Performance Evaluation of Mobile Users Served by Fixed and Mobile Femtocells in LTE Networks

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ABSTRACT: *This paper investigates the concept of Mobile Femtocell with considering the feasibility of deploying Mobile Femtocells in public transportation vehicles such as trains, buses or private cars that form its own cell inside vehicles to serve vehicular and mobile User Equipments. This study is the launch of cell-edge mobile users who have always suffered degradation in the Quality of Service (QoS). Therefore, an investigation on the performance of LTE cell-edge mobile User Equipment e.g. users' throughput, SINR, SNR, SIR, spectral efficiency and Handover performance, have been considered with deploying Fixed Femtocells and Mobile Femtocells in Long Term Evolution network. Two scenarios have been proposed in this study; Fixed Femtocells with mobile users and Mobile Femtocells with mobile users. More scenarios maybe considered in the case of Mobile Femtocell's handover procedure. MATLAB simulation has been used for the purpose of simulating the designed scenarios and implementing the integrated mathematical equations. The simulated results have demonstrated the benefits of having Mobile Femtocells over the Fixed Femtocells in terms of mobile User Equipments' performance.*

Keywords: LTE, Femtocells, Mobile Femtocells, Moving cells, Mobile and Fixed Relays, OFDMA, outdoor and in-car environments

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1. Introduction

Long Term Evolution (LTE) has been standardised by the 3rd Generation Partnership Project (3GPP) which is a standard for wireless communication of high speed data for mobile phones and data terminals. The purpose behind developing the LTE technology is to improving the spectral efficiency and the speed of data rate of a cellular network. In order to simplify the architecture and minimise the control and UE plane latency, a more intelligent BS (evolved Node B (eNB)) was introduced. Moreover, LTE adapts Orthogonal Frequency Division Multiple Access (OFDMA) as the base technique for sharing resources among multiple UEs. Recently, LTE-Advance has been introduced to extend the original proposed LTE that aims to data rates up to 3Gbps and 1.5Gbps in Downlink (DL) and Uplink (UL) respectively by employing advanced multi-antenna multiple-input multiple-output (MIMO) techniques, carrier aggregation (CA) and other schemes [31].

Since, the coverage area of the eNodeB in LTE network is limited due to the fact of the controlled transmission power;

the need of having new techniques to cover the cell edges have become the interest of many researches especially with the increasing number of User Equipments and traffic. The limited coverage area, capacity, capability and cell-edge User Equipments' performance lead many researches to implement and improve new technologies to solve these issues such as; relay nodes, picocells, microcells, femtocells etc. Those technologies play an important role in maintaining the User Equipment's connection especially those User Equipments who are at the edge of the cell (cell's threshold) and crowded areas.

The relay nodes can greatly improve the users' performance and network coverage area in LTE network. In relay communication, intermediate nodes are used to relay the data from/to the eNB [1]. The first deployment of relay nodes was fixed then the need of deploying mobile relays came about which was the debut of Mobile Femtocells (MFemtos). Fixed relays are deployed at locations according to cell planning and radio optimisation to improve the users' throughput, to expand the coverage and improve the cell edge users' performance. While mobile relays are mobile wireless nodes that reach several remote areas that are out of the coverage area of the eNB [14], those mobile relays can be either; mobile user relays or mobile networks. In the mobile user relays, specific users will be chosen to work as mobile relays within close vicinity to relay the information from/to the eNB in LTE networks. On the other hand, the mobile (moving) network offers that relay nodes to be placed on moving vehicles e.g. trains, buses or private cars e.g. Taxis to receive and send data from/to eNB then forward it to the UEs in the edges of the LTE networks. Most of the previous work has been focusing on fixed relays [2]; Fixed Femtocells (FFemto) [4] or mobile user relays [5]. There are only few researches undertaken recently for mobile (moving) networks; therefore, the focus of this research will be on the MFemto technology.

Figure 1 shows the fixed and mobile femtocells which could be either inside buildings, on streets or public transportation like trains and buses. The MFemtos are moving hotspots with multiple UEs who are requesting diverse data services e.g. web browsing, VoIP, e-mailing and video streaming. Since the UEs inside public or private vehicles may execute multiple handovers (HOs) at the same time that cause significant increase in the signalling load and drop in the network connections. This leads to considering the MFemtos as a solution to minimise the signalling load, drop packets, handover time delay.

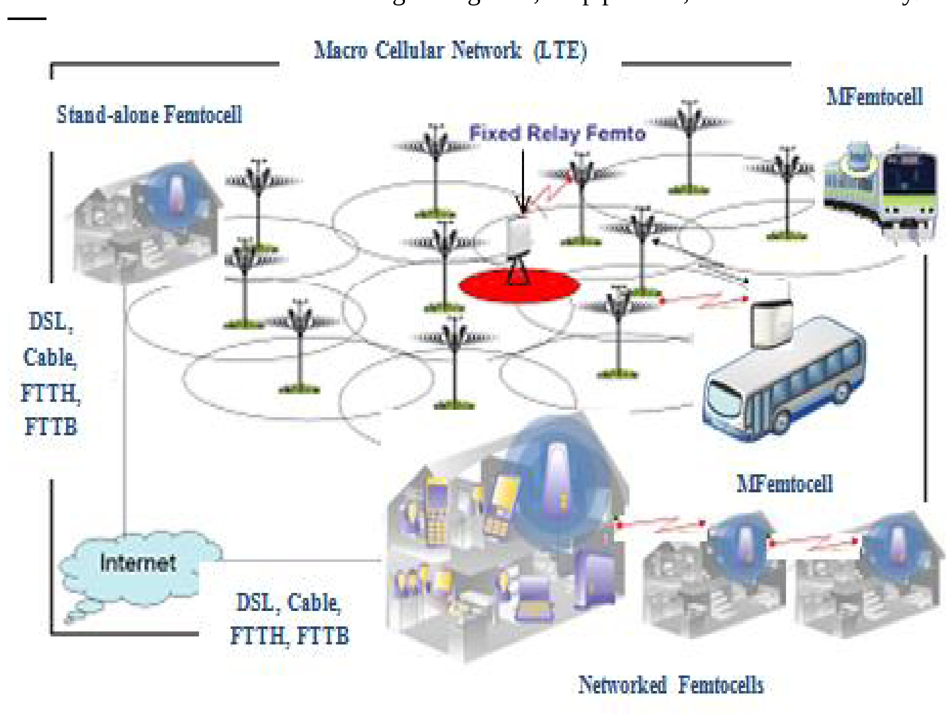

Figure 1. FFemto and MFemto Technologies

Femtocells are also known as home BSs or home evolved NodeB (Home eNB) [6] which can be defined as a small, low power and higher speed access points that users can install at home or camps to get better indoor coverage and improve the throughput of users with reducing the cost of implementation. In contrast, outdoor femtocells are placed outside buildings like streets or mountainous to increase the cell-edge users' performance in the cellular system. Figure 2 gives clear examples about the indoor and outdoor femtocells;

