number of handovers is more significant.

	HOver	HO G=-1	HO G=0	HO G=1	HO G=2	HO G=5	HO G=7
Hyst=0dB	4.9817	4.9259	4.9058	4.8507	4.7583	4.1651	3.1423
Hyst=3dB	4.7206	4.662	4.6869	4.5762	4.5292	4.1256	3.5326

Table 4. SINR level received NumFem=60

We can focus on the statistics about the SINR level provided in the case of 30 femtocells and in the case of 60. If we compare the SINR level received when the margin of hysteresis is 0 dB, in the case of 60 femtoccells, the drop on the SINR level for the case of G=2 is 0.23 dB approximately, and 0.8 dB for the case of G=5. The difference between the SINR level of these cases and the original one has been reduced in comparison with the difference that presents in the case of 30 femtocells. In that case, the difference is 0.75 dB for the G=2 and 1.3 dB for the case with G=5.

5.2.1.4 Ninety Femtocells Deployed

As we have previously mentioned, the idea is to simulate the algorithm in different densities in order to compare the results and to study the performance of it in scenarios with higher density of small cells. For that reason, the number of small cells deployed is increased again until 90.

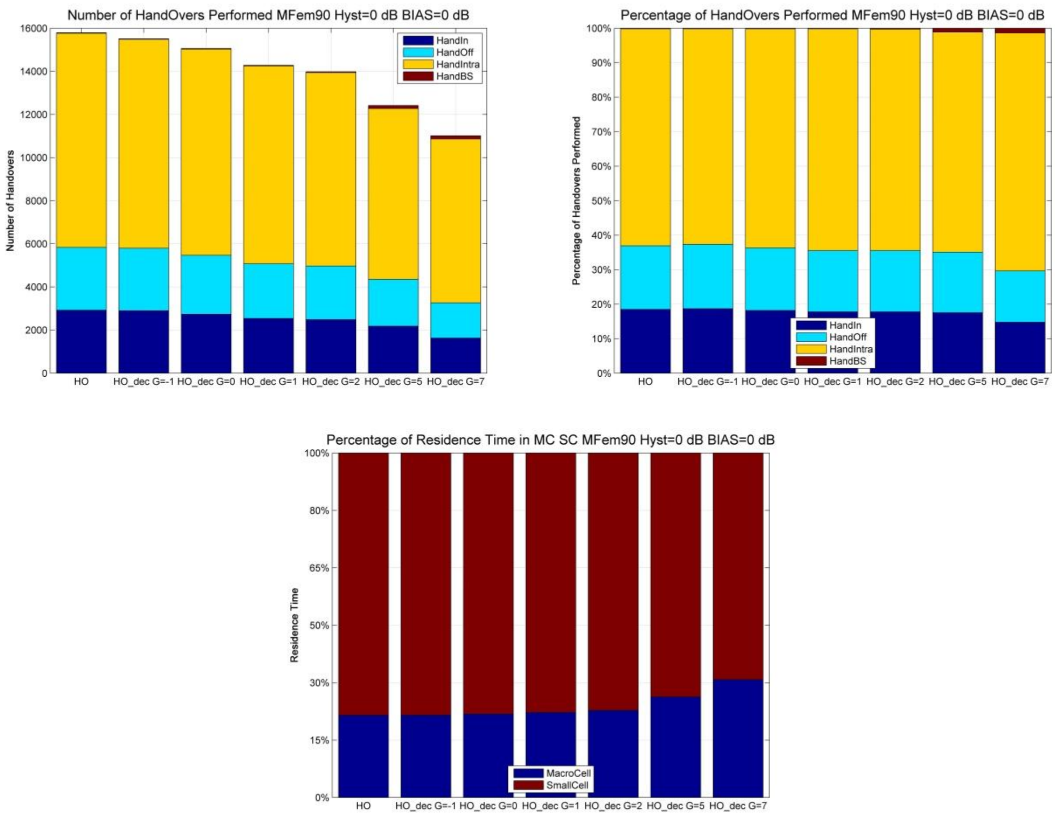

Figure 16. Results of NumFem=90 and MH=0 dB

As we can see in the Figure 16, the total number of handovers performed has increased again. This is due to the increment of small cells deployed, as we have explained previously. However, now every kind of handover has increased, not only the one between small cells, as has happened in the scenario with 60 femtocells. Otherwise, the reduction of the number of handovers performed is achieved again by the proposed algorithm. The reduction is more notorious as the value of the threshold increases. The percentage of HandIntra performed has decreased in this scenario, but the total number of handovers has increased as well. For that reason, the percentage of residence time in the small cell network is more or less the same that we have obtained in the simulation run in the scenario with 60 femtocells. The algorithm achieves to practically maintain the percentage that the conventional technique remains connected to the small cell network. Just in the last simulations, with the highest values of the threshold, the percentage is reduced significantly.

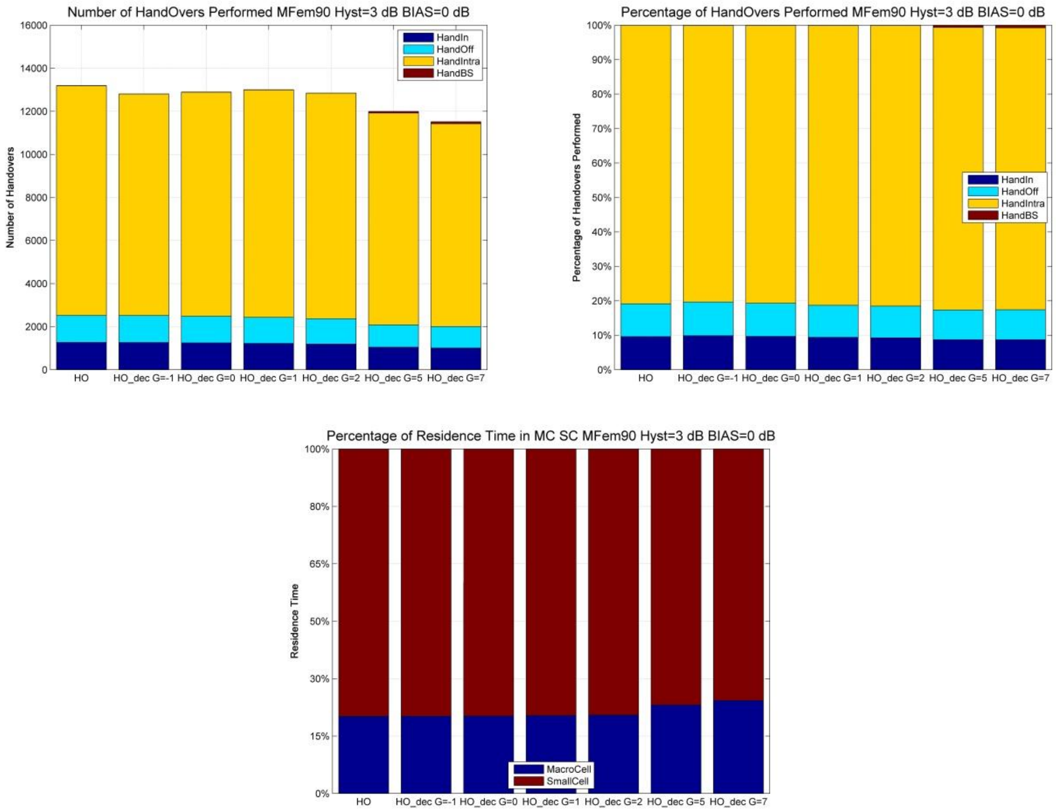

Figure 17. Results of NumFem=90 and MH=3 dB

The performance when the margin of hysteresis takes the value of 3 dB is similar to the previous one. The number of handovers performed is reduces as the threshold increases. The performance with margin of hysteresis fixed as 3 dB behaves in the same way, but the decrement is less effective in this case.

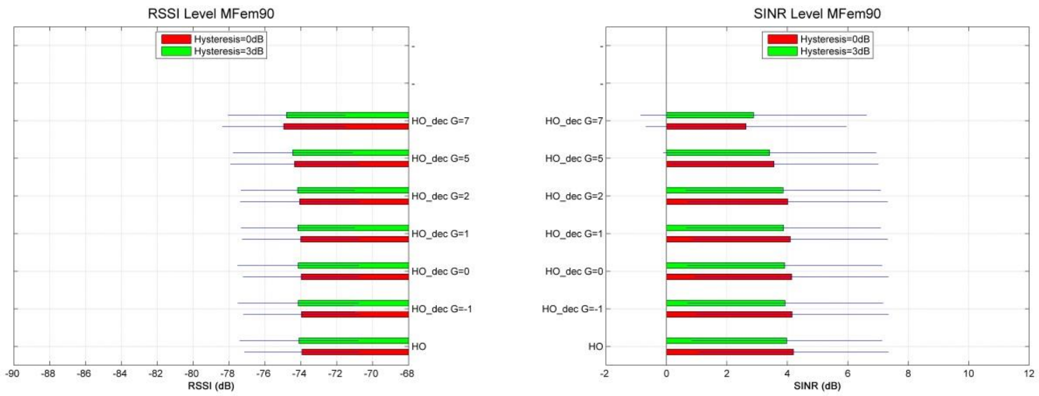

Figure 18. RSSI and SINR Level NumFem=90

Finally, it is time to focus in the RSSI and SINR level that each simulation receives. The RSSI level is less problematic and the level received in each simulation is decreasing as the threshold is increasing. Otherwise, the drop on this parameter is not so problematic than the drop on the SINR. We can study the SINR level in the next table.

	HOver	HO G=-1	HO G=0	HO G=1	HO G=2	HO G=5	HO G=7
Hyst=0dB	4.2059	4.1593	4.1468	4.1004	4.0129	3.5594	2.633
Hyst=3dB	3.9812	3.9254	3.914	3.8794	3.8627	3.4152	2.8839

Table 5. SINR level received NumFem=90

The SINR level drops only 0.19 dB in the case of G=2 and the margin of hysteresis fixed on 0 dB. In the same simulation but for the margin taking the value of 3 dB the decrement is 0.12 dB. However, the decrement of number of handovers is not significant in the case of the margin of hysteresis taking the value of 3 dB, but it is significant when this parameter takes the value of 0 dB. Moreover, if we compare these performances in the scenario with 90 small cells with the one with 60, we can realize that there is an improvement. The difference with the original value of the SINR level in the case of 60 femtocells was 0.23 dB for the margin of hysteresis fixed in 0 dB and 0.2 dB for 3 dB. In the case of G=5, the difference with the original SINR level was 0.8 dB for the margin fixed on 0 dB and 0.6 dB for 3 dB. If we compare these values with the ones obtained in the scenario of 90 femtocells, the results show that the difference in the first case is 0.65 dB and in the second one 0.57 dB.

5.2.2 Comparison with other algorithms

After studying the different parameters obtained with the previous simulations, now it is time to compare the algorithm with other ones. The comparison is done among the conventional handover mechanism, the solution proposed in [20], which is focused on the improvement of the SINR level, and with another algorithm proposed for us. This new algorithm skip the evaluation of the handovers as a good or bad and only estimates the future signal that the UE would obtain if performs the handover to the target cell. This new algorithm is represented in the figures as HO_thres.

The results obtained are classified depending on the number of femtocells deployed and the value of the BIAS used. Each section has the results for the values of hysteresis 0 dB and 3 dB. The results showed are: the number of handovers performed by each algorithm, the percentage of each kind of handover performed, the percentage of residence time connected to the macro cell network or to the small cell network, and the RSSI and SINR level received.

In order to compare the different behavior of each algorithm, we had to choose among the previous simulations. We have chosen them depending on the SINR level received; because of this parameter is the most restrictive. For each comparison, we have selected two values of the threshold *G*. The comparison is done organizing the results for the same hysteresis and then we show together the level of the RSSI and the SINR received by each simulation in order to compare the performance in both hysteresis cases.

5.2.2.1 Thirty Femtocells Deployed

5.2.2.1.1 BIAS=0 dB

The first scenario to describe is the one with 30 femtocells deployed and using the value of BIAS=0.

