DEVELOPMENT OF A MODIFIED HANDOVER DECISION ALGORITHM FOR INTER-FEMTOCELL HANDOVER IN LONG TERM EVOLUTION NETWORK

BY

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NIGERIA

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DECLARATION

I hereby declare that the work in this dissertation titled "Development of a ModifiedHandover Decision Algorithm for Inter-Femtocell Handover in Long Term Evolution Network" has been carried out by me in the Department of Electrical and Computer Engineering. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Kelechi Nnanna OkogwuSignature Date
(Student)

CERTIFICATION

This dissertation titled "**DEVELOPMENT OF A MODIFIED HANDOVER DECISION ALGORITHM FOR INTER-FEMTOCELL HANDOVER IN LONG TERM EVOLUTION NETWORK**" by Kelechi Nnanna Okogwu meets the regulations governing the award of degree of Master of Science (M.Sc.) in Telecommunications Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated toGod Almighty, who gave me the grace to complete this work and to my parents Mr. and Mrs. E.Okogwu, without whom this dream would not have been realised.

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KELECHI NNANNAOKOGWU
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ABSTRACT

The present day cellular network faces an increasing problem of providing capacity and coverage for users. The Long Term Evolution (LTE) system provides a number of ways in mitigating these problems among one of which is the deployment of femtocell technology. The femtocell is an example of a heterogeneous network which comprises of different layers of different cell sizes ranging from microcell, picocell and radio relay nodes.The femtocell is the least in size of network densification and is deployed at indoor environments. Deployment of femtocells is not without its challenges, among which is frequent handover. The problem of frequent handover arises from the nature of the femtocell owing to its unplanned deployment, small cell size and access control techniques. Thefrequent handovers in femtocells reduces the user’s call quality. This research work addressed thefrequent handover problem by considering the users motion as it changes, using the Link Expiration Time (LET) method and theinter-femtocell handover scheme of Rajabizadeh and Abouei in order to accommodate mobile users whose speeds are varying.This scheme was designed to establish a communication link with the nearest femtocell when the users speed undergoes an abrupt change. The developed handover scheme was implemented using a developed Graphical User Interface (GUI) in MATLAB and its performance was evaluated with the traditional handover scheme based on the number of handovers and the time interval between handovers as performance metrics. It was observed from the results obtained that the developed handover scheme performed fewer handovers in comparison to the 3GPP handover schemewhich was better by 24.17%.

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LIST OF ABBREVIATIONS

Acronyms	Definition

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
CA	Carrier Aggregation
CAC	Call Access Control
CDMA	Code Division Multiple Access
CFAP	Cognitive Femtocell Access Point
CN	Core Network
COMP	Co-ordinated Multi-point
CSG	Closed Subscriber Group
DTA	Double Threshold Algorithm
eICIC	enhanced Inter-cell Interference Coordination
eNodeB	evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FAP	Femtocell Access Point
FDD	Frequency Division Duplex
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HeNB	Home evolved NodeB
HDT	Handover Delay Timer
HHM	Handover Hysteresis Margin
HSS	Home Subscriber
IMT-A	International Mobile Telecommunications-Advanced
LET	Link Expiration Time
LTE-A	Long Term Evolution-Advanced
LTE	Long Term Evolution
MAHO	Mobile Assisted Handover
MANET	Mobile Ad-Hoc Network
MATLAB	Matrix Laboratory
MBS	Macro Base Station

MCHO	Mobile Controlled Handover
MDP	Markov Decision Problem
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NCHO	Network Controlled Handover
NCL	Neighbour Cell List
OFDMA	Orthogonal Frequency Division Multiple Access
P-GW	Packet Gateway
PCRF	Policy and Charging Rules Function
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QOS	Quality of Service
RACH	Random Access Channel
RB	Resource Block
RLS	Recursive Least Squares
RNC	Radio Network Controller
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
S-GW	Serving Gateway
SAE	System Architecture Evolution
SAMSRL	Single Agent Multiple Stater Reinforcement Learning
SC-FDMA	Single Carrier Frequency Division Multiple Access
SINR	Signal Interference plus Noise Ratio
TDD	Time Division Duplex
UE	User Equipment
UMTS	Universal Mobile Terrestrial System

CHAPTER ONE

INTRODUCTION

1.1 Background

Intense consumer demand for mobile data and poor signal quality within buildings are two issues mobile network operators grapple with. In mobile communication, it is estimated that nearly two-thirdsof the calls made and over 90% of data usage occurs indoors (Zhang & De la Roche, 2010) and according to a study carried out by Cisco, it observed that the global mobile data traffic will increase nearly 11-fold between 2013 and 2018(Cisco, 2014).

This rapid increase in mobile data activity has led to the development of innovative new technologies and cellular topologies that can meet these demands(Andrews *et al.*, 2012).In order to achieve high data rate communications, the transmitter and receiver can be brought closer to each other to improve system capacity. An example of such idea is the femtocell technology(Chandrasekhar *et al.*, 2008).

A femtocell, also known as a home base station or femtocell access point (FAP), is a short-range, low-cost, low-powered base station installed by a user for better indoor voice and data reception(Chandrasekhar *et al.*, 2008). Compared to microcells and Picocells, femtocells are deployed at indoor environments such as homes, offices, shopping malls and airports etc. to extend the coverage and improve the capacity of a mobile network(Li *et al.*, 2016).The FAP can be classified into two types depending on the capacity and number of users. They are classified as home FAP which can support 3-5 users and enterprise FAP which can support 8-16 users (Shanavas *et al.*, 2013). The femtocell operates in a licensed spectrum and communicates with the operator's network over a broadband connection such as a digital subscriber line (DSL), cable modem or a separate radio frequency backhaul channel (Mahmud *et al.*, 2013).

Femtocells are operated with low transmission power (maximum of 20 dBm)(Rose *et al.*, 2011) and this transmitted signal power defines thefemtocell coverage area. It also has an impact on the interferencethe user experiences, the user equipment (UEs) service off rate, the handover process and signalling(Shbat & Tuzlukov, 2012).The basic difference between a macro cell and a femtocell is the respective backhauls. The femtocell backhaul is simply an interface to the operators core network through the public internet network, while the macro cell backhaul is a dedicated link to the core network (Shbat & Tuzlukov, 2012).There are many advantages for the deployment of femtocells to both the user and the mobile network operator. For the user, the use of a femtocell within the home enables far better coverage and capacity to be enjoyed, the battery life of a UE is also improved because of the low power radiation(Ali-Yahiya, 2011). For the network operator, the cost of deploying extra infrastructure to increase capacity is substantially reduced,as there is no added cost in maintaining and running the femtocells. It simply provides a cost effective means of improving capacity and macro cell reliability.

Despite these advantages of the femtocell technology, there are challenges associated with its deployment. These include interference management, resource allocation, and seamless handover (Li *et al.*, 2016).Cell handover has been considered as one of the most challenging issue in Long Term Evolution-Advanced (LTE-A) macrocell-femtocell network (Xenakis *et al.*, 2014). This is due to the following reasons:

a) The unplanned nature of femtocell deployment
b) The small femtocell radius
c) The denser network layout
d) The employment of access control mechanisms.

The apparent lack of seamless handovers leads to redundant handovers which decreases the user’s throughput because of interruptions(Becvar & Mach, 2013).

1.2 Motivation

In recent times as mobile network operators continually upgrade and expand their network infrastructure to meet demand and generate new revenue streams. There are attendant challenges to the attainment of these objectives. More so the unintentional disruption of the conventional network operation. Furthermore with the explosion data intensive applications and smartphone devices,that these changes brings makes thefemtocella favourite option to increase capacity in areas with high user demand and to fill-in areas not covered by the macro cell network.

1.3 Statement of Research Problem

When femtocells are densely deployed, problems such as inadequate system capacity,increase in the signalling overhead (Badri *et al.*, 2013) and poor quality of service arises. These Problems most times are a result of the frequent handovers that will occur due to the small cell size of the femtocell and the speed of the UE.

1.4 Aim and Objectives

The aim of this research work is to develop a modified handover decision algorithm using the LET mobility prediction technique to mitigate the problem of frequent handover.