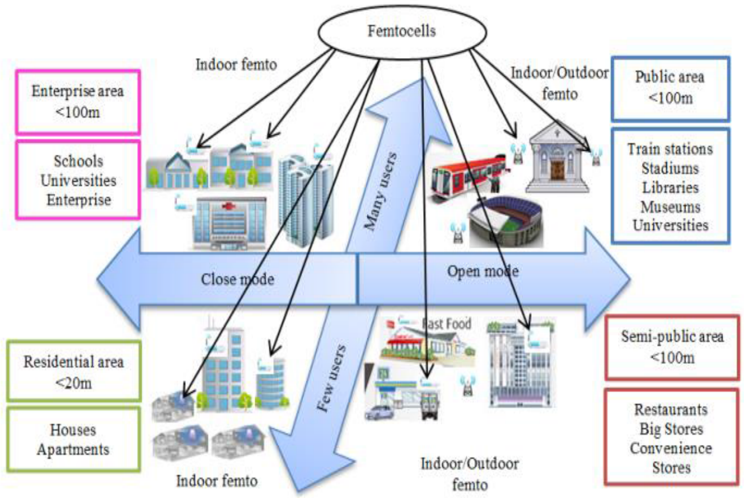

Figure 2. Outdoor and Indoor femtocells

In general, femtocells can be connected to the operator’s core network through the legacy broad band connection which might be an optical fiber or digital subscriber line. Since the transmission range between the femtocell and its users is short, the transmission power of users can be saved resulting in longer battery life.

The motivation of this research came after studying the concept of mobile relays, mobile networks and femtocells. The need to improve the Quality of Service (QoS) of cell-edge mobile users played an important role in developing the MFemto technology. It also covers the remote areas that are hard to be covered by the eNB in LTE networks. However, several challenges can face deploying the MFemtos which needed to be considered from different aspects such as; sharing the resources between the macrocell and MFemto users, improving the spectral efficiency, throughput, SINR, SNR, SIR and HO procedure. Also, the main concern will be about developing a new technique that serves the largest possible number of users with concerning about improving the QoS of cell-edge mobile users. Both of the user selection and the resource allocation scheme are needed to be investigated in this study. Moreover, the position of the FFemtos and MFemtos is needed to be chosen wisely in order to have the smallest possible number of femtocells but with the largest possible coverage area. Using this technique reduces the implementation cost and interference so it is necessary to specify the cell threshold area and place the femtocells near to this area.

More studies have been done on the resource management of femtocell [8][9][24], spectrum sharing efficiency in femtocell [10][11][12][23] and multi-hopping [3] in OFDMA based on LTE network [21].

It is known that femtocells can either be deployed indoors or outdoors [7][18] and it may share the same spectrum with the macrocell or utilise a specific spectrum which can be known as non-orthogonal mode and orthogonal mode respectively [12]. The difference between using the non-orthogonal and orthogonal mode is that in an orthogonal mode, the femtocells use a separate spectrum band that has not been used by the eNB which can have the advantage of avoiding interference from/ to the macro cell, while in the non-orthogonal mode the femtocell may share the same spectrum with the macrocell.

Several studies have considered the interference issue and the impact of that on the network performance in LTE and LTE-Advanced network [19][20][22]. More researches have been done on the mobile user relays and the advantages of using this technology to improve the cell edge users’ throughput [25][26][27][28]. Most of the achieved results showed that there is always an issue with the mobile users relay battery life since it is limited and cannot relayed upon when deploying large number of users. While, there are few studies that consider mobile relay nodes as mobile networks [29][30]. However, the issue with the mobile relay is the limited coverage area which is restricted to a few meters and the limited number of users served. The limited coverage area can be the solution to the interference issue but it raises other issues like the unnecessary HO issue and the HO time delay.

The rest of this paper will be sectioned as following: Section II gives an overview about MFemtocells. Section III presents the system model. Section IV demonstrates the simulated results and finally section V concludes this paper.

2. MFEMTO Cells

The concept of the MFemto has been integrated from combining the concept of FFemto technologies and mobile relays. The main advantage of using MFemto is the ability of this small cell to be moved around and dynamically change its connection to the operator's core network. The concept of the MFemto can be seen as a practical implementation of the moving networks which can be deployed on public transport like trains and buses or on private cars as figure 3 shows.

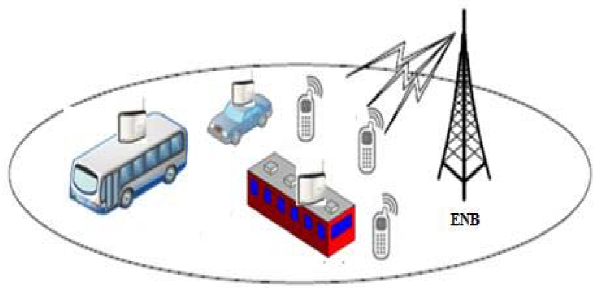

Figure 3. MFemtos

The MFemto adapts the LTE's standard radio interface to communicate with the serving eNB and the group of UEs who are within the coverage of that particular MFemto. The following figure illustrates the MFemto architecture in LTE system:

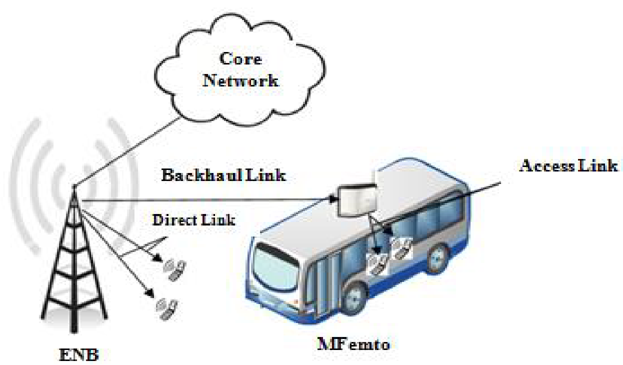

Figure 4. MFemto architecture

Figure 4 shows that there are three types of links that will be used to differentiate between the eNB-MFemto, MFemto-UE and eNB-UE links; the backhaul link, access link and direct link respectively. Moreover, it is important to clarify something here which is about those UEs who are inside the bus or the train while the MFemto is on the top of the same bus/train. In this case, the MFemto will be considered as a fixed femtocell for those UEs who are inside that bus/train because they are moving at the same speed and direction of the MFemto while it will be considered as a mobile femtocell for those UEs who are outside the bus/ train.

3. System Model

The main aim of this research is to look into the MFemto and its impact on the performance of LTE networks especially cell-edge mobile users. The MFemtos and FFemtos are moved and placed respectively in the threshold area that is suffering from high path loss, high interference and weak signal strength between the eNB and the cell-edge mobile UEs. Both of the Macro UEs and the MFemtos/FFemtos' UEs are distrbuted uniformly within the cells. The MFemtos/FFemtos are assumed to have omnidirectonal antennas twordes eNB as well as within the vehicle in the case of the MFemto while eNBs are assumed to have directional antennas. Both the eNB and the MFemto/FFemto transmit data with fixed power per Physical Resource

Block (PRB). Moreover, the eNB gathers the Channel State Information (CSI) from all UEs and MFemtos/FFemtos. Likewise the UEs within the MFemto/FFemto will feedback this information only to the MFemto/FFemto. In the transmission process; the eNB transmits the data to the selected MFemto/FFemto via the backhual link and then the MFemto/FFemto will fully decode the data, buffer it and retransmit it to its UE via the access link.