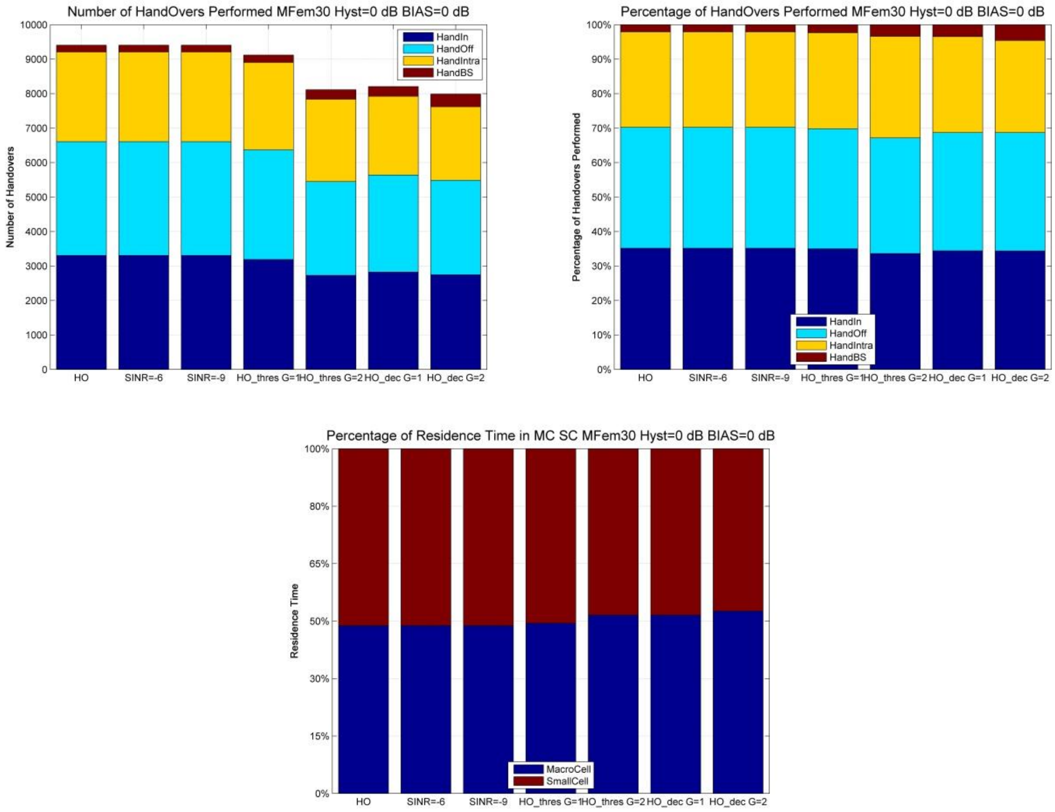

Figure 19. Results of NumFem=30, BIAS=0 dB and MH=0 dB

As we can see in the first figure, the interference coordination handover does not improve the amount of handovers performed. However, the main goal of the proposal is to improve the SINR level and not to decrease the number of handovers performed. On the other hand, the others two algorithms decrease the total number of handovers performed. The main goal of these algorithms is to decrease it. The percentage of each handover performed is more or less constant and the same happens in the percentage of residence time in each network. If we compare the algorithms HO_thres and HO_dec directly, we can observe that the algorithm based on the classification of the handovers as good or bad (HO_dec) achieves to decrease more the number of handovers performed.

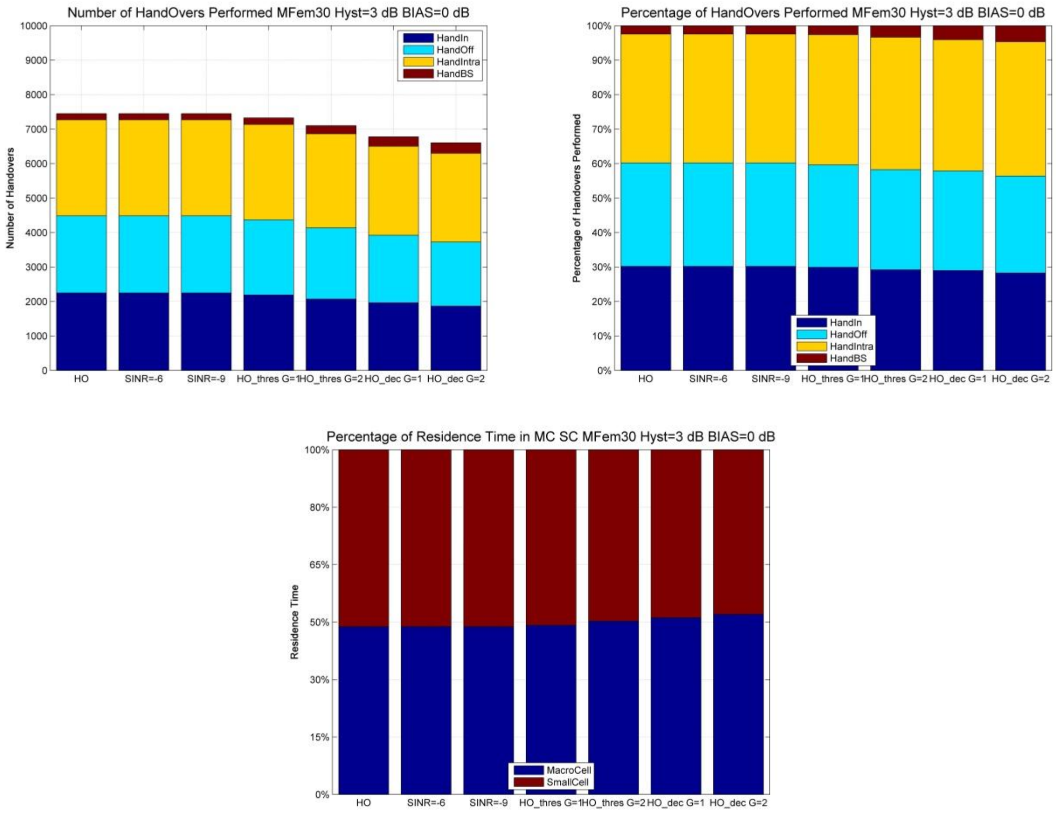

Figure 20. Results of NumFem=30, BIAS=0 dB and MH=3 dB

Now, the margin of hysteresis takes the value of 3 dB. The algorithms decrease again the number of total handovers performed. This decrement is bigger if the threshold takes a higher value. Otherwise, this decrement has more effect when the margin of hysteresis is 0 dB than with the margin is 3 dB. We can identify a significant increment on the number of handovers between macro cells (HandBS) in the last simulations, and due to that, a decrement in the residence time in the small cell network. Again, the handover technique using the classification of handovers decreases more than the others the number of handovers performed.

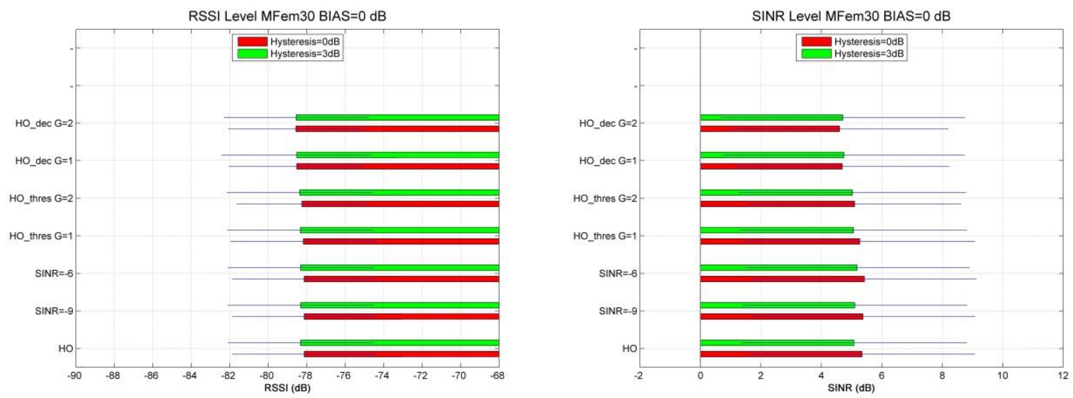

Figure 21. RSSI and SINR Level NumFem=30 and BIAS=0 dB

The RSSI level received by the UEs during the simulations is more or less constant. The average level is not affected in an alarming way. However, the restrictive signal level is the SINR. The drop of this parameter is more evident. The SINR levels obtained are shown in the next table:

	HOver	SINR=-6	SINR=-9	HO_thres G=1	HO_thres G=2	HO_dec G=1	HO_dec G=2
Hyst=0dB	5.3496	5.4253	5.3789	5.2727	5.104	4.6928	4.6051
Hyst=3dB	5.0801	5.1847	5.1075	5.0624	5.0282	4.75	4.7103

Table 6. SINR level received NumFem=30 and BIAS=0 dB

The drop in the SINR level suffered by the HO_dec algorithm is higher than the HO_thres algorithm. This is due to the higher decrement on the number of handovers performed. On the other hand, the interference coordination algorithm provides a higher SINR level than the conventional handover, that is because of the main goal of this proposal is to improve the SINR level.

5.2.2.1.2 BIAS=5 dB

The simulations presented below use the value of BIAS=5 dB in the same scenario than before.

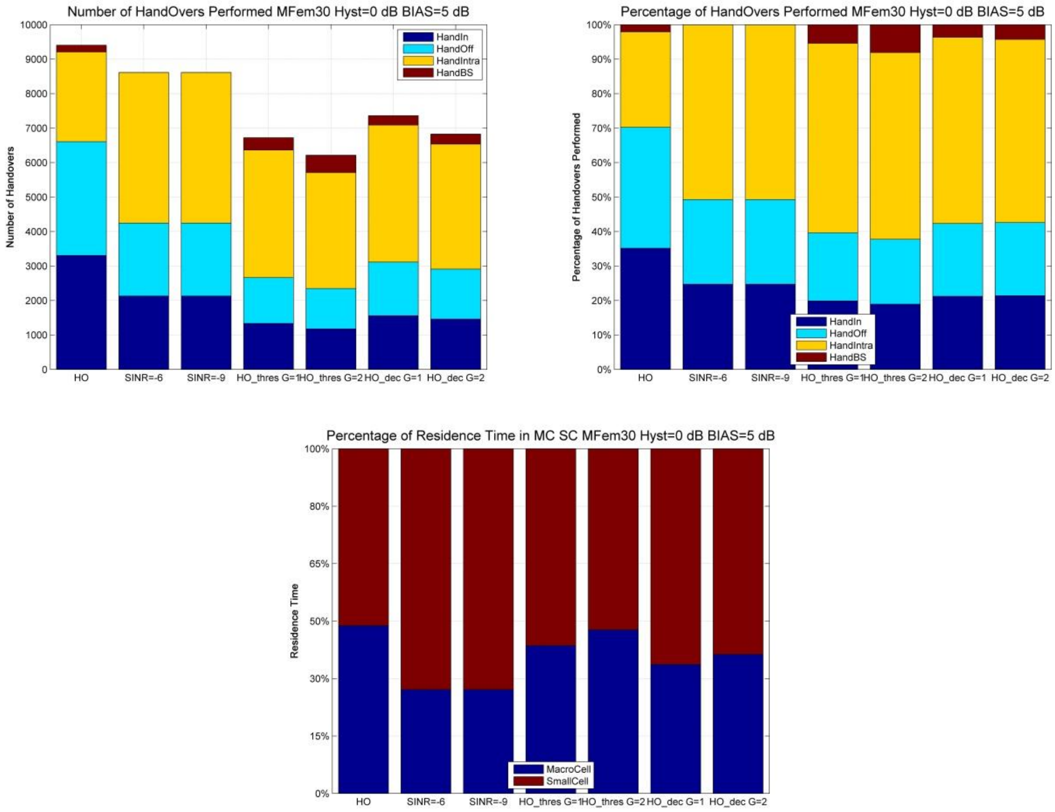

Figure 22. Results of NumFem=30, BIAS=5 dB and MH=0 dB

Using the value of BIAS=5 dB, all the algorithms decrease the total number of handover performed in comparison with the conventional technique. The algorithm that most reduce the amount of handovers is the HO_thres. However, this algorithm increases the number of handover between macro cells. This type of handover is insignificant in the interference coordination technique. This fact allows to this algorithm to be the best one reducing the residence time that the UEs remain connected to the macro cell network. In addition, the HO_thres is the worst in this parameter, maintaining more or less the percentages presented by the conventional technique. The HO_dec algorithm is in the middle of the both algorithms explained previously. The decrement is significant and the performance also allows to increase in a notorious way the residence time in the small cell network.