The objectives of the research are as follows:

a) Replicate and implement the traditional and inter-femtocell handover decision algorithm ofRajabizadeh and Abouei, (2015)
b) Develop a modified handover decision algorithm using the LET method.
c) Compare the performance of the modified handover decision algorithm to that of the traditional handover decision algorithmbased on the number of handovers and time between handovers.

1.5 Scope of Dissertation

This dissertation addresses the problem of handover in a LTE macrocell-femtocell heterogeneous network. The basic concepts of handover and an LTE Network in general, are discussed. Previous research works that treated the handover problem are reviewed. Furthermore, the methods adopted in solving the problem is discussed and finally the performance of the proposed method is evaluated using the number of handover and average time before handover metric.

1.6 Significance of Research

This research work is important because it enables the development of a modified handover decision algorithm in order to determine the effect of user velocity on handovers forfemtocells in close proximity. The research then provides a mechanism that offers improved call quality and reduced handovers.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the fundamental concepts which provide the background knowledge for the research and presents a review of similar studies carried out by various authors.

2.2 Review of Fundamental Concepts

Fundamental concepts relating to this research work are discussed in this section. These concepts provide the background knowledge of the research work carried out.

2.2.1 Long Term Evolution (LTE) System Architecture

LTE is a broadband cellular wireless technology that is developed by the Third Generation Partnership Project (3GPP). It is also known as Fourth Generation (4G) mobile communication standard. The first release of the LTE standard was the release 8, approved in 2008 with download speeds of up to 173 Mb/sec(Jimaa *et al.*, 2011). However subsequent upgrades to the initial standard has been developed (release. 9,10,11,12 and 13) (Astely *et al.*, 2013). LTE supports both frequency division duplex (FDD) and time division duplex (TDD), as well as a wide range of system bandwidths (1.4, 3,5,10,15 and 20MHz) in order to operate in a large number of different spectrum allocations (Astely *et al.*, 2009). The major difference between LTE FDD and LTE TDD is that while LTE FDD uses paired frequencies to upload and download data, LTE TDD uses a single frequency band, alternating between uploading and downloading data through time. The LTE system uses an all Internet Protocol (IP) flat networking architecture, which minimises the number of network elements, This IP part of LTE is called the Evolved Packet System (EPS) which was previously known as System Architecture Evolution (SAE) (Jimaa *et al.*, 2011). The LTE network is optimised for packet switching services but can also handle circuit switched services to legacy cellular standards. The LTE standard uses the Quadrature Phase-Shift Keying (QPSK), 16-Quadrature

Amplitude Modulation (QAM) and 64 QAM modulation scheme. The air interface for LTE is the Evolved Universal Terrestrial Radio Access (E-UTRA) which uses the Orthogonal Frequency Division Multiple Access (OFDMA) for downlink transmission and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink transmission.

The LTE-A (release 10) is an evolution from the initial release 8, which did not meet the International Mobile Telecommunication-Advanced (IMT-A) requirements. It supports further enhancements from the first LTE release. These enhancements are:Co-ordinated Multi-Point (COMP), Carrier Aggregation (CA) and heterogeneous networks, Multi-Input-Multi-Output (MIMO) antenna techniques, enhanced Inter-Cell Interference Coordination (eICIC). LTE-A further, improves the capacity and coverage and ensures user fairness. Figure 2.1 shows the overall network architecture, including the network elements and the standardized interfaces. At a high level, the network is comprised of the Core Network (CN) known as the Evolved Packet Core (EPC) and the access network also known as the Evolved Universal Terrestrial Radio Access Network (E-UTRAN).

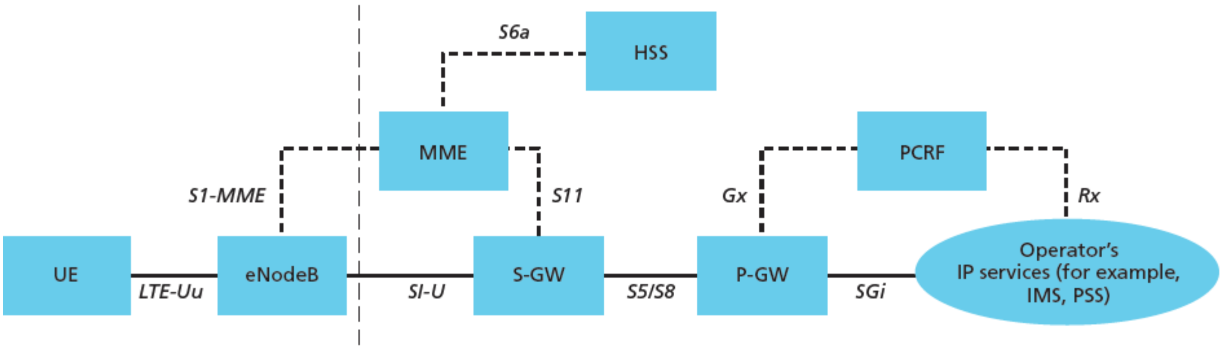


Figure 2.1: Evolved Packet System Network Elements (Palat & Godin, 2009)

The core network consists of logical nodes such as the mobility management entity (MME), serving gateway (S-GW), packet data gateway (P-GW), policy and charging rules function (PCRF), and the home subscriber server (HSS). The access network is made up of essentially just one node, the base station which is called the evolved NodeB (eNodeB) in LTE. The eNodeB connects to the user’s phone, mobile station or UE. Each of these network elements are interconnected by means of interfaces (S1, S1-MME, LTE-$\text{U}_{\text{U},}$ S5/S8, SGi, S11, S6a, Rx, Gx). These interfaces provide the logical connection between these network nodes and transports information between them.

2.2.2 Handover

Handover is the process of transferring an active call or data session from one cell to another, while a user is in motion.In mobile wireless networks, the purpose of handover is to keep ongoing connections uninterrupted, which is a very important function for ensuring the quality of service and continuity of a mobile user (Li *et al.*, 2016). The transfer of the current communication channel could be in terms of time slot, frequency band, or code word to a new base station(Ekiz *et al.*, 2007)

In carrying out a handover process, there are parameters which can be classified as dynamic and non-dynamic. The dynamic parameters include Received Signal Strength (RSS), velocity of the user, throughput, user preferences, handover latency, network load balancing and the non-dynamic parameters include network cost, power consumption, network security and bandwidth(Ravichandra *et al.*, 2013).

Handovers can be classified based on a number of factors. These classifications include the administrative domains involved, number of connections and frequencies engaged etc. (Nasser *et al.*, 2006). Figure 2.2 shows the different classification of handovers based on these factors.