The backhual link between the eNB and the MFemto experiences fast fading with Non Line of Site (NLoS) channel while the access link between the MFemto and the UE is assumed to be LOS with slow fading channel. The used pathloss model will be flexible to be used on the direct and the backhual link in urban and suburban areas where the buildings are of nearly uniform height while there is a different case of using the pathloss model on the acess link within the MFemto.

However, the backhual link is the capacity bottleneck of MFemto technology and many challeges can be faced with deploying this technology. One of these challeges is observed when the UE and MFemto speed goes up, the rapid variations of mobile channels combined with feedback delays reduce the accuracy of the channel state information (CSI) at eNBs. The CSI feedback inaccuracy at the eNB limits the use of advanced MIMO transmission schemes employed in LTE systems to further increase the throughput of the backhaul link.Therefore, the speed of the designed scenarios will be controlled due to the above issue and the MFemto will move in a uniform controlled speed. Furthermore, new challenges regarding the interference management arise due to the use of MFemtos. As the distance between the MFemtos and the mobile UEs who are served by these MFemtos is very short, the mobile UEs and the MFemtos can communicated with less power. But the issue behind that is with the backhaul link which becomes complicated as the interference is expected between different MFemtos bachhaul links and between the MFemto' UEs and eNB UEs. Also, this has the biggest impact on the spectral efficiency of UEs in LTE network. Therefore, the movement and the position of the MFemto will be controlled and organised in the ROI (Regio Of Interest) in LTE network.

In this section several mathmatical equations will be introduced and derived based on the desighned scenarios to be simulated later on via using Matlab simulator. Since the SNR can be defined as the power ratio between the signal and the noise $SNR = \frac{P_{signal}}{P_{noise}}$ [32], the received SNR for the channel eNB-MFemto and eNB-UE can be denoted as the SNReNB-MF and SNReNB-UE respectively, over a RB *k* at time *t* and the transmitted power from the serving eNodeB is *P* [33][13]. Where both of the $d_j\,(k,t)$ and $d_n\,(k,t)$ are the complex channel gains that are considered in this study :

$$SNR_{eNB-MF} = \frac{P\left|d_j(k,t)\right|^2}{P_{noise}} \quad (1)$$

$$SNR_{eNB-UE} = \frac{P|d_n(k,t)|^2}{P_{noise}} \quad (2)$$

➢ **Resource Allocation and User Selection Schemes**

In this work multi-UEs have been assumed where both; the macro and MFemto/FFemto UEs are served over *k* RB which can be given as *k* = 1, …, *k*. Where the MFemtos are scheduled over a detected time-frequency zone in such a set of MFemtos which are selected based on scheduled criterion as figure 5 shows;

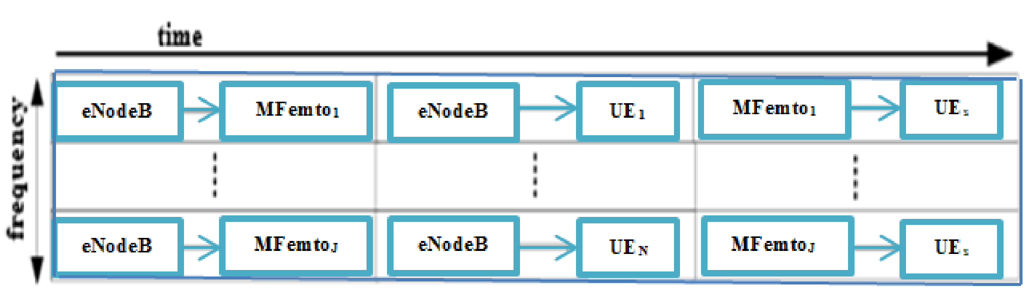

Figure 5. Time sharing strategy for MFemto in LTE network

However, based on the proportional fair sun scheduler which will be demonstrated later; each RB k is allocated to UE n with the highest ratio of instantaneous achievable rate over the average data rate as the following formula shows [35]:

$$n_k = \arg max_{n \in N} \frac{R_n(t,k)}{\bar{R}_n(t-1)} \tag{3}$$

Where the $\bar{R}_n$ $(t-1)$ denotes the average data rate of UE n before the current scheduling subframe t. Where R_n $(t,k) \propto SNR_n$ (t, k) is the instantaneous achievable rate on RB k and it is calculated according to Shannon formula:

$$R\,(t,k) = \frac{BW}{K}\log_2(1 + SNR(t,k)) \tag{4}$$

However, the average data rate of UE n can be updated according to the following rule;

$$\bar{R}_n(t) = \left(1 - \frac{1}{T}\right)\bar{R}_n(t-1) + \frac{1}{T}\hat{R}_n(t) \tag{5}$$

Where T is the average window length which is considered as an important element in the Proportional fair sun scheduler.

It is important to be mentioned here that the scheduler in eNB should consider the limitation of the control channel elements (CCE) when allocates the PRBs to UEs in both directions (uplink and downlink). However, there are two sequential scheduling decisions; the candidates selection followed by the frequency domain resources allocation to assign the PRBs among the selected UEs depending on their traffic needs; e.g. video, voice, data, http etc. First of all, the time domain scheduler will prioritise the UEs based on a given priority criterion (e.g. proportional fair sun as it has been chosen in this work), then it selects only Marco UEs or MFemtos/FFemtos UEs with the highest scheduling priority taking into account the total CCE constraints as well as the available number of PRBs. The proportional fair sun scheduler has been considered in this work and it refers to the amount of resources allocated within a given time window to UEs with better channel quality in order to offer high cell throughput as well as fairness satisfactory. This scheduling technique works as the following; firstly, the scheduler sorts the UEs in descending order according to the proportional fair sun metric and then it picks up only some of the UEs depending on the availability of the CCE, the PRBs and UE's Channel Quality Indicator (CQI). Secondly, the scheduler allocates the PRB k to UE n as equation (3) showed.

Figure 6 illustrates the flow chart of Proportional fair sun scheduler for UEs in LTE network. At the beginning of the scheduling process the eNB compares the CQI from different terminals and selects the UE with the highest CQI. If there is more than one terminal with the highest CQI, a random one is picked by the scheduler. In the first time slot the terminals with higher CQI are scheduled. In the second time slot the terminals are scheduled cyclically in turn. On the third slot period the process is repeated again alternately [34].