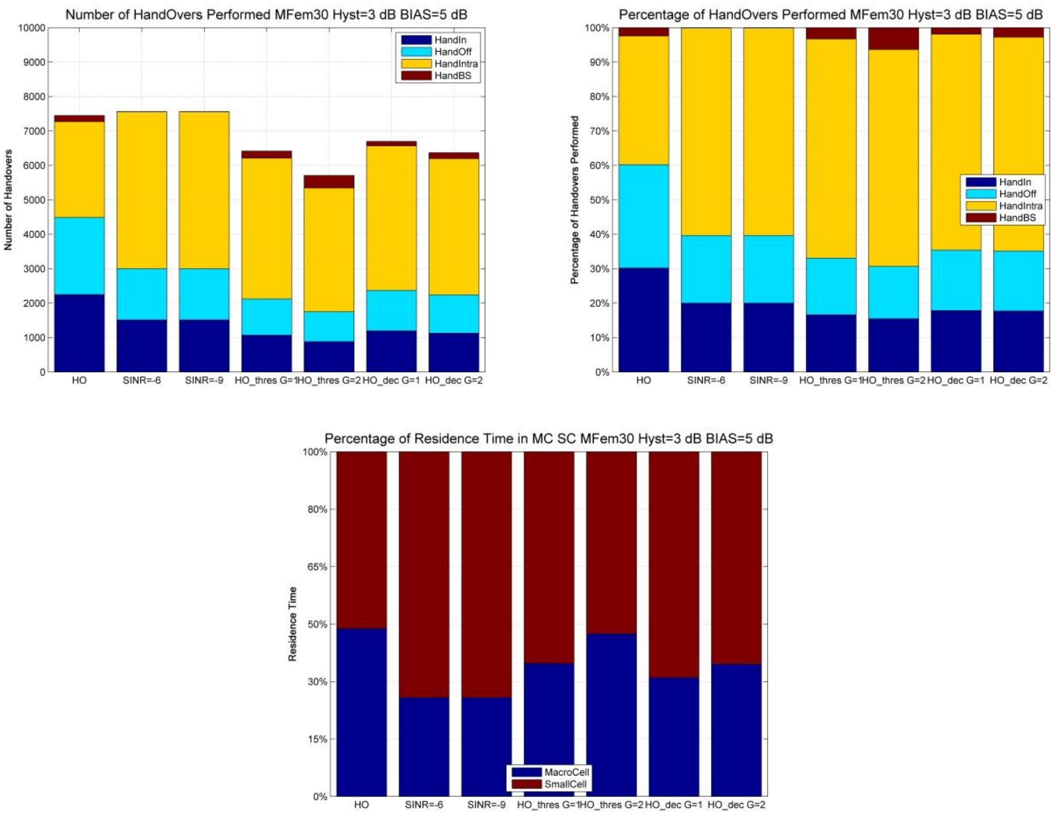

Figure 23. Results of NumFem=30, BIAS=5 dB and MH=3 dB

The behavior of the simulation with Hyst=3 dB is very similar to the simulation with Hyst=0 dB. Taking into account the number of handovers, the performance is really similar, being the HO_thres the one that most reduce, but having the lower residence time in the macro cell network as well. Nevertheless, in this case, we can observe that the interference coordination algorithm increase the number of handovers performed in comparison with the conventional technique.

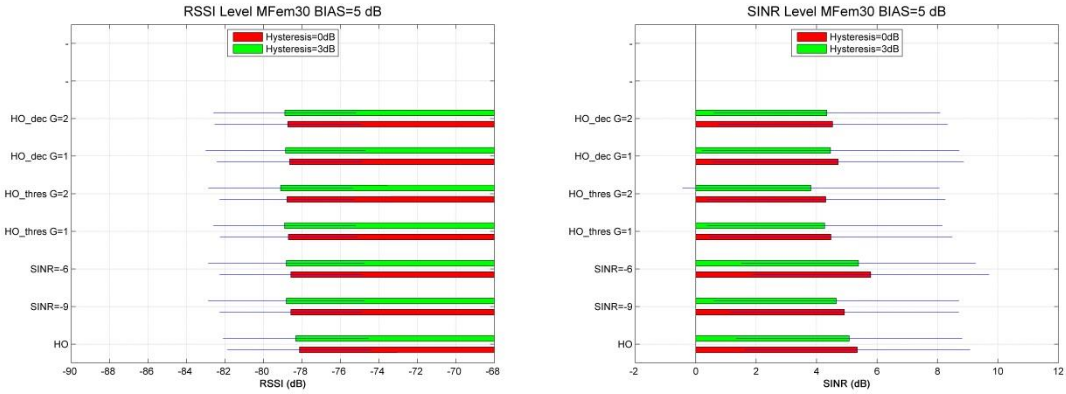

Figure 24. RSSI and SINR Level NumFem=30 and BIAS=5 dB

This time, the drop of the RSSI level in every simulation respect the conventional handover technique is evident. The explanation of that is the use of the parameter BIAS. The goal of using this parameter is to maintain the UE connected to the small cell network, even if the quality of signal is not the best and for that reason, the RSSI level suffers a significant decrement.

In the next table the SINR level of each simulation is presented:

	HOver	SINR=-6	SINR=-9	HO_thres G=1	HO_thres G=2	HO_dec G=1	HO_dec G=2
Hyst=0dB	5.3496	5.7919	4.9207	4.4785	4.3069	4.761	4.5306
Hyst=3dB	5.0801	5.3857	4.6511	4.2669	3.8125	4.4606	4.3415

Table 7. SINR level received NumFem=30 and BIAS=5 dB

The interference coordination algorithm remains providing the best results on SINR. Again, the algorithm achieves his purpose. On the other hand, the algorithms HO_thres and HO_dec provide a lower level of SINR in every case. However, if we pay attention to the results, we can see that the HO_dec provide a closer level respect the conventional technique in every case.

5.2.2.1.3 BIAS=10 dB

The value of the parameter BIAS is 10 dB now and the scenario is the same than before, the one with 30 femtocells deployed.

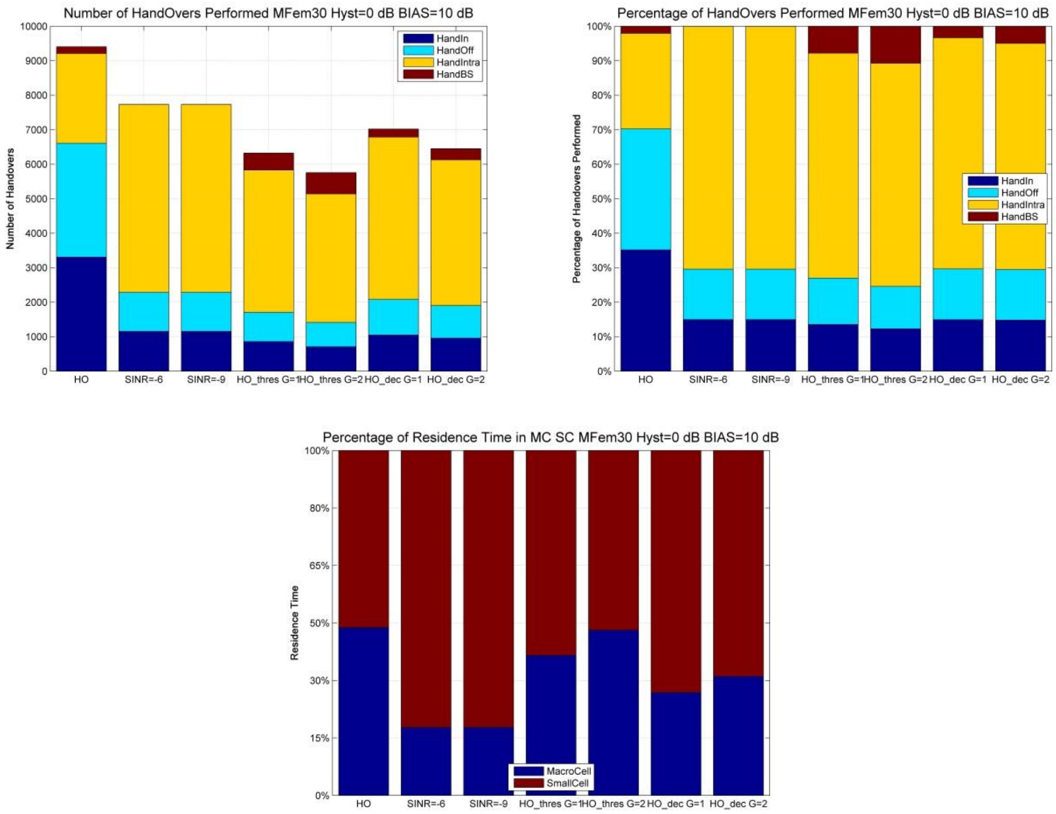

Figure 25. Results of NumFem=30, BIAS=10 dB and MH=0 dB

The number of handovers performed decrease in every case. The algorithm that most reduces the amount of handovers is again the HO_thres. Due to the use of the parameter BIAS with 10 dB, the number of HandIntra increases. It is reflected in the percentage of types of handovers performed, where the HandIntra is the largest type of handover performed. However, in the simulations of the HO_thres, despite that the HandIntra represent a big percentage of their handovers, the HandBS has increased a lot respect to the others proposed solutions. This fact is the explanation of the high residence time spent connected to the macro cell network in the simulations of HO_thres.

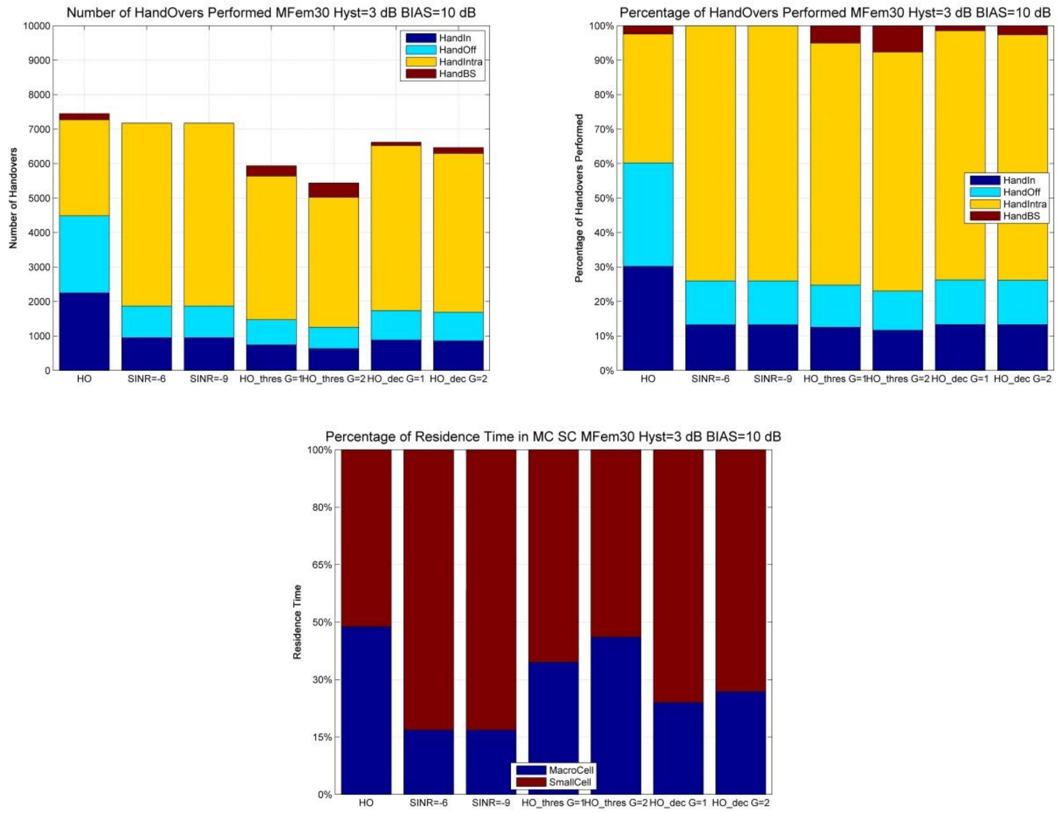

Figure 26. Results of NumFem=30, BIAS=10 dB and MH=3 dB

In the simulations with Hysteresis=3 dB we can see that the performance follows the previous one. The HO_thres is the one that most reduce the number of handovers, but it has the same problems than before. This algorithm increase the number of HandBS and then it supposes the increment of the time that the UEs are connected to the macro cell network. The second algorithm that most reduce the number of handovers performed is again the HO_dec, and the time that the UEs remain connected to the small cell network is similar to the statistics provided by the interferent coordination algorithm.

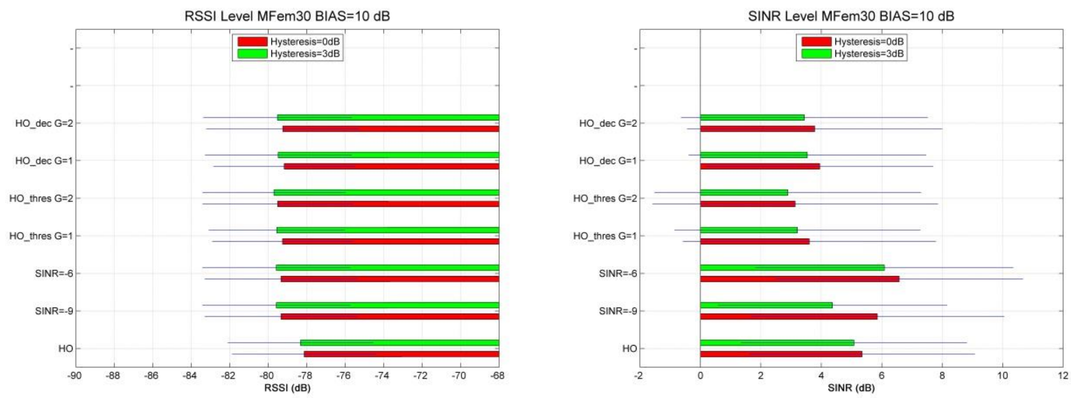

Figure 27. RSSI and SINR Level NumFem=30 and BIAS=10 dB

As in the case of BIAS=5 dB, the RSSI level suffers a loss in every algorithm simulated and, as we have explained previously, the explanation of this is the parameter BIAS. However, the value of the RSSI level is very similar among the different algorithms simulated.