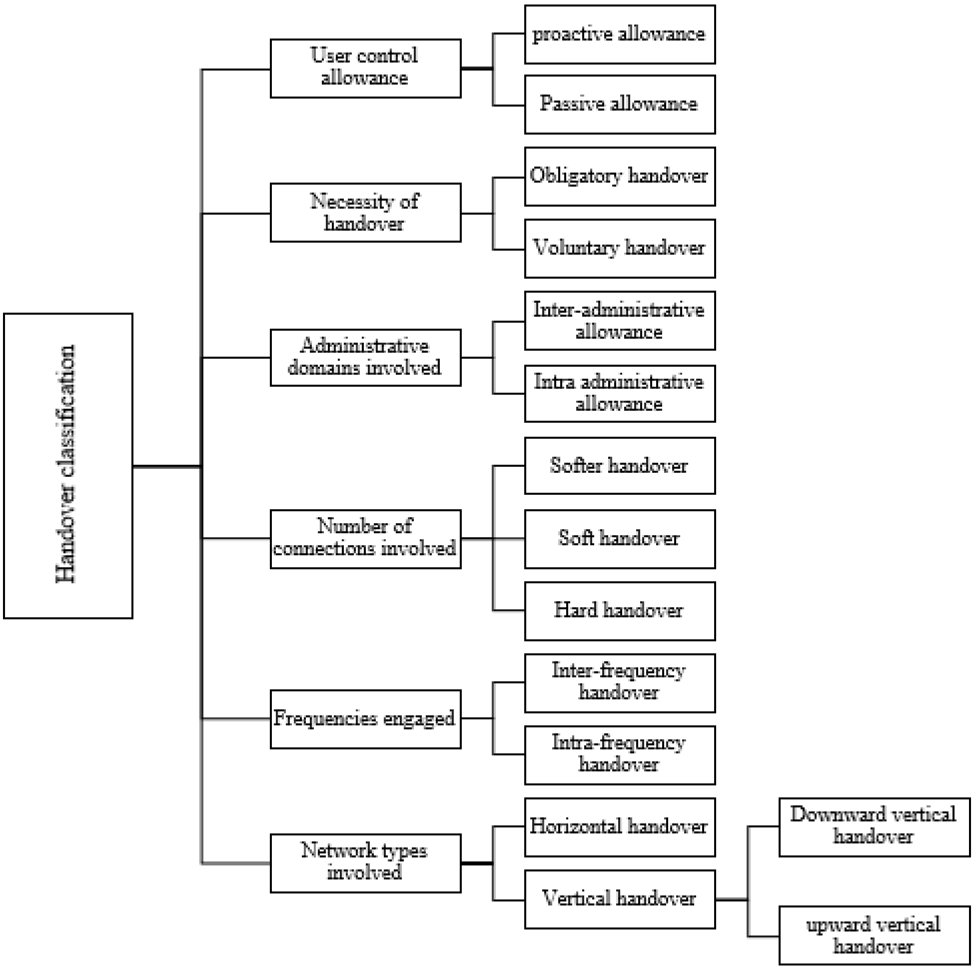


Figure 2.2: Handover Classification Tree (Nasser *et al.*, 2006)

The most common type of classification is the network related handover. There are two types; the horizontal and the vertical handover. Horizontal handovers are handoversbetween two base stations of the same system (e.g., within a GSM/CDMA/LTE network) to maintain service continuity, while vertical handovers are handovers that transfers the active connections between different wireless technologies (e.g., from GSM to CDMA or from LTE to UMTS)(Ravichandra *et al.*, 2013; Sgora & Vergados, 2009).The vertical handover mechanism allows a UE to change between different types of networks in a way that is completely transparent to the user (Ravichandra *et al.*, 2013).

For handovers classified based on the number of connections involved, there are hard handovers, soft handovers and softer handovers. In the case of hard handover, the channel is released at the source cell and only then the channel is engaged at the target cell. Hard handovers are also referred to as***“brake before make”***.The femtocell supports hard handover methods only (Gódor *et al.*, 2015). For soft handovers, the channel is retained at the source cell and used for a while in parallel with the channel at the target cell, they can also be referred to as **“*make before break*”**. This type of handover occurs in a CDMA network(Theodore, 2002).The softer handover is very similar to a soft handover, except that the UE switches connections over radio links that belong to the same access point (Nasser *et al.*, 2006).

2.2.2.1 Handover Initiation

Handover initiation is a phase in the handover process in which the appropriate condition to request a handover to a target cell is triggered. The common handover initiation techniques include; initiation based on relative signal strength, initiation based on relative signal strength with threshold, initiation based on relative signal strength with hysteresis, initiation based on relative signal strength with hysteresis and threshold(Stallings, 2005).

Figure 2.3 shows a UE moving from one BS (BS_A) at position L_A to another (BS_B) at position L_B. The average signal strength of BS_A decreases as the UE moves away from it. Similarly, the average signal strength of BS_B increases as the UE approaches it. The BS averages the signal after a time period to remove the rapid fluctuations due to multipath effects (Stallings, 2005)

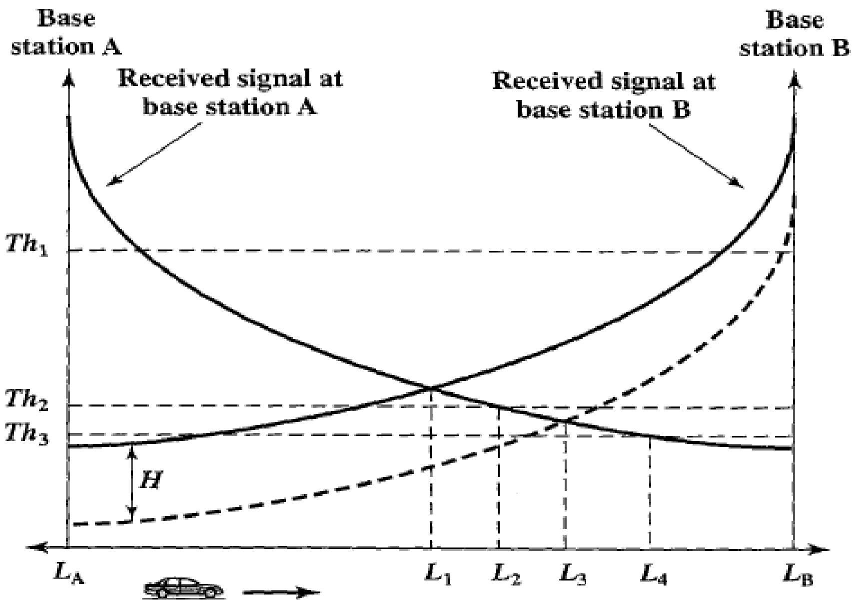


Figure 2.3: Handover Between Two Cells (Stallings, 2005)

a) **Relative signal strength:** The UEis handed over from base station A to base station B, when the signal strength at B first exceeds that at A. If the signal strength at B subsequently falls below that of A, the mobile unit is handed back to A. InFigure 2.3, handover occurs at point L_1. At this point the signal strength to base station A is still adequate but is declining, because signal strength fluctuates due to multipath effects. Even with power averaging this approach can lead to a **ping-pong effect**, a scenario when the UE is repeatedly handed back and forth between two base stations.

b) **Relative signal strength withthreshold:** Handover only occurs when the signal at the current base station is sufficiently weak (less than a threshold) and the other signal is the stronger of the two base stations. The intention is that so long as the signal at the current base station is adequate, handover is unnecessary. If a high threshold is used, such as Th_1,this scheme performs the same as the relative signal strength scheme. With a threshold of Th_2, handover occurs at L_2.If the threshold is set quite low compared to the crossover signal strength (signal strength at L_1), such as Th_3, the UE may move far into the new cell (L_4) before handover. This reduces the quality of the communication link and may result in a dropped call. A threshold should not be used alone because its effectiveness depends on prior knowledge of the crossover signal strength between the current and candidate base stations.

c) **Relative signal strength with hysteresis:** Handover occurs only if the new base station is sufficiently stronger by a margin *(H*) than the current one. In this case, handover occurs at L_3.This scheme prevents the ping-pong effect, because once handover occurs, the effect of the margin *(H)*is reversed.

d) **Relative signal strength with hysteresis and threshold:** Handover occurs only when the current signal level drops below a threshold, and when the target base station is stronger than the current one by a hysteresis margin *(H).* In Figure 2.3, handover occurs at L_3 if the threshold is either Th_1 or Th_2 and at L_4if the threshold is atTh_3

2.2.2.2 Handover Decisions

The handover decision phase involves selecting the target cell for attachment at the time of handover(Pan & Zhang, 2012). The objective of this phase is the selection of the new channel based on actual resource availability and network load.The impact of the handover decision phase is even more prominent in the presence of femtocells, owing to the short-range nature of communications, the denser network layout and the fast varying radio environment(Xenakis *et al.*, 2014). The handover decision protocols used in mobile cellular communications are given as follows (Tripathi *et al.*, 1998):

a) Network Controlled Handover (NCHO): In NCHO protocol, the network makes a handover decisionbased on measurements of theReceived Signal Strength (RSS) of the user equipment at a number of BSs. In general, the handover processtakes between 100-200ms(Tripathi *et al.*, 1998).

b) **Mobile Assisted Handover (MAHO):**A MAHO protocol distributes the handover decision process. The UE makes measurements, and the network makes decisions. The UE periodically relays the link quality measurements back to the serving base station and the handover decision is made by the serving base stations along with the Mobile Switching Centre (MSC) (Stuber, 2002). An example of where the MAHO is used is the GSM. The average handover time is one second (Tripathi *et al.*, 1998).

c) **Mobile Controlled Handover (MCHO):**In MCHO the UE is completely in control of the handover process. The UE continuously monitors the signal of the surrounding base stations and requests a channel from the target base station with the lowest interference(A. Bhuvaneswari & E. George Dharma Prakash Raj, 2011), and a handover is also initialised if the signal strength of the serving base station is lower than that of another base station by a certain threshold (Qing-AN Zeng & Dharma, 2002) . The average handover time for this type of handover is approximately 100ms(Tripathi *et al.*, 1998).