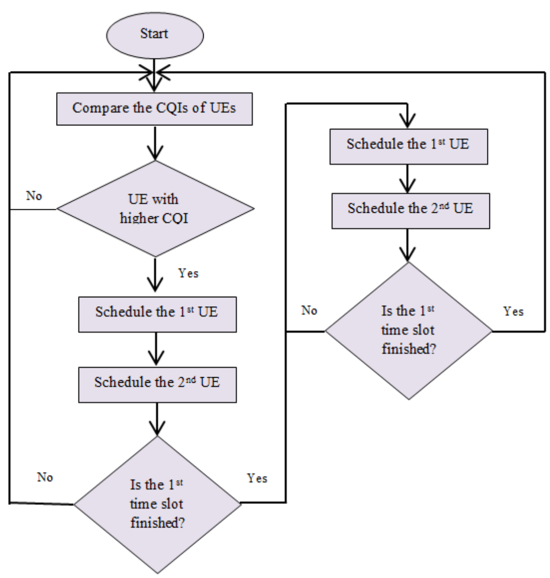

Figure 6. Proportional fair sun scheduler for UEs in LTE network

However, in the OFDMA based system, the whole spectrum is split into orthogonal sub-channels. Since there are different types of links; backhaul link, direct link and access link as mentioned earlier in figure 4 so the spectrum has to be allocated efficiently or reused among these links. The Non-orthogonal resource allocation scheme has been applied in this study and it means that the radio resources are reused by the direct and access link but the radio resources are orthogonally allocated between backhaul and direct, and between backhaul and access links. Non-orthogonal mode means that there will be ICI to the access and direct UEs due to the simultaneous transmissions from the MFemto and eNB on the same sub-channels. This scheme has several advantages over the orthogonal scheme since it improves the resource utilisation via comparing that to the orthogonal scheme. Also, it gives the flexibility to implement the Radio Resource Management (RRM) at the eNB and the MFemto independently.

Since the $SNR = \frac{P_{signal}}{P_{noise}}$, the received SINR for Direct UE ($SINR_D$) can be calculated by [76]:

$$SINR_{n(D)} = \frac{P_1|h_n^{eNB}|^2}{I_{MFemtocell}+B_{eNB}P_{noise}} \tag{7}$$

Where I is the ICI from the MFemtos and this interference can be reduced by regulating the transmission power of the MFemto via using directive antenna or by controlling the MFemto movement and direction. On the other hand, the received SINR for Access UE ($SINR_A$) can be calculated according to the following equation:

$$SINR_{m(A)} = \frac{P_2|h_m^{MFemtocell}|^2}{I_{eNB}+B_{MFemtocell}P_{noise}} \tag{8}$$

However, the $SNR_{MFemtocell\ (B)}$ is the SNR for the backhaul channel of the MFemto when the channel gain of the backhual link of the MFemto is $|h_{MFemtocell}^{eNB}|^2$ can be calculated my the following formula;

$$SNR_{MFemtocell(B)} = \frac{P_1|h_{MFemtocell}^{eNB}|^2}{B_{MFemtocell}P_{noise}} \tag{9}$$

It is important to be mentioned here that since the SINR is the power of a certain signal of interest divided by the sum of the interference (communication) power (from all the interfering signals) and the power of some background noise; if the power of noise term is zero, then the SINR reduces to the signal to interference ratio (SIR) and in this case equation (7) and (8) will be represented as the following;

$$SIR_{n(D)} = \frac{P_1|h_n^{eNB}|^2}{I_{MFemtocell}} \tag{10}$$

$$SIR_{m(A)} = \frac{P_2|h_m^{MFemtocell}|^2}{I_{eNB}} \tag{11}$$

While if the interference is equal to zero; in this case the SINR will be equal to the SNR and this can be achieved by controlling the transmission power of the MFemto or by controlling the movement, speed and direction of the MFemto. The following formulas represent the SNR of both; the direct UE and Access UEs respectively;

$$SNR_{n(D)} = \frac{P_1|h_n^{eNB}|^2}{B_{eNB}P_{noise}} \tag{12}$$

$$SNR_{m(A)} = \frac{P_2|h_m^{MFemtocell}|^2}{B_{MFemtocell}P_{noise}} \tag{13}$$

Where, h_n^{eNB} and $h_m^{MFemtocell}$ are the complex-valued channel gains over direct and acess links respectively. P_1 and P_2 are the transmission power of the eNB and MFemto respectively. B_{eNB} and the BMFemtocell are the *eNB* and MFemto distrbuted bandwidth respectively and P_{noise} is the noise power.

Based on Shannon equation the spectral efficiency of the eNB_{UE} will be calculated by the following equation;

$$Spectral\ efficiency\ \ of\ eNB_{UE} = \log_2\left(1+\frac{P_1|h_n^{eNB}|^2}{B_{eNB}P_{noise}}\right) \tag{14}$$

While the spectral efficiency of the $MFemto_{UE}$ will be calculated by the given equation;

$$Spectraleffciency\ of\ MFemto_{UE} = \log_2\left(1 + \frac{P_2\left|h_m^{MFemtocell}\right|^2}{B_{MFemtocell}P_{noise}}\right) \tag{15}$$

Since this study is considering the Average Spectral Effeciency of UEs by mean that the spectral effeciency of partcular number of UEs in the system divided by the cellular area that those UEs are separated in which is simply $Average\ Spectral\ Effeciency = \frac{Spectral\ Effeciency\ of\ UEs}{Area}$ [36]. Based on the previous equation the average throughput of eNBUE and MFemtoUE will be calculated as the following;

$$Average\ Throughput\ of\ eNB_{UE} = \log_2\frac{\left(1+\frac{P_1\left|h_n^{eNB}\right|^2}{BP_{noise}}\right)}{Area_{eNBUE}} * BW_{eNB} \tag{16}$$

$$Average\ Throughput\ of\ MFemto_{UE} = \log_2\frac{\left(1+\frac{P_2\left|h_m^{MFemtocell}\right|^2}{BP_{noise}}\right)}{Area_{MFemtoUE}} * BW_{MFemto} \tag{17}$$

Where the $Area_{eNBUE}$ and $Area_{MFemtoUE}$ are the areas that direct UEs and Access UEs are spreated in respectivly. The considered areas are representing the calculated throughput of UEs in these particular areas and the average throughput is needed to be calculated since in reality, the statistics are not symmetrical; and there are users who are closer to the base station with a better average SNR; there are users who are stationary and some of them are moving; there are users which are in a rich scattering environment and some with no scatterers around them.