About the SINR level, in the next table we can observe the values for each simulation.

	HOver	SINR=-6	SINR=-9	HO_thres G=1	HO_thres G=2	HO_dec G=1	HO_dec G=2
Hyst=0dB	5.3496	6.5762	5.8524	3.6034	3.1342	3.949	3.7811
Hyst=3dB	5.0801	6.0854	4.3673	3.2075	2.8899	3.5375	3.4397

Table 8. SINR level received NumFem=30 and BIAS=10 dB

Now, the SINR level has decreased in the results provided by the algorithms HO_thres and HO_dec. The usage of the parameter BIAS with a high value makes that the UEs cannot chose the best cells. The stations where the UEs are connected are not the best in a lot of cases and for that reason the SINR is seriously affected. It explains the growth in the SINR in the interference coordination algorithm. The SINR level that the UEs have during the simulations is lower and for that reason the technique proposed by this algorithm is activated more times in order to improve the SINR level that the UE receives.

5.2.2.2 Sixty Femtocells Deployed

In the next simulations, the number of femtoells deployed has increased until 60. The goal is to change the density of femtocell deployed on the scenario in order to study the behavior with more density of small cells.

5.2.2.2.1 BIAS=0 dB

The first simulation uses the parameter BIAS=0 dB.

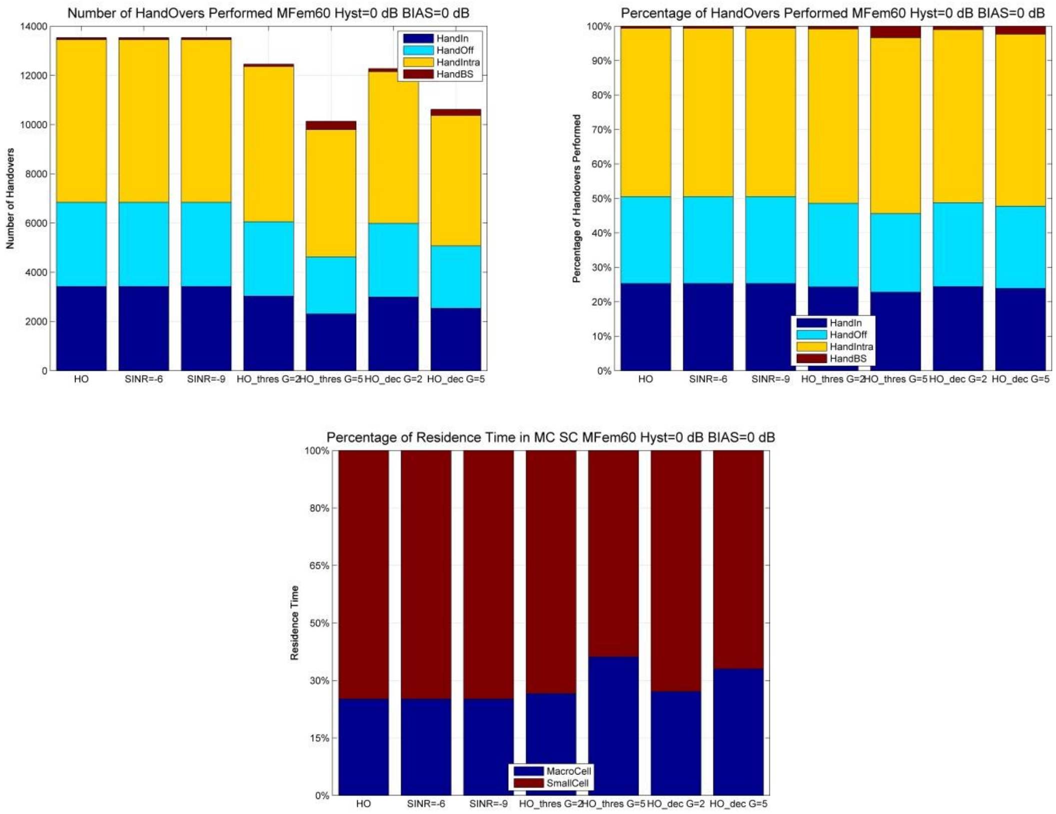

Figure 28. Results of NumFem=60, BIAS=0 dB and MH=0dB

The results show that the interference algorithm behaves in the same way than the conventional technique. This algorithm behaves in this way due to the usage of BIAS= 0 dB. The algorithms HO_thres and HO_dec achieve their goal. Both algorithm decrease the number of handover performed. However, in the case of G=5, the decrement in the amount of handovers performed is more significant. Focusing in the percentage of residence time spent in each network, we can observe that despite of the decrement of handovers performed in both cases with G=2, the residence time in the networks remains similar in comparison to the conventional technique. Nevertheless, when the simulations takes the value G=5, the residence time in the macro cell network is increased.

The next figures represent the results of the simulation using the hysteresis=3 dB.

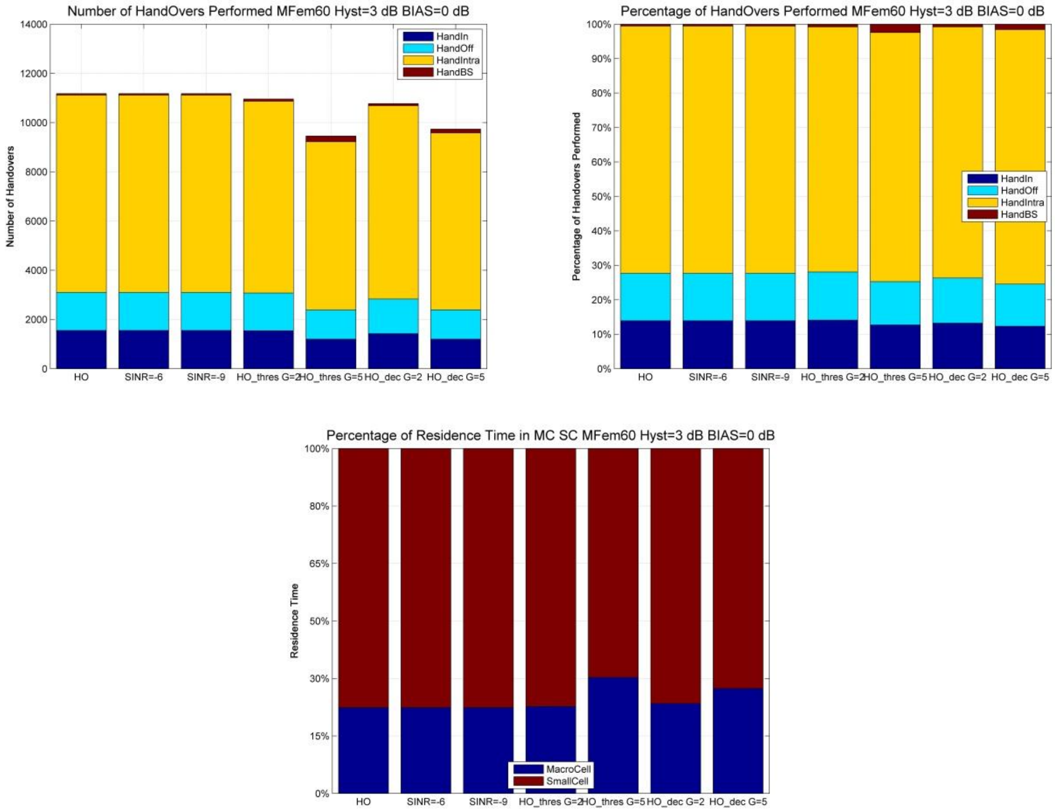

Figure 29. Results of NumFem=60, BIAS=0 dB and MH=3 dB

The performance of the simulations is more or less the same than we have previously explained for the hysteresis=0 dB. The interference coordination algorithm behaves in the same way than the conventional technique and the HO_thres and HO_dec decrease the number of handovers, but it affects as well to the residence time connected to each mobile network. Otherwise, the reduction in the amount of handovers performed is less significant in the cases with G=2.

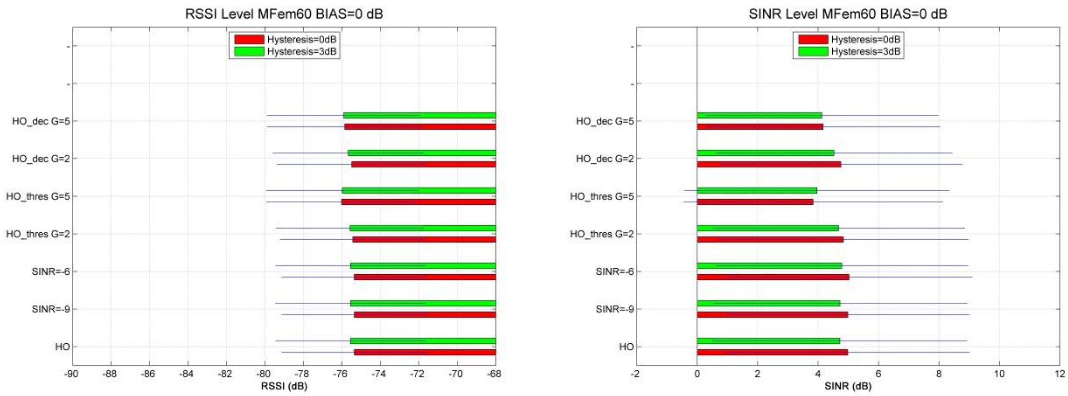

Figure 30. RSSI and SINR Level NumFem=60 and BIAS=0 dB

The RSSI level does not present a significant drop in the cases with G=2, as we can see in the figure. Nevertheless, it suffers a drop in the simulations with G=5. The amount of handovers reduced in these last two simulations is significant and it has consequences in the RSSI level and in the SINR level, as we can see in the next table.

	HOver	SINR=-6	SINR=-9	HO_thres G=2	HO_thres G=5	HO_dec G=2	HO_dec G=5
Hyst=0dB	4.9817	5.0268	4.9871	4.8376	3.8365	4.7583	4.1651
Hyst=3dB	4.7206	4.7855	4.7276	4.6783	3.9622	4.5292	4.1256

Table 9. SINR level received NumFem=30 and BIAS=0 dB

The statistics about the SINR level reveals that the interference coordination algorithm is working correctly. The algorithm achieves to improve the SINR level in every case. Focusing in the other two algorithms simulated, the performance of each one has to be compared. The statistics of the simulations with G=2 show that the HO_thres is behaving in a better way than the HO_dec. However, if we take into account the simulations with G=5, we can observe that the SINR level of HO_dec is closer to the level provided by the conventional technique than the SINR level provided by the HO_thres. Nevertheless, the levels obtained in the simulations with G=5 suffer a problematic drop.

5.2.2.2.2 BIAS=5 dB

Now the simulations are done using the parameter BIAS= 5 dB. This parameter will permit that the macro cell network off-load his traffic and it will prevent the overload of this network.

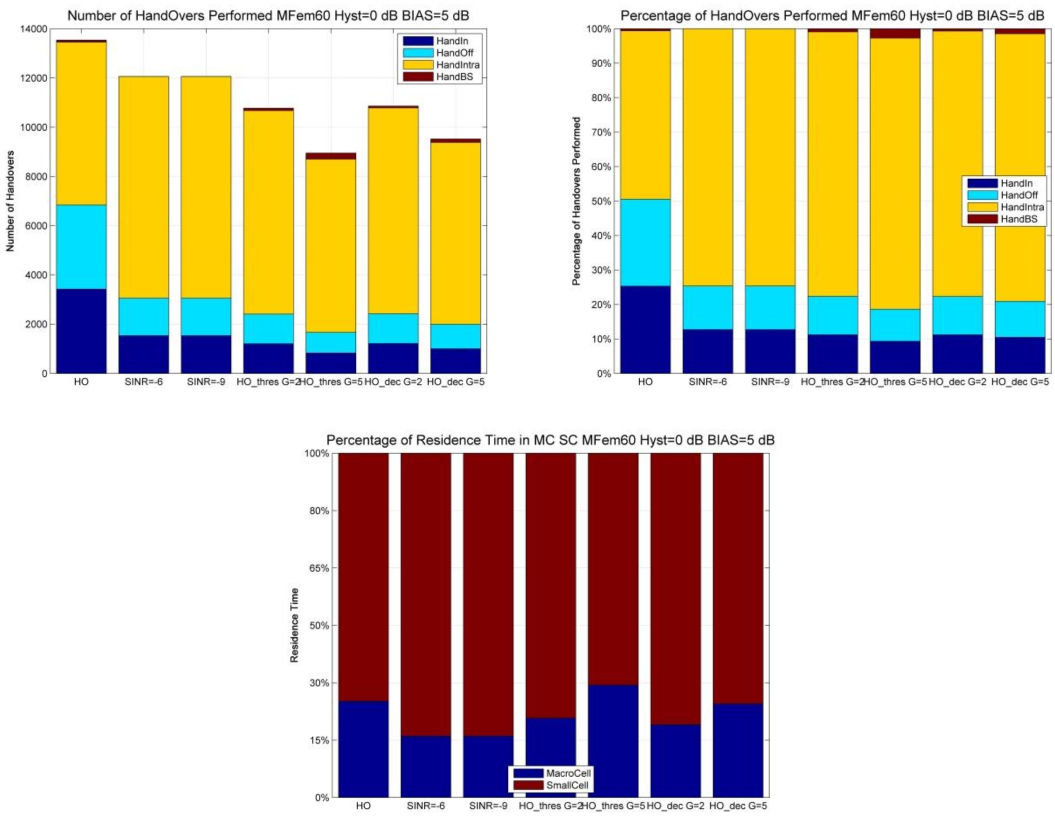

Figure 31. Results of NumFem=60, BIAS=5 dB and MH=0 dB

The algorithms simulated achieve to decrease the number of handovers performed. In addition, the percentage of HandIntra performed in every simulation is close to 70 % of the total of handovers performed. If we compare this statistics with the conventional technique, which the percentage of HandIntra represents the 50% of the handovers performed, we can say that the improvement is evident. Otherwise, we have to study the statistics carefully. If we focus on the residence time in each network, we observe that the residence time in the small cell network is increased in almost every simulation evaluated. Nevertheless, the simulation of HO_thres with G=5 decreases the time connected to the small cell network and, contrary to this, the HO_dec with G=5 achieves to maintain the percentage respect the conventional technique.