2.2.2.3Handover Performance Indicators (HPIs)

The Handover Performance Indicators are performance metricsused in evaluating the performance of a handover algorithm. Some of these performance indicators includes Handover failure ratio, Ping Pong handover and the rate of handover

a) **Handover failure ratio**

The handover failure ratio (HPI_{HOF}) is the ratio of the number of failed handovers (NHO_{fail}) to the number of handover attempts. The number of handover attempts is the sum of the number of successful (NHO_{succ}) and the number of failed handovers(Jansen et al., 2010):

$$HPI_{HOF} = \frac{N_{HOfail}}{(N_{HOfail} + N_{HOsucc})} \quad (2.1)$$

b) Ping-Pong handover ratio

If a call is handed over to a new cell and is handed back to the source cell in less than the critical time (T_{crit}) this handover is considered to be a ping-pong handover. The ping-pong handover ratio (HPI_{HPP}) represents the number of ping-pong handovers ($N_{HO}pp$) divided by the number of ping-pong handovers ($N_{HO}pp$), the number of handovers with no ping-pong ($N_{HO}npp$) and the number of failed handovers (N_{HOfail})(Jansen et al., 2010):

$$HPI_{HPP} = \frac{N_{HOPP}}{(\mathrm{N_{HOPP}}) + (N_{HOnpp}) + (N_{HOfail})} \quad (2.2)$$

c) **Rate of handover**

This is the number of handovers per unit time combined with the average call duration. The handover rate can be calculated using the formula in(B. Singh *et al.*, 2005):

$$\lambda_H(\mathrm{h}) = \frac{KD}{320}\left\{1 - \exp(-\frac{b}{h^a})\right\} \quad (2.3)$$

where:

K is an adaptive parameter
D is the base station separation
h is the hysteresis margin
a is the ratio of the path loss exponent (γ) to the standard deviation (σ)
b is the ratio of the correlation distance (d_o) to the averaging distance (d_{av})

2.2.2.4 LTEHandover Measurements

The handover procedure in LTEis based on the UE's measurements. After these measurements are made they are sent to the network to make decisions. These measurements includeReference Signal Received Power(RSRP),Received Signal Strength Indicator (RSSI),Reference Signal Received Quality (RSRQ)and Signal Interference plus Noise Ratio (SINR).

a) **Reference Signal Received Power (RSRP)**

This measurement is used mainly to rank different LTE candidate cells according to their signal strength and is used as an input for handover and cell reselection decisions. RSRP is calculated based on the transmit power of the cell, the path loss value and shadow fading (Jansen *et al.*, 2010).

$$RSRP_{c,UE} = P_c - L_{UE} - L_{fad} \qquad (2.4)$$

where:

P_c is the cell transmit power,
L_{UE} is the path loss values from the users to the different cells and
L_{fad} is the additional shadow fading with a log-normal distribution and a standard deviation of 3dB.

b) **Received Signal Strength Indicator (RSSI)**

The RSSI is defined as the total received wideband power observed by the UE from all sources, including co-channel interference, adjacent channel interference and thermal noise within the bandwidth measured (Sesia *et al.*, 2009).

c) **Reference Signal Received Quality (RSRQ)**

The RSRQ metric describes the signal quality of candidate cells. While the RSRP is an indicator of the signal strength, RSRQ takes the interference level into account due to the inclusion of RSSI. The RSRQ describes the combined effect of signal strength and interference (Sesia *et al.*, 2009).The RSRQ is calculated as:

$$RSRQ = \frac{N.RSRP}{RSSI} \qquad (2.5)$$

Where N is the number of Resource Blocks (RBs) contained within the bandwidth measured.

d) **Signal Interference plus Noise Ratio (SINR)**

SINR is defined as the ratio of signal power to the combined noise and interference power.

$$\mathrm{SINR} = \frac{\mathrm{P_{signal}}}{\mathrm{P_{noise}} + \mathrm{P_{interference}}} \qquad (2.6)$$

2.2.2.5 LTEMeasurement Reporting

In LTE, measurements taken are reported at periodic intervals. This periodic interval could range from 120 milliseconds to 60 minutes(Cox, 2012).Measurement reports are triggered by measurement events, which happens when a signal level crosses a set threshold. In LTE there are 5 intra system measurement report events and 2 inter system report events(Johnson, 2010). The intra system measurement report events are: event A1, event A2, event A3, event A4 and event A5 while inter system report events are: event B1 and event B2.Event A3, is typically used to trigger a handover within LTE. It is defined as a triggering event which occurs when a neighbour cell becomes an offset better than the serving cell. The event is triggered when the following condition is true(Cox, 2012):

$$M_n + Of_n + Oc_n > M_s + Of_s + Oc_s + Off + H_{ys}$$

And the triggering event is subsequently cancelled when the following condition holds true:

$$M_n + Of_n + Oc_n < M_s + Of_s + Oc_s + Off - H_{ys}$$

where:

$M_{n\ \mathrm{and}}M_s$is the UE measurement of the neighbouring and serving cells.

$Of_{n\mathrm{and}}$ $Of_s$is the optional frequency specific offsets.

$Oc_{n\ \mathrm{and}}$ Oc_s is the cell specific offsets.

Offis the hysteresis parameter for handovers.

Hysis the hysteresis parameter for measurement reporting.

2.2.2.6 LTEHandover Control Parameters

The handover control parameters are parameters used in controlling the handover procedure. These control parameters can be tuned by the handover algorithm in order to obtain a desired performance. In LTE, the hysteresis and time-to-trigger values are two parameters that are used. The valid hysteresis values vary between 0 and 10 dB with steps of 0.5 dB(3GPP, 2012).While the time-to-trigger values are (0, 0.04s, 0.064s, 0.08s, 0.1s, 0.128s, 0.16s, 0.256s, 0.32s, 0.48s, 0.512s, 0.64s, 1.024s, 1.280s, 2.560sand 5.120s)(3GPP, 2012). Hence there are 336 valid control parameter combinations from the hysteresis and time-to-trigger values(Jansen *et al.*, 2010).

2.2.2.7 Handover Procedure in LTE

There are two types of handover procedures in LTE for UE's in active mode, the S1-handover procedure and X2-handover procedure. The S1-handover procedure is performed between two eNBs without the X2 interface, while the X2 handover is used when there is a direct connection between source and target eNBs(Ermolayev, 2016). The handover procedure starts with the measurementreporting of a handover event by the UEto the serving eNB. The UE periodicallyperforms downlink radio channel measurements based onthe Reference Symbols Received Power(RSRP) and the Reference Symbols Received Quality (RSRQ)(3GPP, 2013). If certain network configured conditions are satisfied, the UE sends the corresponding measurement report indicating the triggered event. In addition, the measurement report indicates the cell to which the UE has to be handed over, which is called the target cell. Based on these measurement reports, the serving eNB starts handover preparation(Dimou *et al.*, 2009). The handover preparation involves exchange of signalling messages between the serving and target eNB and admission control of the UE in the target cell as shown in Figure 2.4. Upon successful handover preparation, the handover decision is made and consequently the handover Command will be sent to the UE. The connection between UE and the serving cell will be released. Then, the UE attempts to synchronize and access the target eNB, by using the Random Access Channel (RACH). Upon successful synchronization at the target eNB, an uplink scheduling grant message from the target eNB is sent to the UE. The UE responds with a handoverconfirm message, which notifies the completion of the handover procedure at the radio access network part(Dimou *et al.*, 2009).