4. Simulation Results

The MFemto/FFemto performance in LTE network has been evaluated using the dynamic level system simulator which considers the LTE specification. The MFemto/FFemto and mobile UEs were considered to be distributed homogeneously and uniformly respectively in the cell. A single base station with three sites (3 eNBs) and 3 FFemtos or 1 MFemto in each 1Km2 have been considered. FFemto/MFemto UEs and macro-cell UEs were assumed to be 10 and 40 respectively. Two designed scenarios have been simulated; FFemto with mobile UEs and MFemto with mobile UEs, and the derived mathematical equations have been used in the simulated scenarios to create the desired environment. It is important to mention that LTE frame structure has been considered, which consists of blocks of 12 contiguous subcarriers in the frequency domain and 7 OFDM symbols in the time domain. The scheduling period is 1 ms per each sub-frame. The carrier bandwidth is fixed at 20 MHz with 100 RBs. In the eNB all UEs are equipped with a single antenna since the directional antenna has been used while the MFemtos/FFemtos have two antennas working in diversity mode since they are using the omnidirectonal antennas. The gain on the backhaul link which is between the eNB and the MFemto (G) is assumed to be 8 dB. A full eNB buffer is considered where there are always buffered data ready for transmission for each node. However, more detailed parameters have been considered in our simulation are shown in Table 1.

4.1 Simulated Scenarios

In this part of the paper, two scenarios were considered and simulated in order to draw a comparison between FFemto and MFemto mobile UEs in term of their UEs' performance. This comparison is discussed later on in this paper to outline the advantages and disadvantages of deploying the FFemtos and MFemtos in LTE Networks.

★ Fixed Femto-Mobile UEs scenario

The FFemto in the outdoor environment when LTE penetration loss is equal to zero is needed for cell edge mobile UEs. Placing the FFemtos nearer to the threshold of the cell would be a reasonable solution to improve the QoS for cell edge UEs. A good example that can represent this case is to have mobile UEs moving closer to the cell edge and FFemtos are placed closer to cell edge to improve the performance of those UEs as figure 7 shows;

Parameter	Value
Carrier frequency	2 GHz
System bandwidth	20 MHz
Number of PRBs	100
Number of cells	3
Number of FFemtos/MFemtos	3 FFemto or 1MFemto per each 1 Km2
Inter-site distance (ISD)	500 m
MFemto/FFemto type	In-band, decode and forward
MFemto/FFemto position	Homogeneous density
Number of macro UE	40
Number of FFemto/ MFemto UE	10
UE position	Uniform distribution
MFemto speed	1.3889 m/s and 13.889 m/s
Mobile and vehicular UE speeds	1.3889 m/s and 13.889 m/s
eNB transmission power	40 dBm
FFemto/MFemto transmission power	5 dBm
UE scheduler	Proportional fair sun
Penetration loss	Outdoor: 0dB and in-car: 7dB
eNB antenna height	20
MFemto antenna height	2
Antenna gain eNB	15dBi
Antenna gain FFemto/ MFemto	0
Environment	Urban
PRB bandwidth	180 MHz

Table 1. Simulation parameters

★ **MFemto-Mobile UE scenario**

Another scenario is to have the MFemto with mobile UEs. This MFemto can be possibly mounted on a moving bus or a train. In this case several criteria will be considered e.g. UEs/MFemto speed, direction and distance. However, it is important to be mentioned here as it has been acknowledged earlier; this MFemto will be considered as a fixed femtocell for those UEs who are inside the bus while it will be considered as a mobile femtocell for those UEs who are outside the bus.

4.2 Handover process in MFemtocell

Before moving to the results' section, there is another part needs to be covered here which is the MFemto handover (HO). Due to the fact of using the MFemto in our study, therefore, the HO process will occur differently than the FFemto. In general femtocell handover consists of three scenarios as the following [15], [16] & [17];

★ Inbound scenario: The HO occurs from the eNB to the femtocell.

★ Outband scenario: The HO occurs from the femtocell to the eNB.

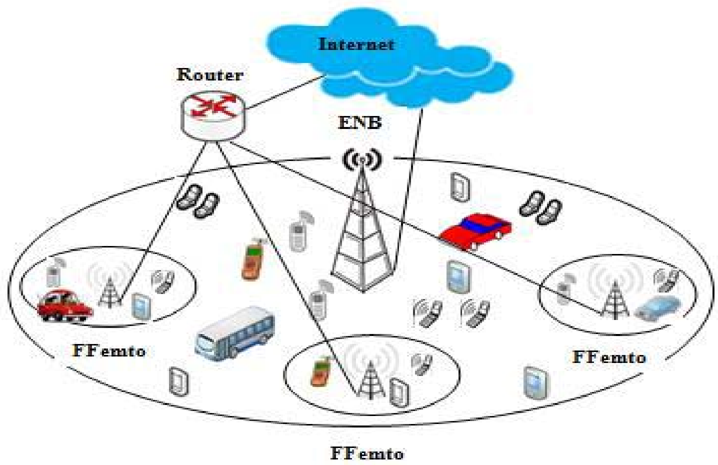

Figure .7 Mobile UEs served by FFemto

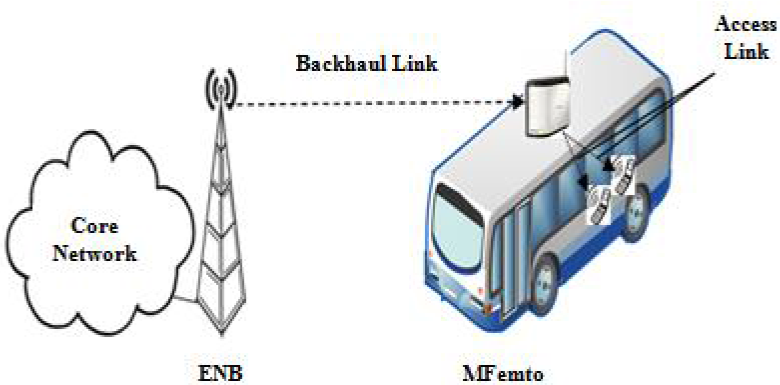

Figure 8. Mobile UEs with MFemto

★ Femtocell to femtocell scenario: The HO occurs between one femtocell to another close by femtocell.

In our research two HO scenarios will be investigated; the first scenario is the HO from one MFemto to another close by MFemto and the second scenario is handing-over the MFemto from one eNB to another neighbouring eNB. Figure 9 illustrates when UEs move from train A to train B which means from one MFemto to another so the HO procedure needs to be established in order to maintain the signal strength of those moving out/in UEs.

The HO from one MFemto to another MFemto occurs when the UE needs to move out of the range of one MFemto to another. In this case the UE needs to select an appropriate target MFemto among many neighbouring MFemtos in order to be handed to. Checking the authorization of the UE during the HO preparation phase is an important part for the HO to be completed correctly.