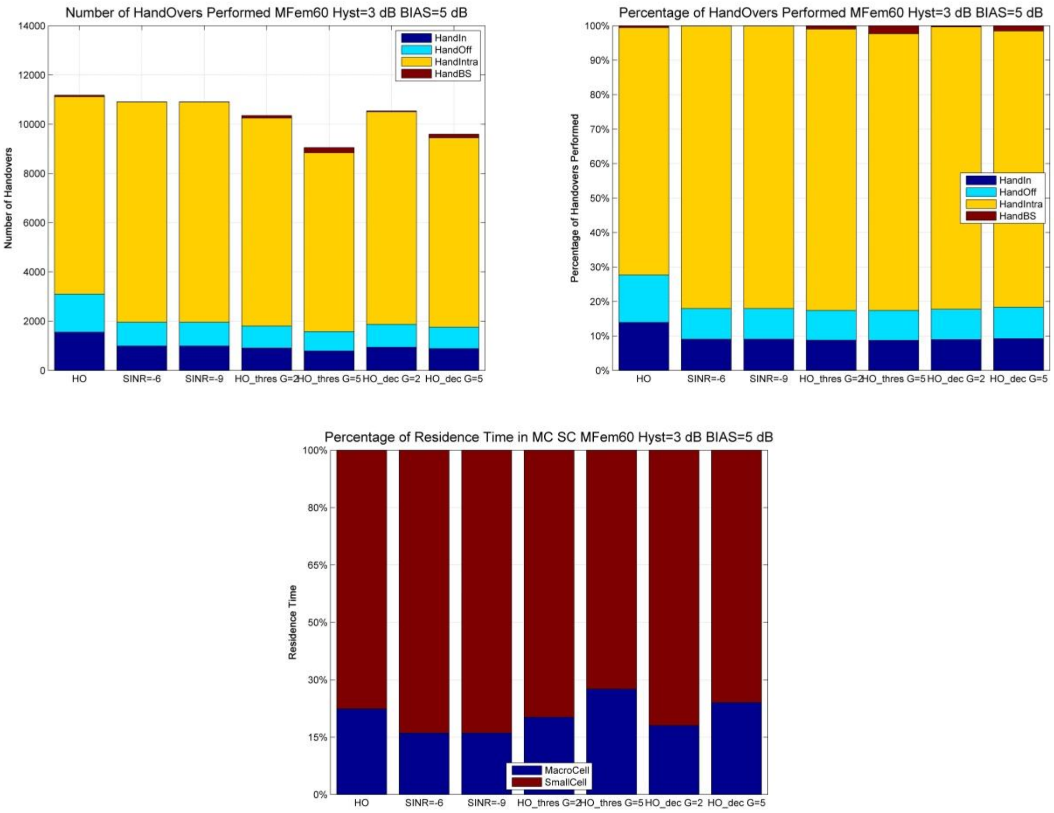

Figure 32. Results of NumFem=60, BIAS=5 dB and MH=3 dB

The reduction on the total number of handovers performed is less significant with the simulations using hysteresis of 3 dB. The behavior of each simulation is really similar with the hysteresis=0 dB. The percentage of handovers performed between small cells is increased again but in lower amount respect to the conventional technique. Moreover, the number of handovers between small cell network and macro cell network are decreased, as it happened with the hysteresis=0 dB.

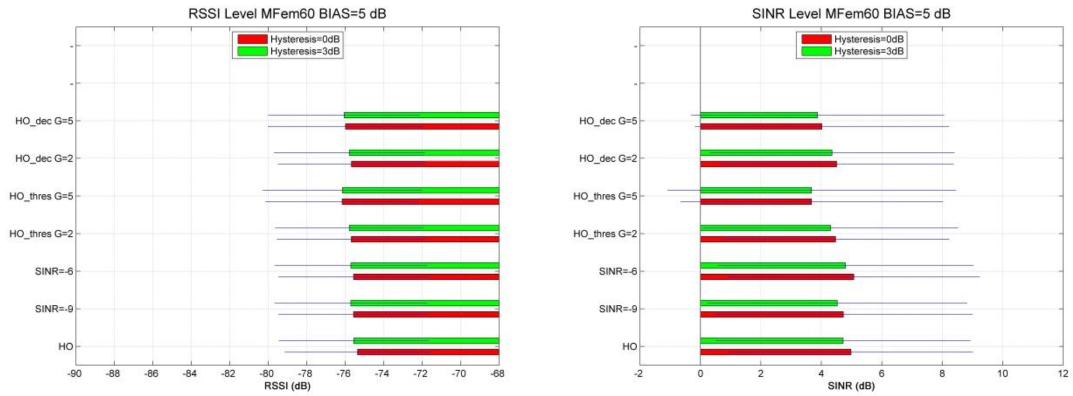

Figure 33. RSSI and SINR Level NumFem=60 and BIAS=5 dB

The RSSI level does not suffer a dramatic drop in the solutions proposed. The most evident drop is performed in the simulations of the last two algorithms using G=5.

	HOver	SINR=-6	SINR=-9	HO_thres G=2	HO_thres G=5	HO_dec G=2	HO_dec G=5
Hyst=0dB	4.9817	5.0758	4.7292	4.4732	3.6769	4.5081	4.0179
Hyst=3dB	4.7206	4.8012	4.5288	4.3055	3.6768	4.354	3.873

Table 10. SINR level received NumFem=60 and BIAS=5 dB

In the table we can observe the SINR level received by each simulation. As we can see, the HO_dec presents a better performance in this aspect. Despite of the levels obtained with G=2 are very similar for both cases, the interesting fact is in the simulation with G=5. The algorithm which uses the classification of the handovers as good or bad (HO_dec) has a significant difference in the SINR level obtained in comparison with the HO_thres. The HO_dec algorithm improves the level in more than 0.3 dB in the case of hysteresis=0 dB and 0.2 dB in the case of hysteresis=3 dB.

On the other hand, the interference coordination algorithm achieves to maintain or even improve the SINR level obtained in each simulation.

5.2.2.2.3 BIAS=10 dB

The new round of simulations are done with the parameter BIAS=10 dB. The goal is to off-load more the macro cell network and to study the results of it.

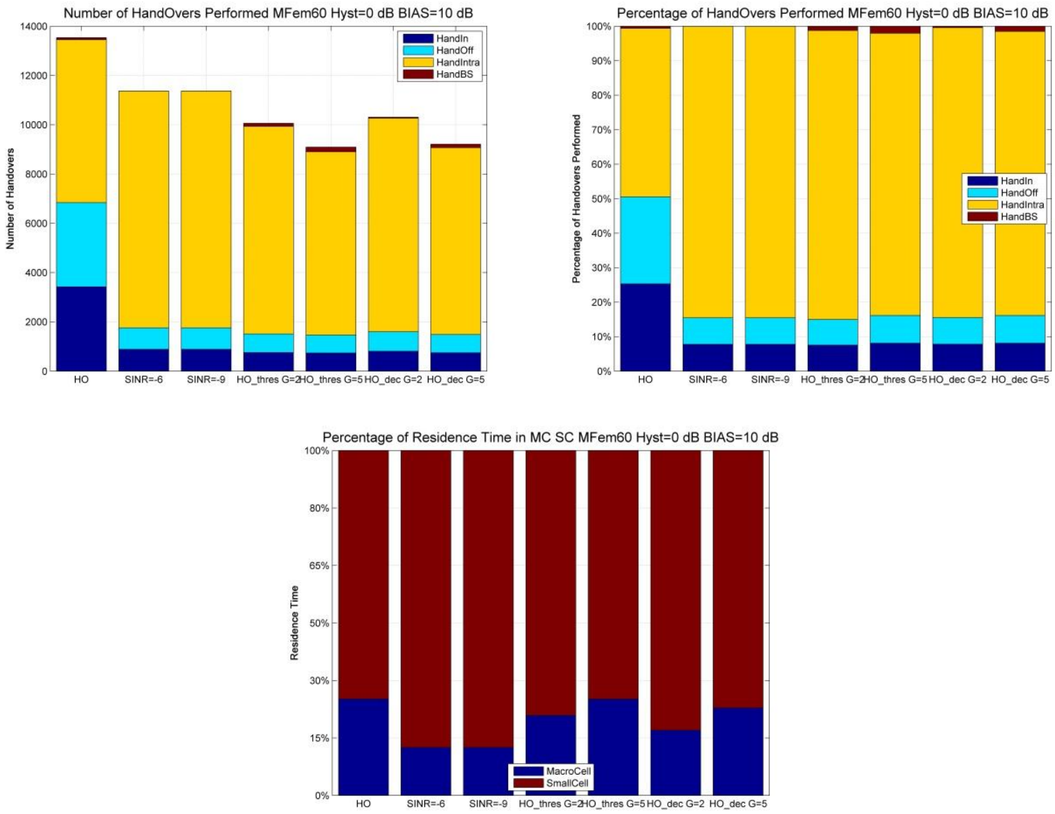

Figure 34. Results of NumFem=60, BIAS=10 dB and MH=0 dB

The reduction of the handovers related with the macro cells is notorious. The usage of higher value of BIAS allows this behavior. All of the algorithms reduce the amount of handover. Specially, HO_thres and HO_dec reduce the number of handovers performed. The HandIn and HandOff are reduced dramatically in all algorithms simulated. The behavior of each one is similar. In all of them, the HandIntra represent almost the 80% of the handovers peformed. However, the percentage of residence time presents differences in each algorithm. Again, the HO_dec presents better results than the HO_thres. The first algorithm achieves to decrease in both simulations the residence time in the macro cell network in comparison with the conventional handover.

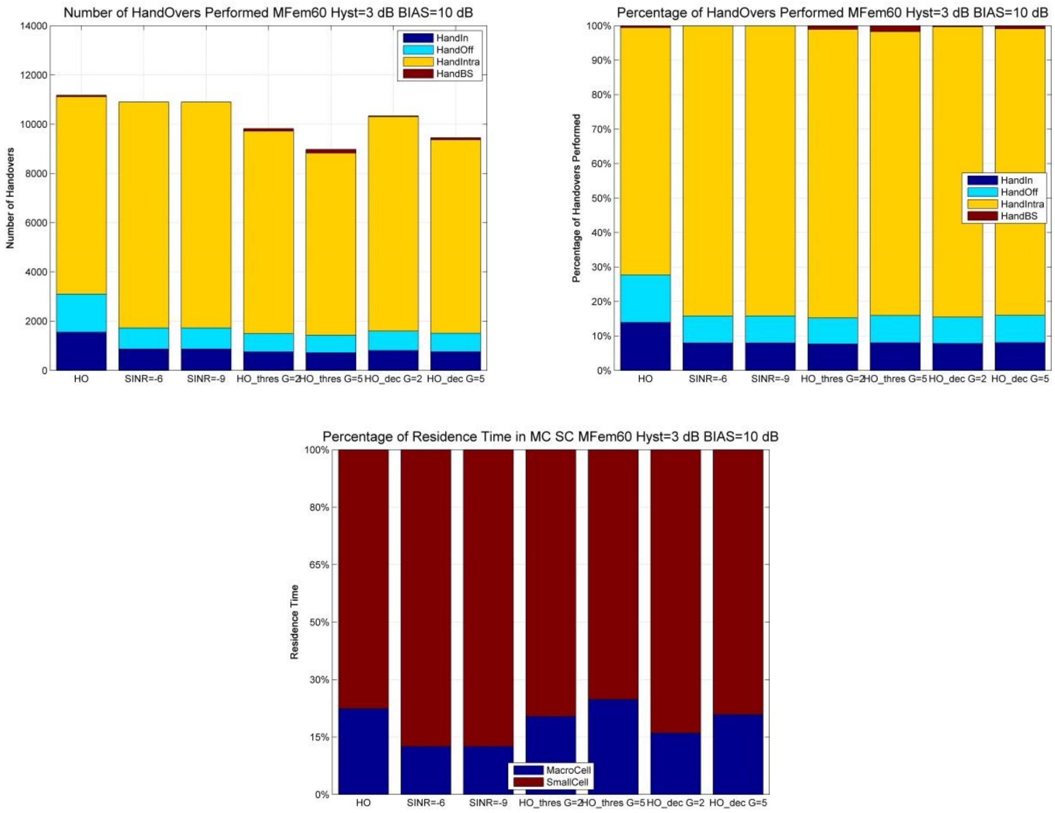

Figure 35. Results of NumFem=60, BIAS=10 dB and MH=3 dB

With the results presented above, we can say that the simulations with the hysteresis of 3 dB follow the same behavior than the previous one. The number of handovers performed is reduced in all the algorithm, the main type of handover in the performance is HandIntra and the residence time in each network follows the same behavior than the simulation with the margin of hysteresis of 0 dB.