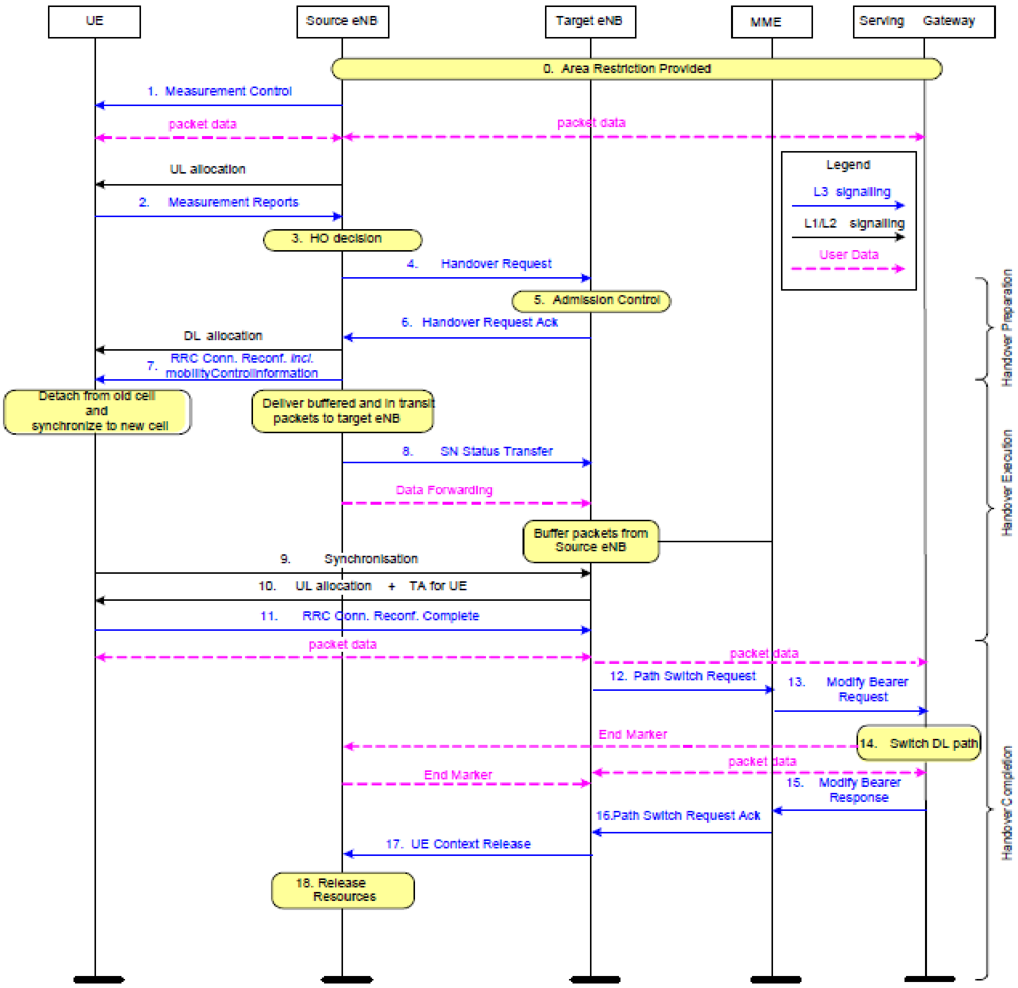


Figure2.4: LTE Handover Procedure(3GPP, 2013)

2.2.3 Femtocells

A femtocell is a small, low power and low cost base station that is deployed indoors for providing better coverage and higher data rates. The femtocell incorporates the functionality of a base station and a Radio Network Controller (RNC). It connects to the core network through the DSL internet connection. The femtocells can be deployed either by the network operator or by the end users forming a two-tier network, i.e., the macro cell serving as the umbrella cell and the femtocells deployed within its coverage area (Khalid & Kwak, 2013).Femtocells have the characteristic of unplanned installation and management by users. The unplanned and indoor deployment of femtocells within the existing macro cell networks introduces a number of challenges like interference and mobility management (Nasrin & Xie, 2015). A typical deployment of a femtocell scenario is shown in Figure 2.5.

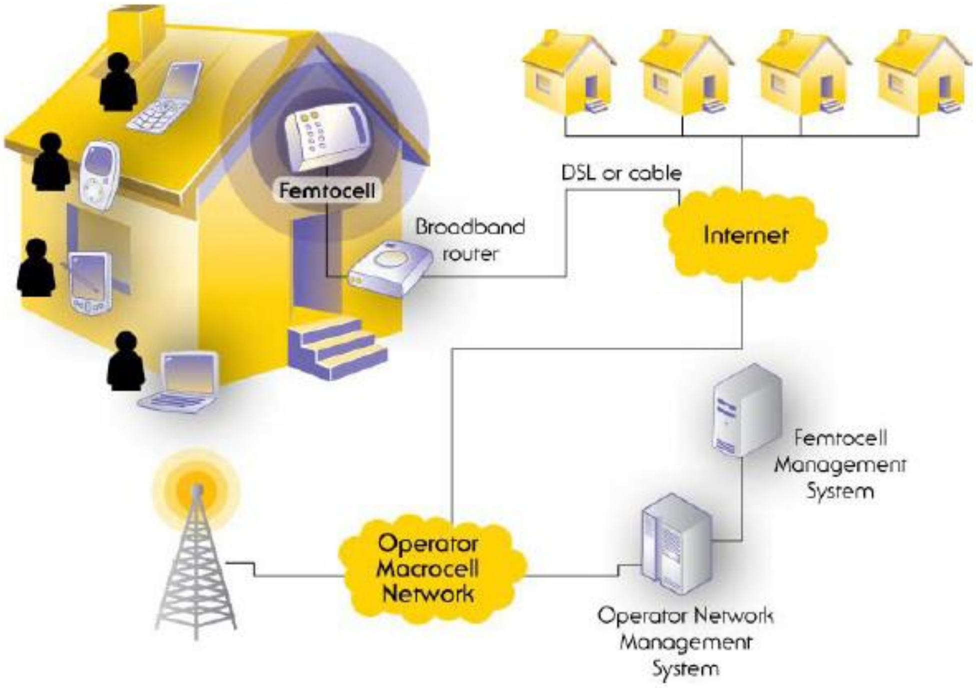


Figure 2.5: Basic Femtocell Deployment(Small Cell Forum, 2013)

2.2.3.1 Femtocell System Architecture

The overall LTE system architecture with femtocell deployment is shown in Figure 2.6. Two standard interfaces (i.e., X2 and S1) are specified by 3GPP. The X2 interface describes functionalities for mobility and information exchanged between different eNBs (Li *et al.*, 2016). The S1 interface supports interconnection between the MME and the eNB.

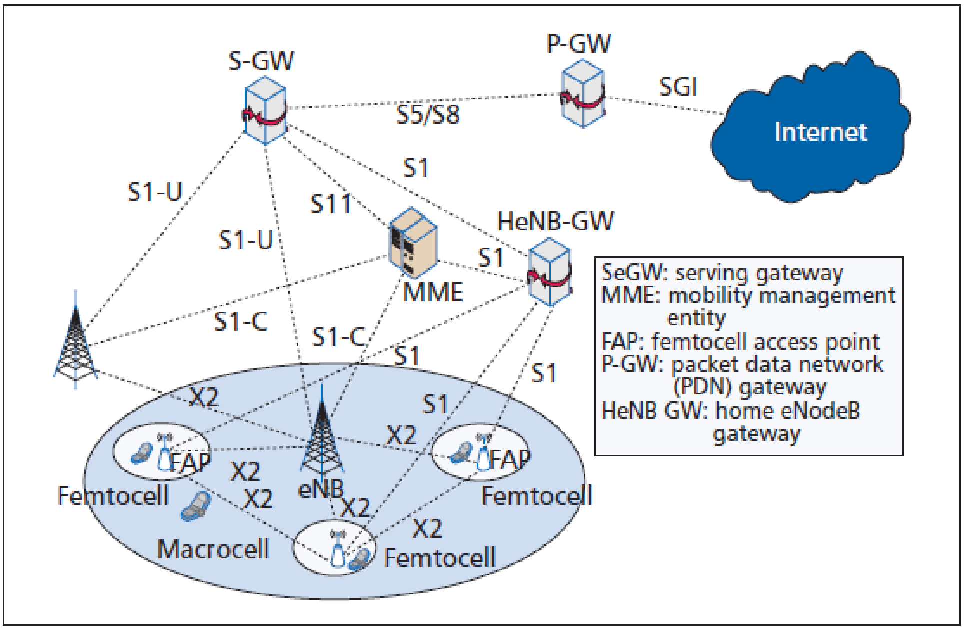


Figure 2.6: Macro-Femto Heterogeneous Network Architecture (Li *et al.*, 2016)

Femtocell Access Point (FAP)

The FAP refers to the generic term femtocell in E-UTRAN. It is a plug-and-play consumer device that can be easily installed by a user in the home or office environments. The FAP uses the subscriber's broadband backhaul to connect to the operator's core network(Ali-Yahiya, 2011).