The second scenario of the MFemto HO is when the MFemto moves away from one cell to another. Here the MFemto needs to be handed over to the next neighbouring cell. In order to avoid the overload that the next cell might suffer from; another MFemto needs to be moved out from the second cell to another next neighbouring cell. In this scenario there should be an excellent time management otherwise the connection will go down. So whenever MFemto (A) starts its HO procedure; MFemto (B) needs to starts its HO procedure almost at the same time to move out of cell (B) to cell (C). Figure 10 shows how this scenario functions;

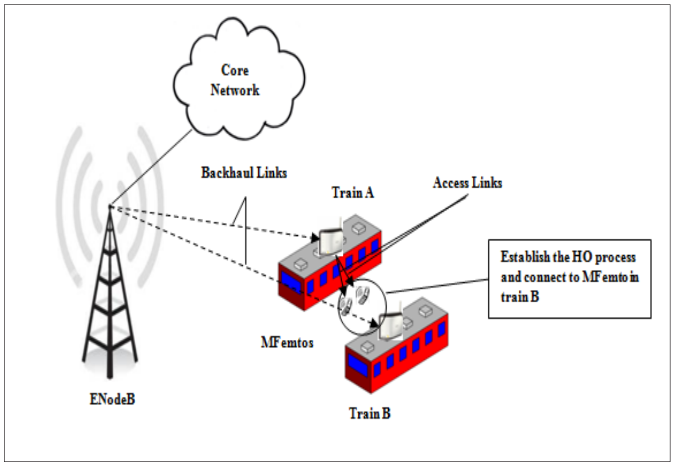

Figure 9. HO in MFemtos

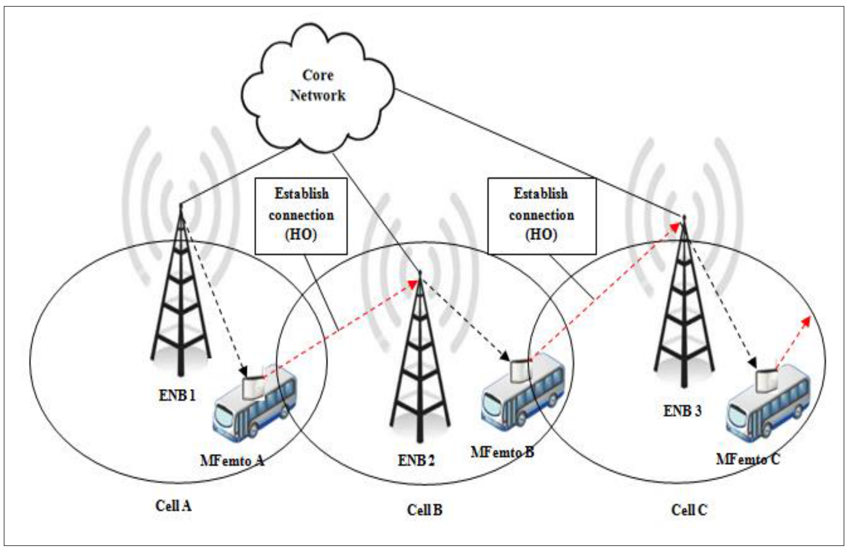

Figure 10. MFemto HO between two cells

In the above scenario whenever the signal level between the source MFemto and the source eNB goes down, the MFemto initiates a HO to other neighbouring eNBs (The chosen neighbouring cell depends on the direction of the MFemto). However, if the available PRBs in the next macrocell are not enough to accept the MFemto, the CAC allows the release of some Bandwidth (BW) from the existing direct link UEs by degrading their QoS level. Also the CAC policy will permit the reduction of the required BW for the MFemto request. The system allows a maximum (BeNB - Bmin required) amount of BW reduction for an existing MFemto or requested HO call. Therefore, the system increases the number of connected MFemtos and served UEs as well as reduces the HO call dropping probability. If the minimum required BW Bmin required is not available in the next eNB after releasing of some BW from the existing direct link UEs, then the MFemto will not be connected to the next cell and the UEs inside the train/bus will not be served by the next cell till there is the available number of required PRBs.

However, in the above scenario there is always a chance of an overlapping issue between two MFemtos if e.g. MFemto handed off to cell B and there is not any other MFemto left cell B at the same time due to the time delay issue. The problem with that is the connection of UEs who are inside the bus of MFemto will go down due to the fact that all the PRBs of the cell B are occupied and there is no chance for the MFemto to work at cell B. But there is another solution can be worked in this case and that takes us to the following scenario (solution).

This means that those UE who are inside the bus/train can be served by any close by FFemtos or MFemtos even by a MFemto on another moving bus next to their bus/car and moving at the same speed of their bus/car.

The following scenario is considered as the worst case scenario as the high volume of traffic is the main issue. e.g., when there is a MFemto moving close to the cell edge and there are vehicular UEs inside their cars/buses near to the cell edge as well who are needed to be connected to a MFemto in order to maintain their connection. In this case, this connection of those vehicular UEs might not last more than few seconds depending on the speed of both; target MFemto and the vehicular UEs so as long the vehicular UEs move far away from the coverage area of the MFemto that they are attached to; the connection breaks down. Figure 11 illustrates this scenario;

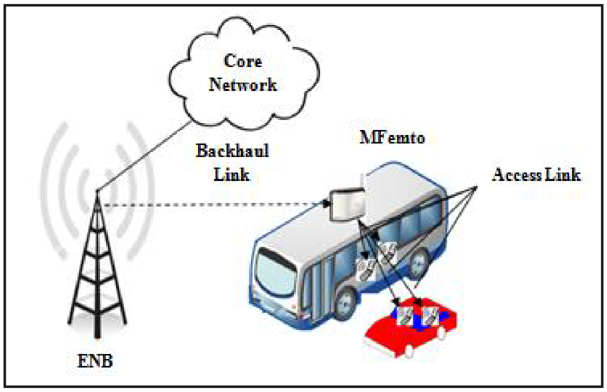

Figure 11. Connection establishment in the worst case traffic

Figure 11 shows that whenever there is a new vehicular/mobile UE needs to be attached to the MFemto; the CAC initially checks whether the MFemto coverage is available or not. If the MFemto coverage is available, then the MFemto is the first choice to connect the UE to. The MFemto accepts the new UE if the received SINR level is satisfied and the PRBs in the MFemto are available since the $SNIRT_{MF}$ is the received SINR of the target MFemto. Then if the above conditions are not satisfied, the UE tries to connect with the overlaid macro-cellular network (eNB). The eNB does not allow the QoS degradation policy to accept any new UE and this UE will be rejected if the requested BW is not available in the overlaid macro-cellular network. The following figure illustrates the diagram that summarises the process that has been demonstrated earlier;