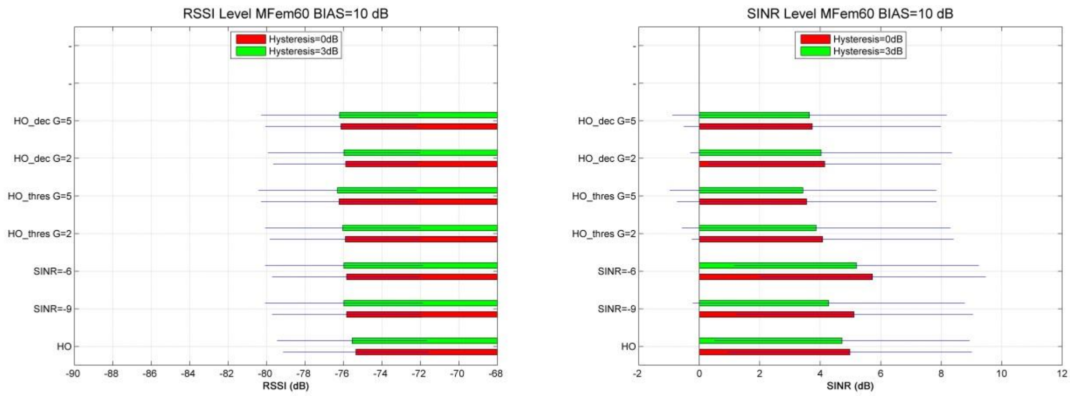

Figure 36. RSSI and SINR Level NumFem=60 and BIAS=10 dB

The RSSI level suffers a drop in every algorithm simulated. This drop is due to the usage of the parameter BIAS=10 dB, which force the UEs to remain connected to the small cell network. For the same reason, the SINR level suffers a drop, as we can see in the next table.

	HOver	SINR=-6	SINR=-9	HO_thres G=2	HO_thres G=5	HO_dec G=2	HO_dec G=5
Hyst=0dB	4.9817	5.728	5.1193	4.0794	3.5531	4.1488	3.7389
Hyst=3dB	4.7206	5.2007	4.2804	3.8652	3.4286	4.0279	3.6462

Table 11. SINR level received NumFem=60 and BIAS=10 dB

The drop on the SINR level is suffered in the algorithms focused on reducing the number of handovers. The HO_thres and HO_dec suffer a remarkable decrement in the SINR level. However, we can observe that the HO_dec presents better results on this parameter in comparison with the HO_thres algorithm. The SINR level is higher in all the simulations done. The most remarkable fact is that the difference between the simulations of HO_thres and HO_dec with G=5 is almost 0.2 dB for each margin of hysteresis, and the reduction of handovers performed is similar in both cases.

On the other hand, the interference coordination algorithm presents a big improvement in the SINR due to the high value of the BIAS used.

5.2.2.3 Ninety Femtocells Deployed

The density of femtocell is increased again. This time the number of femtocells deployed reaches 90 cells. With this increment, we want to study the results for higher density of femtocells in the same scenario in order to test the performance of the algorithms with this amount of cells and to compare these performances with the ones with lower density.

5.2.2.3.1 BIAS=0 dB

The first round of simulation for this amount of femtocells is again using the parameter BIAS=0 dB.

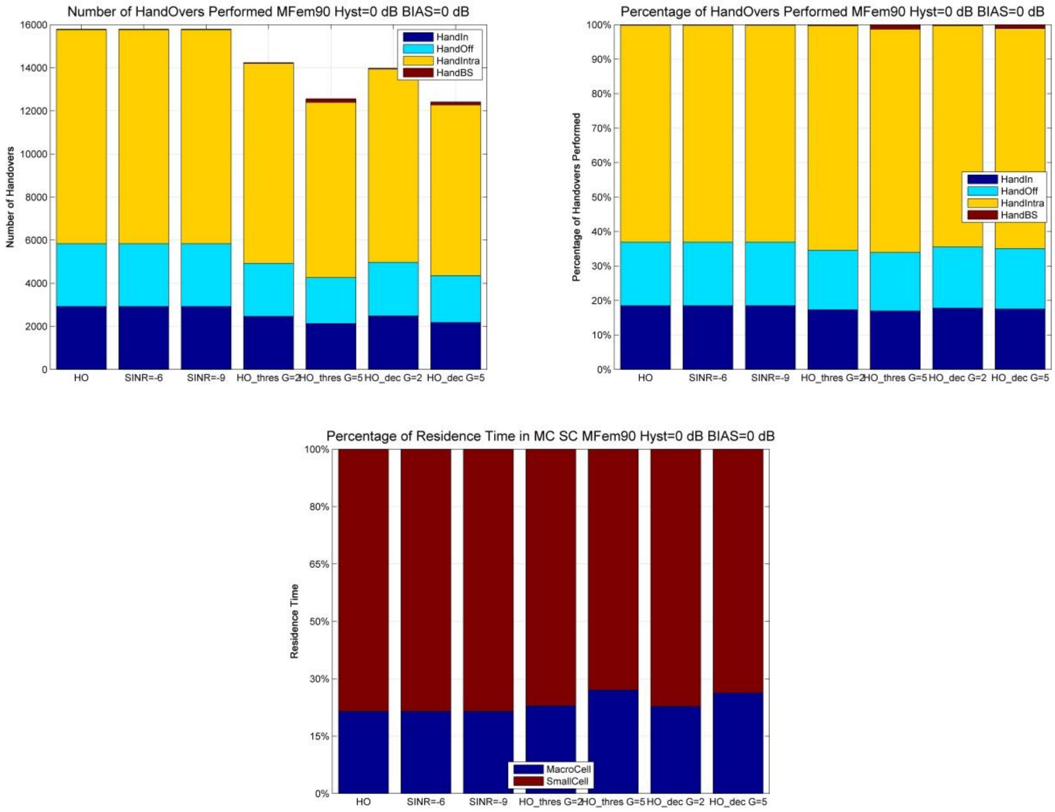

Figure 37. Results of NumFem=90, BIAS=0 dB and MH=0 dB

As we have explained in previously simulations. The interference coordination algorithm behaves in the same way than the conventional handover due to the parameter BIAS takes the value of 0 dB. On the other hand, the algorithms based on reducing the number of handovers performed achieve their goal and they decrease the amount of them. Moreover, in the case of G=2, the algorithms achieve to almost maintain the percentages of residence time in each network in comparison with the statistics provided by conventional technique. If we compare both of them directly, we can see that both algorithms behave in a really similar way. The number of handovers performed, the percentage of each kind of handover performed and the residence time in each network is practically the same.

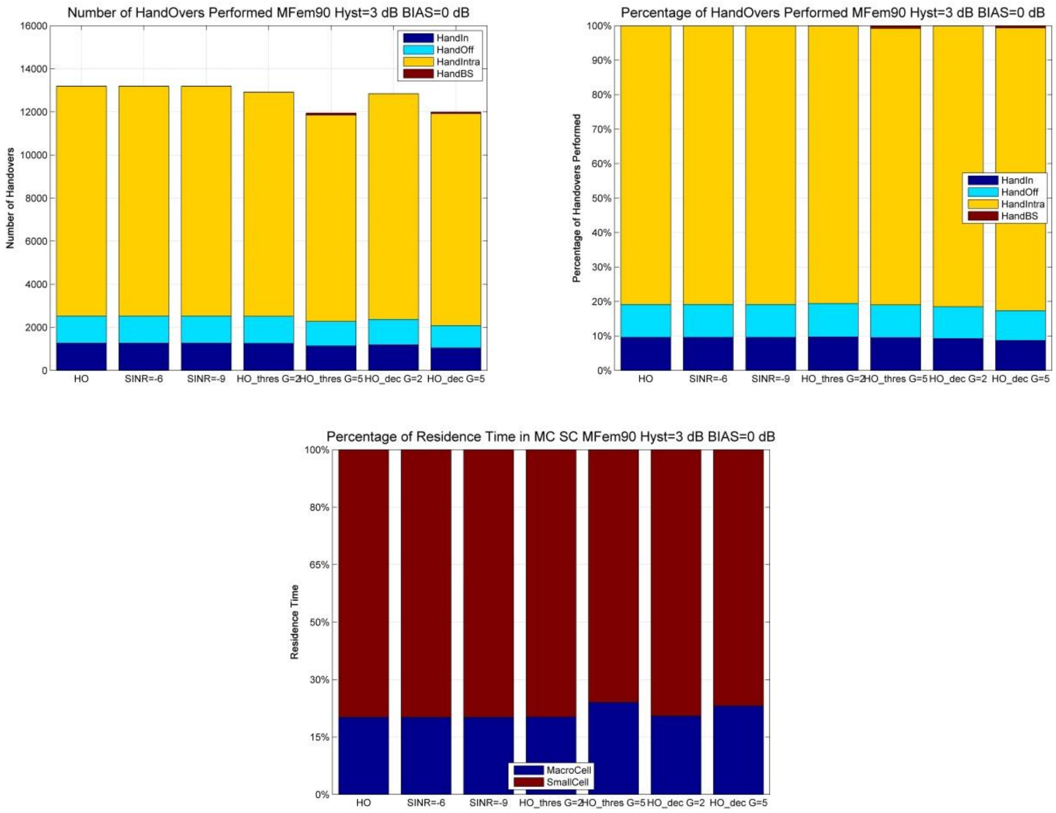

Figure 38. Results of NumFem=90, BIAS=0 dB and MH=3 dB

The performance of the simulation using the hysteresis of 3 dB is similar than the simulation with 0 dB of hysteresis. However, the reduction on the number of handovers performed presented by the algorithms HO_thres and HO_dec is less significant in these cases.

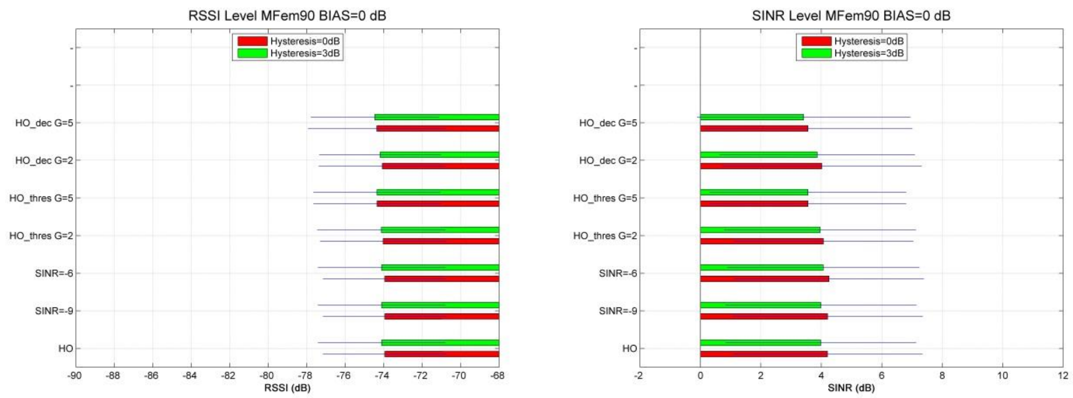

Figure 39. RSSI and SINR Level NumFem=90 and BIAS=0 dB

The RSSI level is similar in every simulation performed. The difference of signal level among the different algorithms is small and practically imperceptible. However, as we can see in the next table, the drop in the SINR level is more significant:

	HOver	SINR=-6	SINR=-9	HO_thres G=2	HO_thres G=5	HO_dec G=2	HO_dec G=5
Hyst=0dB	4.2059	4.2541	4.2078	4.0682	3.5577	4.0129	3.5594
Hyst=3dB	3.9812	4.0661	3.9837	3.9583	3.4509	3.8627	3.4152

Table 12. SINR level received NumFem=90 and BIAS=0 dB

On the statistics, we can see that the interference coordination algorithm improves a little bit the SINR level in comparison with the conventional technique. However, now, the other two algorithms provide results really good. Apart from reducing the number of handovers performed, the algorithms achieve to maintain the SINR level close to the level which provides the conventional technique. Focusing on the hysteresis=0 dB, because is the one that presents the most decrement on the amount of handovers performed, the difference between the SINR levels are less than 0.2 dB on the simulation with G=2. Using the parameter G=5, the SINR levels obtained are less than 0.7 dB below the conventional technique value. On the other hand, with the simulations using the hysteresis=3 dB, the SINR levels obtained in each simulation is more closer respect the SINR level obtained by the conventional technique.