Home eNodeB Gateway(HeNB GW)

TheHeNB GW plays the role of a concentrator and a distributor (Ali-Yahiya, 2011). It aggregates control plane messages from the FAP and forwards them to the MME.

Mobility Management Entity (MME)

The MME implements the functions of core networksignalling for mobility management support, idle state mobility handling (e.g. paging), security and authentication (Xenakis *et al.*, 2012)

Serving Gateway (S-GW)

The S-GW acts as a router, and forwards data between the eNB and the PDN gateway. The User-plane data is forwarded from FAP directly to S-GW via the S1 interface(Gódor *et al.*, 2015).

Packet Data Network Gateway(P-GW)

The P-GW is responsible for IP address allocation for the UE. It serves as the point of entry and exit for the UE to external packet data networks.

2.2.3.2 Access Modes in Femtocells

Access modes are the means through which end users accesses the femtocell technology. The access strategy employed plays a key role in the performance of the femtocell as it relates to signalling messages, interference mitigation etc.

a) Open access mode

In the open access mode, all UEs are given access. This can be used in a hotspot-type scenario like in a shopping mall or airport. In this mode, the femtocells become another part of the Public Land Mobile Network (PLMN)(Ali-Yahiya, 2011). A benefit of the open access consists in an opportunity to offload the macro base station by serving several outdoor users in areas with heavy traffic load or by serving users far from the macro base station (Small Cell Forum, 2010). However, one of the disadvantages with this mode is that it leads to an increase in the number of handovers and signalling in areas with high density of FAPs(Becvar & Mach, 2010).

b) Closed access mode

In the closed access mode, only subscribed users belonging to the Closed Subscriber Group (CSG) are allowed to connect to a privately accessible femtocell. UEs that are not part of the CSG would not get access to the femtocell except for emergency calls(Ali-Yahiya, 2011). Among the three access control mechanisms, the closed subscriber group is the most desired (Roche *et al.*, 2010).

c) **Hybrid access mode**

The hybrid access approach is similar to the closed access mode. It allows UEs not part of the CSG to connect to the femtocells, but they will be allowed only a certain part of the resources with preferential charging and access to the subscribers. This may mean that services to UE not part of the CSG may be pre-empted or rejected in favour of subscribers(Ali-Yahiya, 2011).

2.2.3.3 Handovers in Femtocell

Handovers in femtocells follows the same principle as handovers in macrocells. However femtocell networks using the same set of handover parameters as macrocells may degrade mobility performance (Lopez-Perez *et al.*, 2012).Since femtocells are naturally different from macrocells (small coverage range and different access modes), the handover algorithm in a macro-femto heterogeneous networks will be more complicated than that in macro-cellular networks(Li *et al.*, 2016). With the introduction of the femtocell into conventional network, three new handover scenarios can be distinguished depending on the type of serving and target cell as described in Figure 2.7(Becvar *et al.*, 2012).

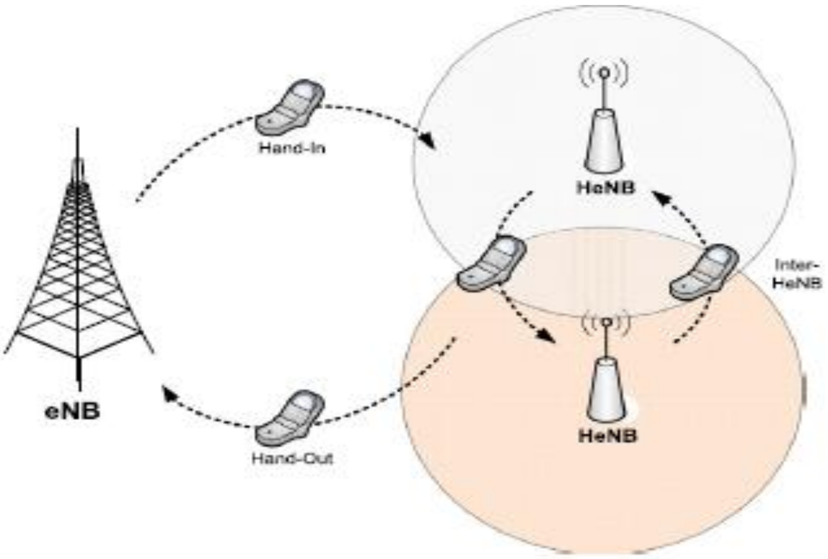


Figure 2.7: Handover Scenarios in LTE Femtocell Environments (Gódor *et al.*, 2015)

The first type of handover is represented by a switching of the UE from a serving macro cell (eNodeB) to a target femtocell (HeNB). This handover is called a**hand-in**. In this particular scenario, the femtocell admits the UE according to the femtocell's access mode (close, open, or hybrid). Successful execution of hand-in further depends on the available backbone capacity of the target femtocell. The second type of handover is called **handout**. The UE is disconnected from the femtocell and is going to be served by the macro cell. The third handover type corresponds to the situation when handover from a femtocell to another Femtocell is executed. This type of handover is called the **inter-femtocell** handover. For this handover type, the admission procedure follows the similar policies as in the case of hand-in (Becvar *et al.*, 2012). The handover from femtocell to femtocell is quite demanding and complicated because there are hundreds of possible target FAPs when the UE moves out from the coverage of its serving area (Zhuang *et al.*, 2012).There can also be delays associated with this type of handover since the time requiredto transmit a single message via the public internet network could be over 200ms (Shbat & Tuzlukov, 2012). In practice, it takes less than 100ms for a handover process between macrocells (Dimou *et al.*, 2009).

2.2.4 Link Expiration Time (LET) Mobility Prediction

The LET method uses a Global Positioning System (GPS) to compute the exact location and mobility information of a mobile node. This mobility prediction technique is used in Mobile Adhoc Networks (MANET)(Su *et al.*, 2000). In cases where GPS is not used, an approximate value for inter-node distance is computedusing transmission power samples measured periodically from packets received from a node's neighbour(Gavalas *et al.*, 2010). Based on this prediction, a communication link can be reconfigured before they disconnect.When motion parameters (speed, direction, radio propagation range) of two neighbours are known,then the duration of time D_t that two nodes *i* and *j* will remain connected, will be calculated as(G. Singh *et al.*, 2016):

$$D_t = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \qquad (2.7)$$

where:

$$a = V_i \cos\theta_i - V_j \cos\theta_j \qquad (2.7a)$$

$$b = x_i - x_j \qquad (2.7b)$$

$$c = V_i \sin\theta_i - V_j \sin\theta_j \qquad (2.7c)$$

$$d = y_i - y_j \qquad (2.7d)$$

The transmission range is given as *r*, the coordinates for the mobile host *i*is (x_i, y_i) and the coordinates for the mobile host*j* is given as (x_j, y_j). While V_i and V_j are the respective speeds for the nodes. The moving directions are given as θ_i and θ_j $(0 \le \theta_i, \theta_j \le 2\pi)$

2.3 Review of Similar Works

Yang *et al.*, (2011)proposed a modified handover procedure between a macrocell and femtocell. An asymmetric handover scheme usedDouble Threshold Algorithm (DTA) and Call Access Control (CAC) to reduce the unnecessary handovers. The CAC was used to manage the cell dwell time and to differentiate between pre-registered users and un-registered users. The DTA compared the signal level of the source and target cell based on two preselected threshold values. The authors also considered the interference level generated, using this parameter to optimise the handover decision. However, the delay from the proposed algorithm led to frequent call failure since, the signalling involved was much.

Becvar and Mach, (2011)proposed an adaptive technique to reduce redundant handovers in femtocells. The authors made use of two parameters- Windowing and Handover Delay Timer (HDT). These parameters were designed to adaptively adjust based on the channel quality related to the user's position in a cell. The adaptive duration of HDT led to a significant throughput gain while the fixed HDThad the same amount of reduced handovers. The gain obtained was between 8% and 13% for optimal duration of HDT.Alsofrom the obtained results it was observed that the adaptive window size significantly reduced the number of performed handovers for low number of averaged samples, however this gain was at the cost of lower efficiency of handover elimination leading to more handovers performed often.