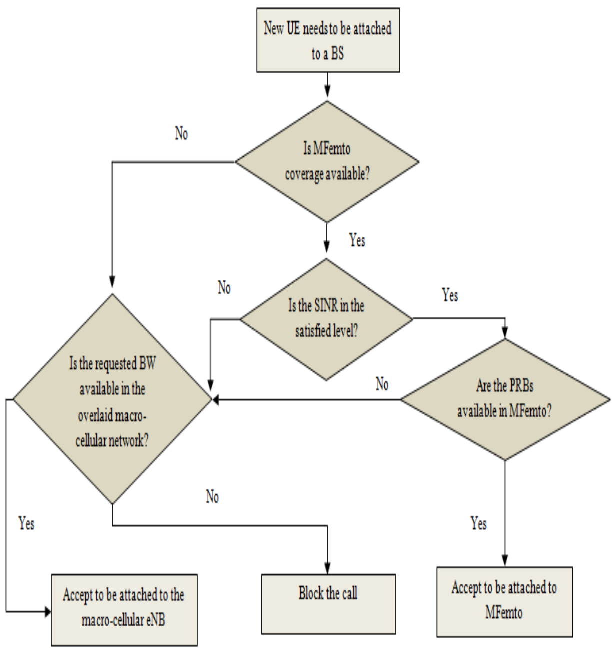

Figure 12. New connected UEs case 1

Also, there is a case when those mobile/vehicular UEs are connected with the eNB. Whenever the moving UE detects a signal from a MFemto, the CAC policy checks the received SNIR level e.g. SINRTMF of the target MFemto. The eNB UEs handed over to the MFemto when the current receive SINR level of the eNB is less than or equal to the SINRTMF. If any of the above conditions is satisfied; the CAC policy checks the PRBs availability in the target MFemto. Then those mobile UEs will be handed over to the target MFemto especially if those UEs are close to the edge of the cell and their signals are going down. The following figure illustrates what has been presented earlier;

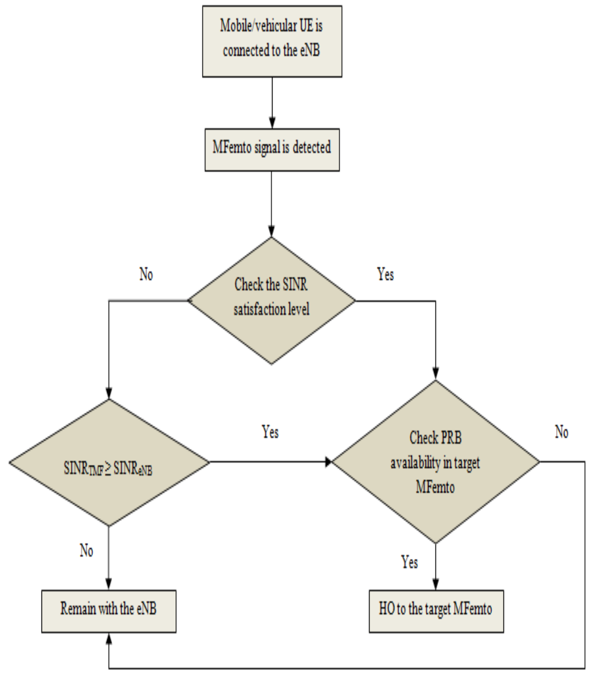

Figure 13. New connected UEs case 2

4.3 UE Spectral Efficiency

Since the theoretical part of calculating the spectral efficiency has been discussed earlier in the system model section; here it is needed to discuss the simulated spectral efficiency results. It is important to be mentioned here that several criteria might have the biggest impact on the achieved spectral efficiency which have been considered in this work;

• Since the transmission power of each the FFemto/MFemto might affect the spectral efficiency; an appropriate transmit power has been chosen (5dBm) because if the transmit power is too high, this may cause interference to the neighbouring macrocell and MFemtos/FFemtos that might cause low SINR or SIR which could affect the system performance. On the other hand, if the transmit power is too low; this may limit the coverage area of the MFemto/FFemto and that will limit the achieved results.

• When there is no enough distance between the eNB and FFemtos/MFemtos, the interference issue will occur again but this time not only between the base stations only, between the UEs who are served by those base stations. Therefore, since the MFemto has the flexibility to move from only place to another, it was easier to control the distance gaps between each others. This has the impact to mitigate the interference issue since MFemto are using the same frequency band that might affect the spectral efficiency of the UEs.

• The speed of the MFemto plays an important role in the network performance since this last can create HO failures, HO delay or unnecessary HOs under the high speed MFemtos that would affect the spectral and performance efficiency. Therefore, in order to overcome the previous issues the speed of the MFemto will be controlled and united in all used MFemtos.

Before discussing the results it is important to discuss the nature of the considered measurements of the x and y axes, since the x-axis represents the simulated equations in term of the ECDF at the Y-axis. The empirical cumulative distribution function (ECDF) is a non-parametric estimator of the underlying CDF of a random variable. It assigns a probability of D to 1 / *n* each datum, orders the data from smallest to largest in value, and calculates the sum of the assigned probabilities up to and including each datum.

Therefore, the following figure shows a comparison between the spectral efficiency of mobile UEs after placing the FFemto and MFemto in the cell. It is obvious here that the average spectral efficiency of the mobile UEs after adding the MFemto is much better than adding the FFemto. Because controlling the coverage area and the interference of the MFemto is much easier than the FFemto. For example, sometimes when there is high interference between the MFemto and another MFemto or the eNB; it is easier to control the movement of that MFemto and let UEs enjoy better connection and services. Basically, the simulated plot shows that the average spectral efficiency of particular group of UEs in a particular area has been considered to calculate their average spectral efficiency over that specific area. The result shows the improvement of the spectral efficiency among the ECDF which reaches its maximum faster when there is no femtocells in the cell, while it shows some improvement after adding the femtocells in the cell. The highlighted area 1 shows that at EDCF 0.5 the average spectral efficiency of FFemto UEs is 3 b/cu since it is 4 b/cu at the MFemto. While the highlighted area 2 represents the improvement in the average spectral efficiency of MFemto UEs (black line) since their ECDF is less than the macro UEs without femtocell and with FFemto (blue and red lines respectively).

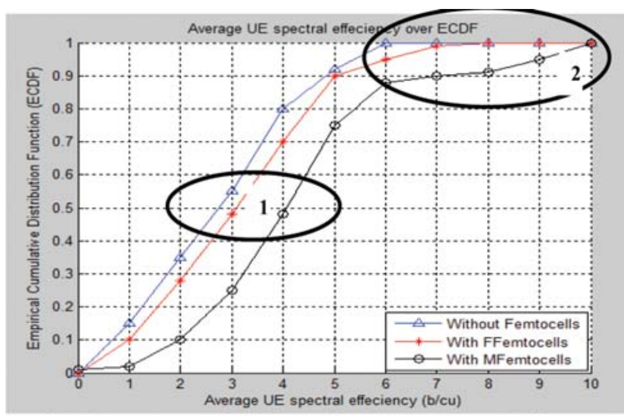

Figure 14. Average spectral efficiency of mobile UEs without &with FFemtos/MFemtos

4.4 UE Throughput

As it has been mentioned earlier that whenever there is a MFemto the number of scheduled UEs increases and at the same time the throughput of those UEs improves due to the fact that MFemto can reach areas the FFemto cannot reach and that count as an advantage for the MFemto over the FFemto. Figure 15 shows a comparison between the throughputs improvement of mobile UEs after adding the FFemto and MFemto in the cell. The average throughout of a group of mobile UEs among particular area has been calculated in term of the ECDF. The results show that the average throughput of mobile UEs after adding the FFemto reaches its maximum at 7Mbit/s while it reaches its maximum at 10Mbit/s after adding the MFemto as the highlighted area shows. Having the femtocell in the macro-cell in general improves the average UE throughput since the results show that the average UE throughput of the macro-cell before adding the femtocells reaches its maximum at 6Mbit/s after a dramatic increase in the ECDF. However, it is important to be mentioned here that the UE throughput can be affected by the following; packet loss due to the cell congestion especially when the transmitted bit rate of UEs is larger than the available bandwidth. Packets might be dropped when the packets queues are full due to the cell congestion or the packet might be lost due to the bit errors. Also, the UE throughput can be degraded when some users send large packets which require higher bandwidth than other users so the users who required more bandwidth will require more services and resources than others which put the network under the extra load services. Those issues can be solved easily by implementing the MFemto in the network because using this technology serves the UEs faster since it can reach the congested areas and offer its bandwidth to the needed UEs while FFemto does not have the movement flexibility.