5.2.2.3.2 BIAS=5 dB

The next simulations use the parameter BIAS=5 dB. The goal of the usage of this value is to off-load the main network, as we have previously explained.

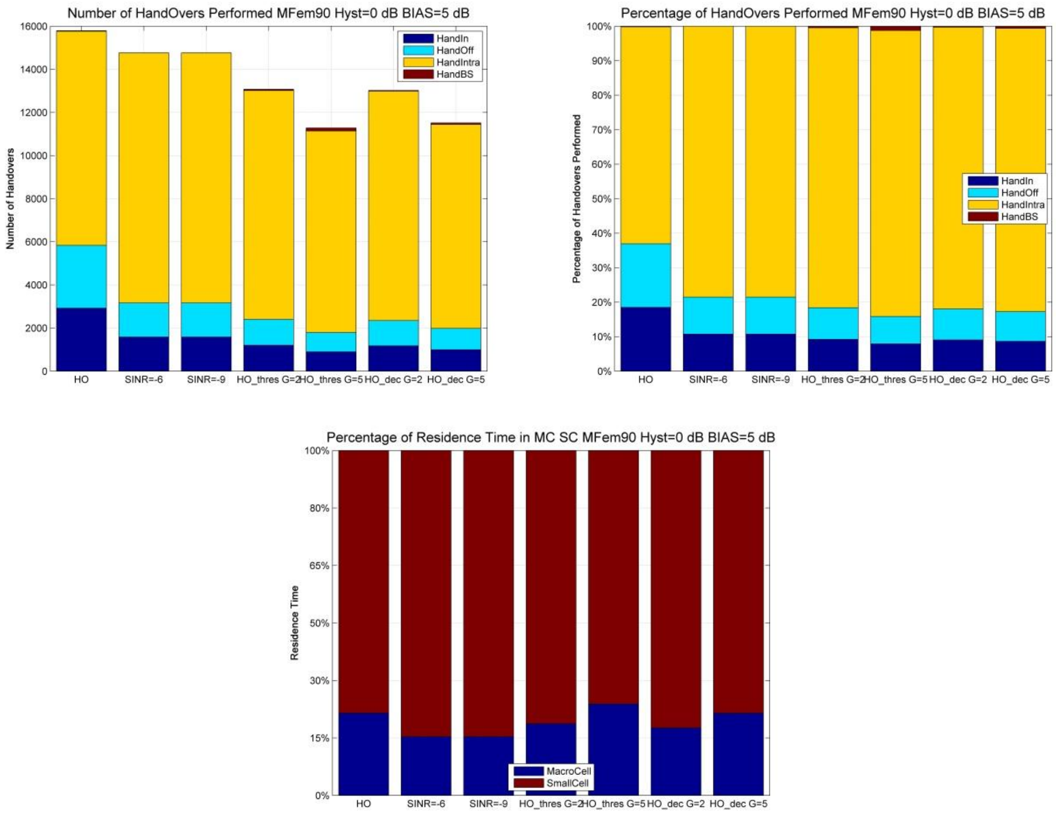

Figure 40. Results of NumFem=90, BIAS=5 dB and MH=0 dB

Both algorithms focused on the reduction of number of handovers performed achieve their goal in a similar way, that is, the reduction of the amount of handovers performed is really similar. Nevertheless, there are differences between both algorithms. Despite of performing a similar number of handover, the HO_thres performs more handover between macro cells than the algorithm HO_dec. This fact allows to the last algorithm to improve the statistics about the residence time in each network. The HO_dec reduces in both cases the time connected to the macro cell network in comparison with the HO_thres algorithm. On the other hand, we can observe that the percentage of residence time connected to the macro cell network is lower than the conventional algorithm in the case of G=2 and almost the same in G=5.

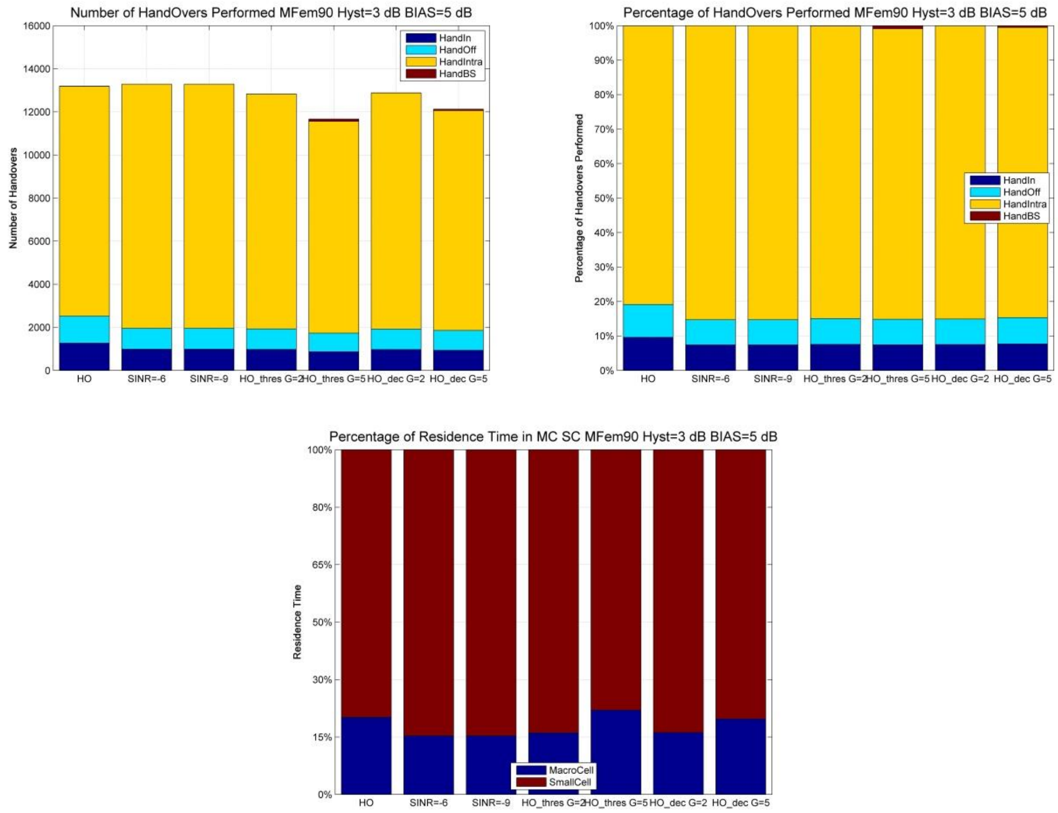

Figure 41. Results of NumFem=90, BIAS=5 dB and MH=3 dB

The behavior of the algorithms in the simulations using the margin of hysteresis of 3 dB is really similar to the previous one. The algorithms HO_thres and HO_dec remain decreasing the number of handovers performed. However, this time, the interference coordination algorithm increases a little bit the number of handovers performed. The percentage of residence time is always improved with the algorithm HO_dec.

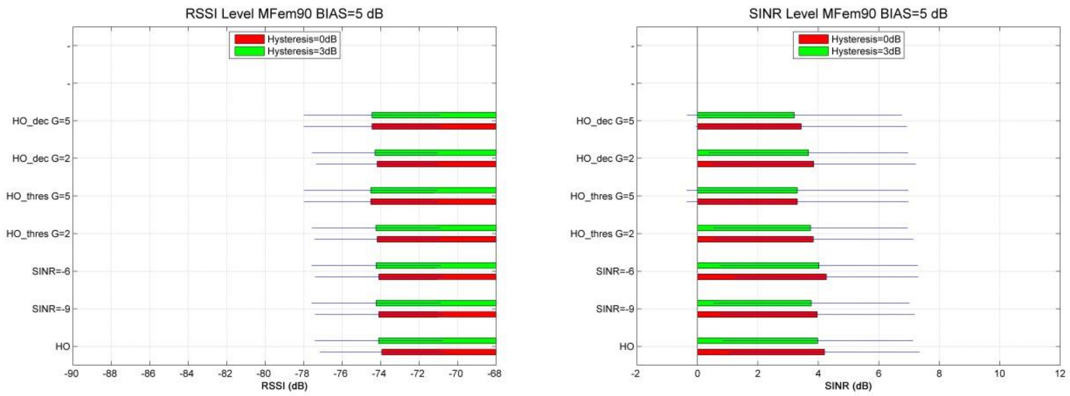

Figure 42. RSSI and SINR Level NumFem=90 and BIAS=5 dB

As happens in the simulations with BIAS=0 dB, the drop on the RSSI level is insignificant. The drop is only perceptible in the simulation with G=5. On the other hand, the decrement in the SINR level is more significant and it has to be studied:

	HOver	SINR=-6	SINR=-9	HO_thres G=2	HO_thres G=5	HO_dec G=2	HO_dec G=5
Hyst=0dB	4.2059	4.2676	3.9637	3.8357	3.3083	3.848	3.4345
Hyst=3dB	3.9812	4.0217	3.7697	3.744	3.1243	3.6748	3.2038

Table 13. SINR level received NumFem=90 and BIAS=5 dB

The table presented above shows the SINR level received in each simulation. The interference coordination algorithm with the threshold=-6 dB improves with both margin of hysteresis the performance. However, with the threshold of -9 dB, the algorithm suffers a drop on the SINR level. The level obtained is very similar with the results obtained with the HO_dec and HO_thres simulations when the parameter G is 2 dB.

5.2.2.3.3 BIAS=10 dB

In the last round of simulations, the parameter BIAS takes again the value of 10 dB. We want to study the behavior of the algorithms when the parameter BIAS takes his higher level and the scenario has the highest number of femtocells deployed.

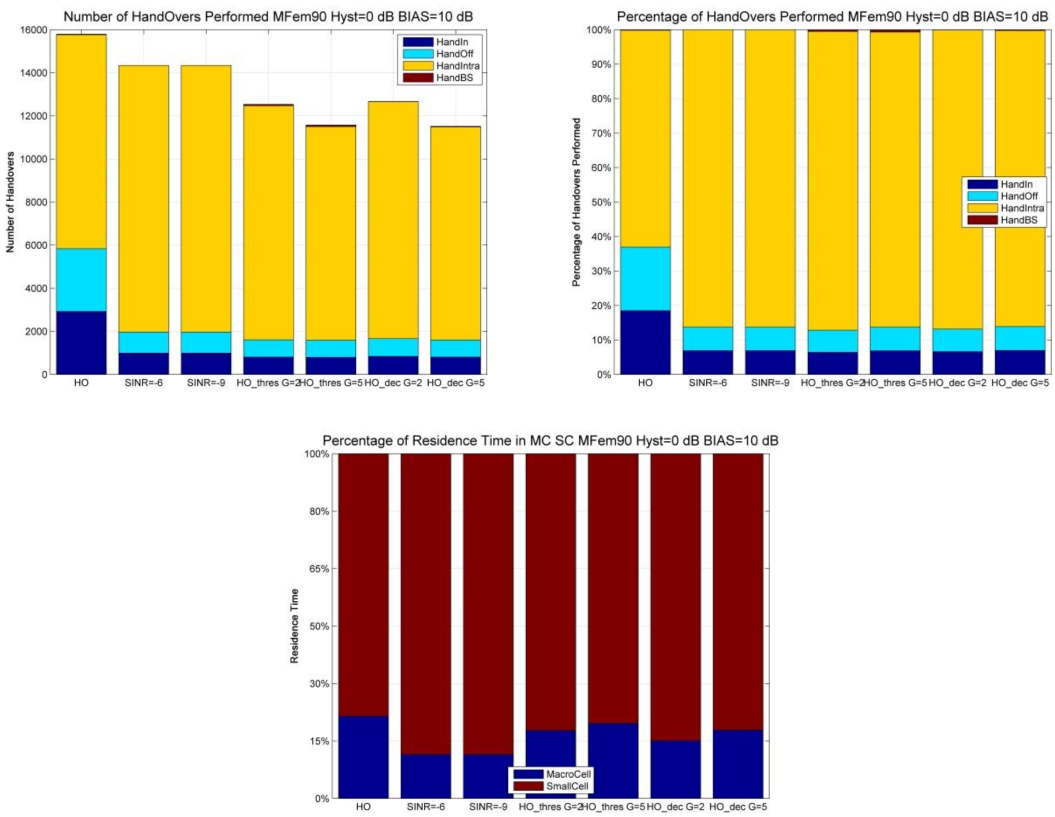

Figure 43. Results of NumFem=90, BIAS=10 dB and MH=0 dB

The results presented above reflect the goals of each algorithm. The interference coordination algorithm reduces the number of handovers performed due to the parameter BIAS and increase the residence time in the small cell network. In addition, the algorithms HO_thres and HO_dec, which are focused on reducing the number of handovers performed, present a higher decrement in comparison with the algorithm previously mentioned. Moreover, both algorithms achieve to maintain or even increase the percentage of HandIntra performed during the evaluation. However, the results about residence time connected to the small cell network show that the algorithms focused on reducing the number of handovers performed spend more time connected to the macro cell network than the interference coordination algorithm. Nevertheless, the HO_thres and HO_dec spend less time than the conventional handover algorithm connected to the main network in every simulation.