Zhuang *et al.*, (2012)proposed a new handover mechanism for inter femtocell handover and designed a neighbour femtocell list which consideredthe received signal level, the hiddenFAP problem, and access mode of the FAP. When a serving FAP detected signals from a neighbouring FAP, it acquired information such as the access mode and current load, it then checked if the user equipment is allowed in that cell for a closed subscriber group or a hybrid case, resulting in a priority setting. Once the serving FAP receives a handover request which contains the RSSI information of a neighbouring FAP (whose RSSI level was stronger than a set threshold), it would set a priority to this neighbour FAP. The neighbour FAP whose distance was close and its RSSI was less than the threshold but stronger than the original was regarded as a hidden FAP and it got a certain priority level. Based on the initial priority setting, a neighbour femtocell list was created, if one of the highest priority FAP hadspare bandwidth resource it would be put into the list and on goes the list. However, the authors did not consider the cell dwell time and mobility of the UE which would affect the handover performance in a densely deployed scenario, leading to frequent handovers.

Shbat and Tuzlukov, (2012)proposed a femtocell-to-femtocell handover approach based on a simple feedback technique from the UE to the HeNBs, using a femtocell-to-femtocell interface that allowed for the exchange of initial priority lists of UEs created by each HeNB. This helped the HeNBs to handle the handover procedure between femtocells and to balance the load also. This approach was implemented across all access modes and the UE velocity was not considered since the signalling systemwas assumed to be fast. The results obtained, showed that the proposed feedback scheme for femtocell-to-femtocell handover reducedthe number of service off UEs. However, the signalling overhead forthe system when deployed on a larger scale will lead to high bandwidth utilization, resulting insignificant delays. Furthermore, the authors did not validate their results for the time delay associated with the backhaul of the femtocell, since the motivation for the research was based on the perceived delay that the public internet backhaul would cause.

Becvar and Mach, (2013)proposed a solution for efficient elimination of redundant handovers in networks with FAPs, if the advantage of coordination among Macro Base Station (MBSs) and the FAPs via backbone was exploited. The proposed handover decision algorithm was based on estimation of throughput gain acquired, by performing handover to the FAP. The gain in throughput was derived from the estimated evolution of the signal levels of all involved cells measured by the UE and the estimated time spent by the users in the

FAP. The handover was performed only if the estimated throughput offered to a UE by the FAP exceeded the throughput offered by the MBS. Both radio as well as backbone parameters of the FAPs and MBSs were taken into account in the handover decision. Consequently, the proposed procedure rejected only those handovers to the FAPs that do not introduce any considerable improvement in the users' connection. However the authors did not considerthe effect of user mobility on the handover decision process as this would affect the number of handovers made.

Lee and Yoo, (2014)proposed a handover decision procedure that compared the data capacity on a probabilistic pathwith the residence time of a UE. The estimated path was the expected distance from the entry point of the current femtocell to any point of exit in the femtocell coverage area. The comparedavailable data capacity that the UE could obtain,was based on the received signal power fromthe macrocell and femtocell. If the estimated data capacity was better, the UEwas handed overto a femtocell, if it was not better the UE remained connected to the macrocell to preventfrequent handover.However,the authors did not validate their method with the UE's actual mobility pattern, in order to ascertain the number of actual handovers performed with the estimated one.

Hoang *et al.*, (2014)proposed a cell selection scheme for femtocell-to-femtocell handover which reduced unnecessary handovers and supported the user's connection quality by not performing handover to an already overloaded target cell. The authors proposed two cell selection methods for femtocell-to-femtocell handover, which wasbased on mobility prediction and femtocell capacity estimation. The mobility prediction scheme made use of average RSS of nearby femtocells while the femtocell capacity estimation was based on the monitored downlink transmission occupancy of nearby Cognitive Femtocell Access Points (CFAPs). A dense femtocell deployment scenario was considered. The performance of the cell selection schemes, was evaluated based on two performance metrics; number of handovers and data delay, when transferring data from a CFAP to a user. Results obtained revealedthat each proposed scheme had a particular effectiveness. The mobility prediction-based scheme effectively reduced the unnecessary handover frequency while the proposed Sensing-based scheme improved the channel capacity for the user after handover.However, the data capacity of the associated algorithm had a poor performance due to the increased time to trigger for a handover.

Mutlu and Canberk, (2014)proposed a handover decision algorithm based on path loss measurements and spatially estimated path loss of future locations. The ordinary kriging interpolation method was used to spatially estimate the path loss measurements. This method comprisedtwo parts. First, the mobile station's newly defined path loss was calculated then this value was compared with the predefined threshold to make a handover decision. Secondly, the newly defined path loss was calculated, by considering the path loss of future locations which are the locations that the mobile station would most likely reach in future. The proposed handover scheme was compared to the conventional handover scheme based on number of unnecessary handover and ping-pong handover rate. However, the delay associated with this approach was much because from the proposed handover management mechanism the time to trigger increased leading to call drops.

Kalbkhani *et al.*, (2014)proposed a handover decision algorithm based on the prediction of RSS, in order to improve the throughput of the user and reduce the ping pong handovers. In the proposed method, the base stations with RSS greater than a set threshold and thosewith RSS greater than the serving base station plus a hysteresis margin are identified. The future RSS samples of the identified base station and the current serving base station are predicted using the adaptive Recursive Least Squares (RLS) algorithm. These estimated samples are used for future SINR samples. Finally the candidate base stations list was pruned down based on the estimated SINR and predicted RSS and the base station with the highest throughput was chosen. The proposed algorithm was evaluated based on the Ping Pong Rate (PPR), Outage Probability (OP) of the UE, the throughput, the Number of Handover (NHO) and error in RSS prediction.However, the authors did not consider the cell dwell time of the mobile stations in each femtocell as it can also reduce the number of handovers and ping pong rate.

Chen *et al.*, (2014)proposed a joint handover decision and channel allocation resource algorithm. The handover decision and channel allocation problems were formulated as a Markov Decision Problem (MDP) whose objective was to maximize the expected total reward per connection over an infinite horizon. The parameters considered were the UE velocity, UE buffer size, cell switching cost and call dropping penalty. Then a Q-learning algorithm was used with the MDP to obtain the optimal cell handover and channel allocation policy. The proposed handover algorithm was compared with the Single-Agent Multiple-State Reinforcement Learning (SAMSRL) handover decision algorithm. The MDP-Q algorithm obtained better convergence behaviour. However,this method experienced frequent handovers since cell dwell time was not considered.

Rajabizadeh and Abouei (2015)proposed a handover decision algorithm between femtocells, using the RSS and user velocity as a decision criteria. The proposed algorithm was designed to select a femtocell further away from theUE than adjacent femtocells. This was based on the idea that choosing a femtocell further away, suppresses frequent handovers before arriving at the selected target femtocell.Thus, by choosing such a femtocell further away, as the target the UE can stay connected with that femtocell for a longer time duration. Which implied that frequent successive handovers was eliminated. To avoid frequent handovers initiated by high velocity users, the algorithm handed over these users to the macrocell.However, the handover algorithm performed poorly whena user with varying velocity stopped abruptly at a cell preceding the target cell which led to poor handover performance.

Ben Cheikh *et al.*, (2015)proposed a handover decisionalgorithm that used mobility prediction based on theHidden Markov Model (HMM). The mobility prediction scheme used the current and historical movement information of the UE as well as the signal quality of candidate cells for handover. Other parameters considered included; the access mode of the target cell, resources availability, UE velocity and direction. The handover problem was formulated as an optimization problem whose objective was to find the best FAP assignment strategy that minimized the number of unnecessary handover while maintaining a good quality of wireless communication. The performance of the proposed algorithm was evaluated using the following performance metrics: (i) number of handovers (ii) dwell time (iii) Ping pong handovers. The results obtained showed that the optimised handover with mobility prediction hada better performance when compared with to, Handover-to-nearest NeighbourFemtocell (HNF) and Handover-to-Randomly selected NeighbourFemtocell (HRNF). This approaches was done under different network densities. However, when a new user comes into the network, the mobility prediction cannot accommodate this user because it does not have the historical information of the user.