4.5 UE SINR

Figure 16 demonstrates the difference in the results of the average SINR of mobile UEs after adding FFemtos or MFemtos in the cell. As the previous plots, the results have been measured with the respect to the ECDF and in general the results showed some improvement after adding the femtocells in the cell. However the highlighted area shows that the negative side of the SINR UE after adding the MFemto is less than the negative side of the SINR UE after adding the FFemto since it -8 and -12 respectively.

And it is obvious that in math whenever the negative number increased that means the number is small and whenever the number decreased that means the number is big so since the negative side of the MFemto is less than the FFemto that means the signal of MFemto UEs is much better than the FFemto UE. Because in the case of the MFemto it is easier to mitigate the interference and the noise since it is easier to control the MFemto position and that will improve the signal connection between the UE and the MFemto or the eNB since there is an inverse relation between the signal and the interference plus the noise power.

However, the simulated results here showed the realistic case when the signal experience interference and noise at the same time and because of that the SINR of UE has been measured while as it has been mentioned earlier in the system model when the power of noise term is zero, then the SINR reduces to the signal to interference ratio (SIR). Conversely, zero interference reduces the SINR to the SNR.

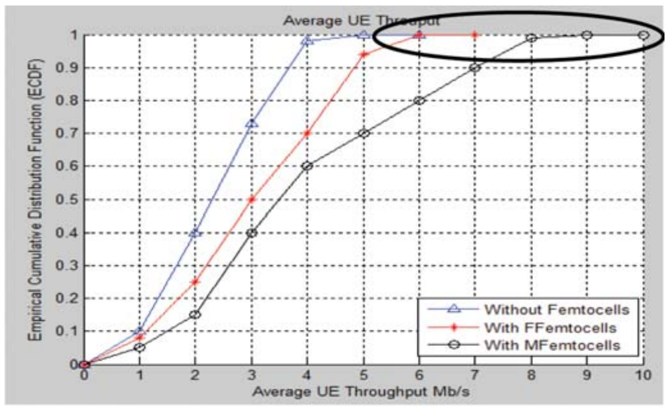

Figure 15. Average throughput of mobile UEs without & with FFemtos/MFemtos

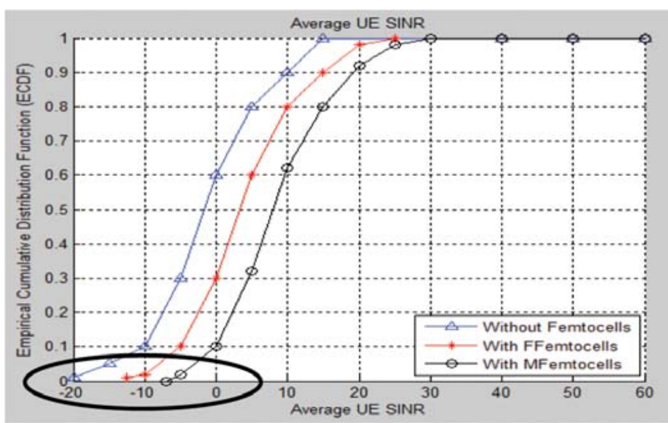

Figure 16. SINR of mobile UEs without & with FFemtocells/MFemtocell

4.5 Handover Strategy

The HO procedure has occupied a significant part in this work and the simulated results of this part will be discussed. Figure 17 shows a compression between the FFemto and MFemto, and the number of HOs. However, due to the facts of the small coverage area of the femtocell, low power and its density; the UE in the femtocell system will face the very frequent unnecessary HO since the UE will be moving from one femtocell to another repeatedly. Since this study is considering the mobile and vehicular UEs so if the added femtocells are FFemtos; it means that whenever the mobile/vehicular UEs are moving from the coverage area of FFemto to another, a HO process will be needed which will increase the number of unnecessary HOs and makes the network spends more time and resources for these HOs. Because there is a positive relationship between the UEs' velocity and the number of HOs in the network since those UEs require more HOs than the low speed UEs require. While if MFemtos have been added to the cell, this will reduce the number of HOs since those vehicular UEs who are inside the bus/train will be served by the MFemto that mounted on the top of that bus/train because in this case there will be a mobile coverage area that moves with the UEs whenever they are going. Figure 19 shows the results of the number of HOs in terms of the number of FFemtos/MFemtos which is 1 and 3 respectively in each 1km^2.

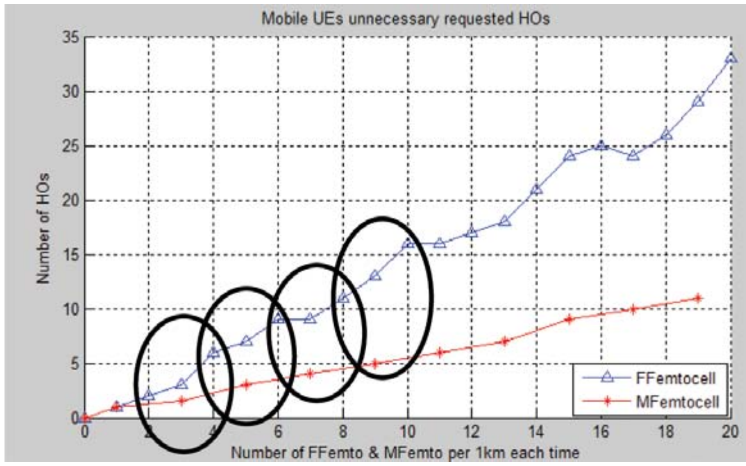

Figure 17. Number of FFemto and MFemtos and the number of HOs

5. Conclusion

In this document, a demonstration of two scenarios in LTE cellular network have been presented as the following; FFemtos with mobile UEs, MFemtos with mobile UEs. The performance of FFemtos and MFemtos has been investigated in term average UEs' spectral efficiency, average UEs' throughput, average UEs' SINR and the unnecessary HOs reduction. Based on the achieved results via Matlab simulator, mobile UEs have enjoyed better QoS after adding the MFemto in the cell than adding the FFemto. The author proved that MFemto technology has a bright future as it is seeing as the next generation technology which implies having less number of MFemtos in the cell. Using MFemtos will reduce the cost, interference number of unnecessary HOs especially for mobile and vehicular UEs and improve the system's overall performance.

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