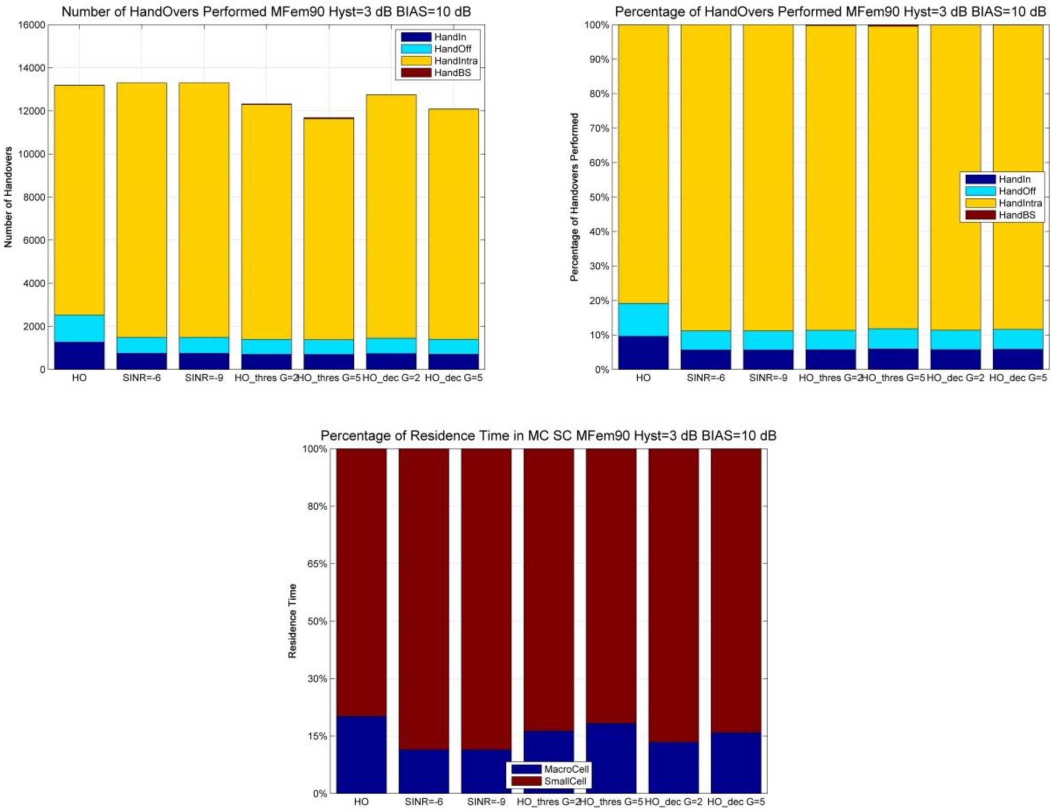

Figure 44. Results of NumFem=90, BIAS=10 dB and MH=3 dB

The results of the simulation for the margin of hysteresis of 3 dB follow the behavior than the previous one. The significant difference is that now, the interference coordination algorithm does not decrease the number of handovers performed and it increases a little bit this amount. However, the number of handovers which involves the macro cell stations is decreased in every simulation and the residence time in the small cell network is increased by all of the algorithms.

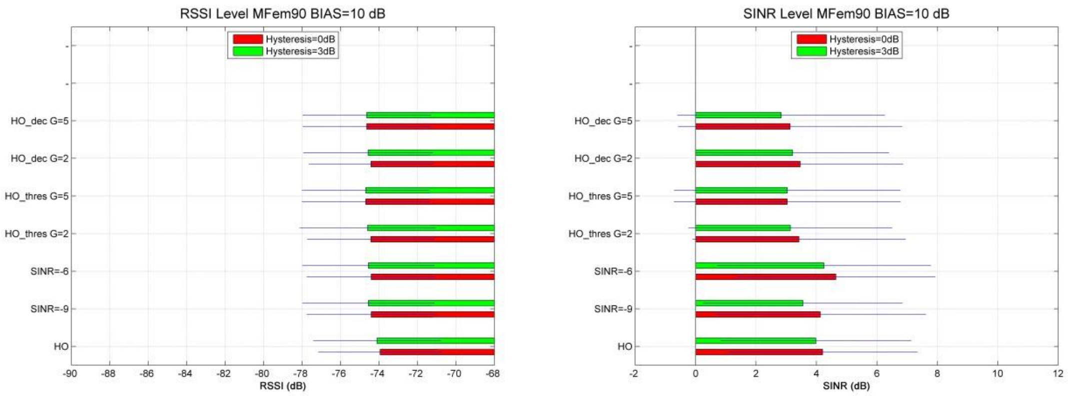

Figure 45. RSSI and SINR Level NumFem=90 and BIAS=10 dB

Finally, the RSSI and SINR level of the performance have to be studied. The RSSI level suffers a drop in every simulation. However, the decrement is similar within the algorithms evaluated. Otherwise, as we have previously explained, the drop in the SINR level is more significant than the drop in the RSSI level.

	HOver	SINR=-6	SINR=-9	HO_thres G=2	HO_thres G=5	HO_dec G=2	HO_dec G=5
Hyst=0dB	4.2059	4.6433	4.1264	3.4229	3.0324	3.4617	3.1274
Hyst=3dB	3.9812	4.2465	3.5498	3.1342	2.7717	3.205	2.8302

Table 14. SINR level received NumFem=90 and BIAS=10 dB

As show the results on the table, the drop on the SINR level is high. Even in the simulation of the interference coordination algorithm with the hysteresis fixed in 3 dB and the threshold fixed in -9 dB, the drop in the SINR is significant. However, again the HO_dec has better results in comparison with the HO_thres, but the drop in both values of G is significant. The explanation is that the value of BIAS forces the UEs to remain connected to the small cell, even when the signal level received from the small cells is significantly lower than the signal level received from the macro cell stations, as we have previously mentioned.

6 Conclusion

This thesis presents an algorithm to reduce the number of performed handovers using the estimation of the future signal level and learnign from past hadover decisions. With the estimation of the future signal level, the algorithm introduces new requirements to be fulfilled in order to perform the handover. More specifically, the work proposes an algorithm in order to improve the handover decision in scenarios with femtocells deployed.

The simulations show that the algorithm outperforms competitive algorithms if the number of femtocells deployed is increased. The reduction of the amount of handovers performed during the simulations are more significant when the number of femtocells deployed are higher. Moreover, the evaluation of the SINR level reveals efficiency of th eproposed algorithm.

The comparison with the other algorithm shows that our algorithm is possitively influenced in terms of SINR when the Range Expansion is used. The results obtained demonstrate that when the lower number of performed handovers is more significant, the algorithm „Hadnover Decision with Throughput Estimation and Learning“ has a better performance in the scenario. The simulations have demonstrated that the proposed solution is able to reduce the number of handover in a 18% respect the conventional handover process in a scenario with high dense of femtocells, maintaining at the same time the SINR level 0.35 dB lower than the one obtained by the conventional process.

The proposed algorithm can be extended with a mechanism to control the SINR level in order to improve the level obtained, as it is done in the interference coordination algorithm.

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8 Appendices

8.1 *Mobility model*

As is defined in [14], the mobility model used in the simulations is based on the movement of users in urban areas. The mobility model used is based on Manhattan mobility model supplemented with points of interest (POIs).

The streets are composed by sidewalks with 2 meters of width, and the width of the streets is 16 meters, including both sidewalks. The users move around the scenario with a speed of 1 m/s. We assume that the users do not stop while they across the scenario of simulation. Anyway, it has not change for our evaluation. The algorithm could work in the same way with user without movement. However, if the users do not stop, we can obtain interesting results due to the increase of movement of all the users, and, in the same way, the increase of handovers between the different base stations. For that reason, in this mobility model, when one user reaches his destination, he starts moving again to another destination. Moreover, the users cross the streets only at intersections.
The POIs considered in this scenario are ten blocks of flats, two restaurants, two shops and two office buildings. The positions where the users enter and leave the simulation area are also included as POIs. The users move in the scenario choosing always the shortest way to reach their destination. Furthermore, the position of all the POIs follows the real situation of the simulated scenario.

We can classify the users in four types. The first one represents people who live in the simulated area. This kind of users lives in this area and they never leave the scenario. They have just one POI: their home. The users move around the scenario with a specific destination, they just walk around the area following the conventional Manhattan mobility model (Figure 46.a). The length of each walk is generated randomly.

The second type of users is composed by users who visit the scenario. These users enter into the scenario at a random intersection and visit some POI with a different probability. They can just pass through the scenario (probability of 25 %), visit a shop (12.5% per shop), a restaurant (12.5 % per restaurant), a block of flats (2 % per block) or an office building (2.5 % per building). When they reach their POI, the next destination is to leave the area using one of the intersections chosen randomly (Figure 46.b).

The next type is called as resident. This kind of user represents people who live in the area but works outside it. For that reason, one of the POI of them is their home and another one is one intersection among the ones that are in the scenario. However, the users can visit other places into the scenario, such as shops or restaurants. We distinguish the probability of visit these places between the way to the work and the way to home. When they leave their home, the users can visit a shop (probability of 15 % per shop) or a restaurant (15 % per restaurant). When they finish their stay there, they come back to home. On the way to home, when they enter the scenario using one of the intersections, they can visit a shop (10 % per shop) or visit a restaurant (10 % per restaurant). Furthermore, the user can also go to the work directly without visiting any place (probability of 50 %), going towards the intersection point directly. We can observe their behavior at the Figure 46.c.

Finally, the last type of user is the one composed by people who works inside the scenario but live outside. The place of working for them is chosen randomly. The location of the job can be a restaurant (probability of 5 % per each restaurant), a shop (5 % per each shop) or an office building (40 % per each office building). The user can also visit a shop or a restaurant. On the way to work, the user can visit a shop with a probability of 5 % per shop. On the other way, the way to home, the user can visit a shop (now with a probability of 10 % per each shop) or a restaurant (10 % per each restaurant).

In the simulation, the amount of each kind of user is different. The percentage of each one used in this simulation is: 40% of residents, 30% of workers, 20% of visitors and the rest of roaming visitors.

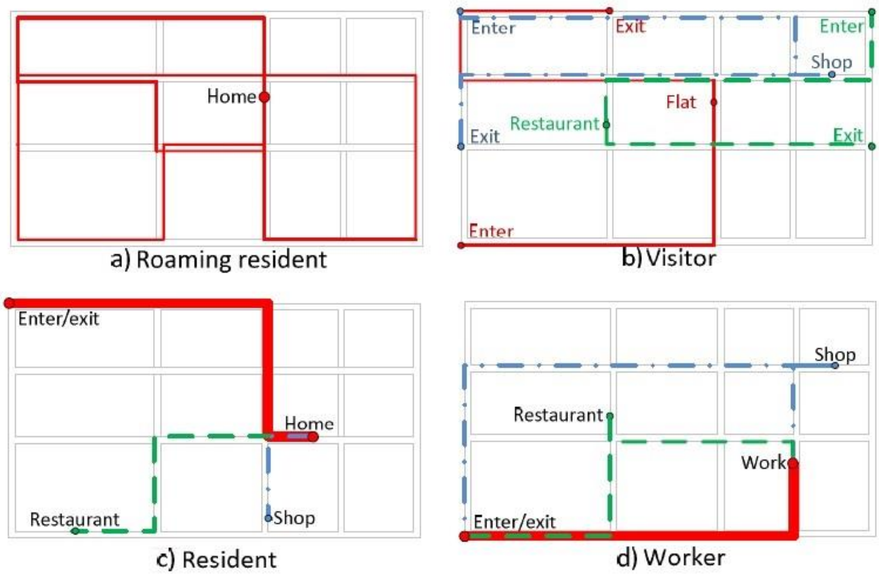

Figure 46. Examples of the users' movement.