Chuang and Chen, (2015)proposed a navigation-assisted seamless handover scheme to reduce unnecessary handovers and ping-pong effect. A bi-casting scheme was used with COMP and CA techniques in the handover procedure to avoid packet loss and to enhance throughput respectively. The assumptions madeincluded;UE equipped GPS, UE supportedMIMO, and geolocation serverfor neighbouring HeNBs. Which made it possible to know the location of other HeNBs. The proposed scheme had two triggers-(i) The first trigger occurredwhen the RSRP value of the UE was less than a first threshold and (ii) the second triggeroccurred when the RSRPvalue was less than a second threshold. The navigation assisted handover decision made use of the UE which gave the destination and the navigation systemplanned an optimal path to the destination. The performance metrics used in evaluating the proposed scheme included packet loss, normalized network throughput, average handover latency and number of handover. However, the addition of the geolocation server provided an increased amount of signalling. Furthermore, the energy consumed increased because of the constant connection to the GPS and the geolocation server.

Nasrin and Xie, (2015)proposed a self-adaptive handover decision algorithm based on locationhistory in aCSG femtocell network. The proposed algorithm used theNeighbour Cell List(NCL) in a dense femtocell network to obtain the location of users. Based on the user location history a new concept-(*handover frequency*), was introduced to assist intelligent handover decision making. The hysteresis margin in the proposed algorithm was able to adaptively adjust to the deployed environment and also to the mobility pattern of the user. The authors used this self-adaptive algorithm to reduce the rate of unnecessary handovers and service failure, and at the same time increase the cell utilization. However, the work did not consider the signalling cost incurred for this handover algorithm as this led to significant delays when carrying out the handover.

Habibzadeh *et al.*, (2015)proposed a handover decision algorithm that was based on the traffic (channel holding time) and propagation (RSS) metrics. In the proposed scheme, when the average signal power from the macrocell was below a set threshold and the average signal power from the femtocell was larger by a constant factor (hysteresis margin) the UE connected to the femtocell. Also, when the estimated time spent in the femtocell was longer than the holding time, the UE was connected to the femtocell. The authors' pointed out that this was done to achieve a higher rate of handover to the femtocell while minimising the number of handover. However, there are delays associated with this scheme, when deployed in a dense area because of the signalling overhead that was incurred in trying to ascertain the nature of the target cell.

Xenakis *et al.*, (2016)proposed a novel handover decision algorithm which utilized measurement from candidate cells to optimise two Handover Hysteresis Margins (HHMs). The first HHM was used to avoid cells that could compromise service continuity, while the second HHM was used to identify cells that requiredminimum UE transmit power. When the handover event was triggered, the serving cell acquired the maximum transmit power, the cell interference and the downlink RS transmit power for all candidate cells by using the private mechanism for non-standard use. The two adaptive HHMs are subsequently evaluated for all candidate cells and the subset of cells that sustain service continuity was identified. The cell that required the minimum UE transmit power was subsequently selected and the handover execution phase was initiated. However, inusing the candidate cell list as an input to the algorithm, there are delays associated with the handover decision since the list was not optimised.

From the literatures discussed above, the occurrence of frequent handovers has been a challenge for seamless connection, however the problem relating to the mobility of the user has not been adequately addressed. Works addressing this problem however did not adopt approaches that considers the unique ability of the user to move abruptly thus leading to frequent handover problem. This research work usedthe LET method to develop an adaptive handover scheme,to mitigate the problem of frequent handover which occurs when a user's velocity is varying.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in carrying out the modelling of a macrocell-femtocell architecture, placing of femtocells, user mobility and finally simulation of the handover schemes. All this was achieved using a developed MATLAB Graphical User Interface (GUI) based model. The methodology adopted in this research is described as follows:

a) Replication and implementation of the inter femtocell handover decision algorithm of (Rajabizadeh & Abouei, 2015) and 3GPP handover decision algorithm. The following steps were carried out:
   i. Development of femtocell blocks of size $d \times d$ deployed on both sides of a direct street (where $d = 10m$)
   ii. Development of a macrocell-femtocell network architecture consisting one macrocell and N femtocells (where $N = 50\ femtocells$)
   iii. Development of a direct movement mobility model to model the movement pattern of the UE with constant velocity V
   iv. Obtain the pathloss between the FAP and the outdoor UE, using the channel model for dense HeNB deployment in 3GPP simulation and parameters for FDD (frequency division duplex) HeNB R4-092042 (3GPP, 2009)
   v. Two neighbour cell lists which contains the signal strength profiles of the FAPs detected by the UE
   vi. Implementation of steps (i-v) in MATLAB

b) Development of the modified handover decision algorithm. To achieve this, the following steps were adopted:

i) Steps (i-v) were repeated, with step (iii) having varying velocity

ii) The LET mobility prediction technique was applied to the inter-femtocell handover decision algorithm

c) Comparison of the performance of the modified handover decision algorithm with the 3GPP handover decision algorithm based on the handover rate and the average time between handovers.

3.2 Replication of Inter-Femtocell Handover

The steps involved in replication of the Inter-Femtocell Handover are discussed here in the following sub-sections:

3.2.1 Development of Femtocell Blocks

In order to depict blocks of apartments in which the femtocells are densely deployed, the assumptions for simulation and parameters from (3GPP, 2009) are used. The dual-stripe model of the dense HeNB deployement is used. This consists of two stripes of apartments and each stripe has 1 by N apartments, where N=50 (Rajabizadeh & Abouei, 2015). The length of the femtocell block is given as 10(N+1)m X 70m(3GPP, 2009). Each apartment is of size 10m x 10m, and the femtocell block has L floors, in this work L is chosen as 1. Adirect street of width 20m is in between the two stripes.The MATLAB code used in implementing the developed femtocell block is Appendix G.

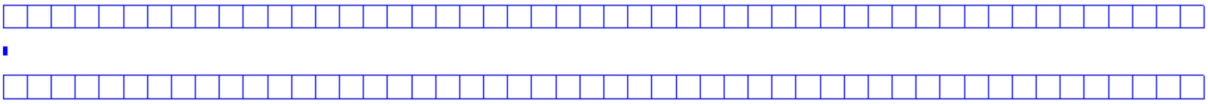


Figure 3.1: Femtocell Block

3.2.2 Development of Macrocell-Femtocell Architecture

The developedmacrocell-femtocell architecture comprises of one macrocell and *N* femtocells where the maximum number of femtocells to be deployed is 50. The developed architecture is shown in Figure 3.2. The femtocells are randomly deployed on either side of a direct street using uniform distribution. The Macro cell is depicted as the bigger red rhombus while the femtocells are the smaller red rhombus in the femtocell blocks. The UE which is the mobile node depicted as the blue square is currently connected to the femtocell with the green marker. This marker indicates the femtocell which currently serves the UE.From (3GPP, 2009) the parameter known as the deployment ratio,is used to determine whether an apartment is deployed with a HeNB or not. In this work it is given as 0.01, this means that on average, each floor has 1 HeNB (=0.01*100) and each block has 1L HeNBs.Also, the activation ratio which describes the percentage of active HeNBs is given as 100% in this work. Table 3.1 shows the urban-dense HeNB modelling parameters. A snippet of the MATLAB code used in implementing Figure 3.2 is shown in Appendix H.

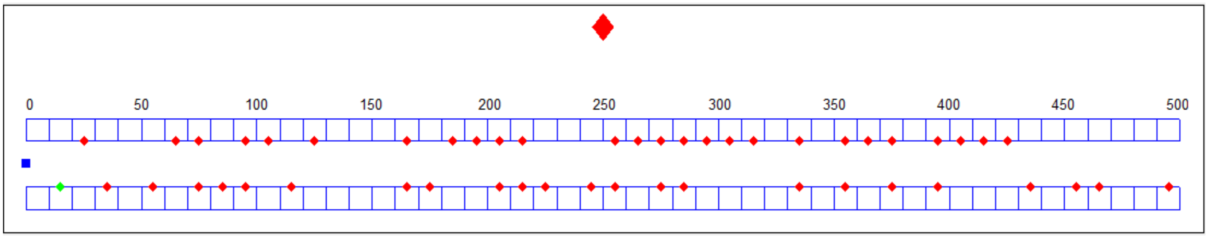


Figure 3.2: Macrocell-Femtocell Architecture

Table 3.1: Urban-dense HeNB Modelling Parameters(3GPP, 2009)

Parameters	**Value**
N (Number of cells per row)	50
L (Number of floors per block)	1
M (Number of blocks per sector)	1
R (deployment ratio)	0.01
P (activation ratio)	100%

3.2.3 Mobility Model

The motion of the UE is modelled using the equation of (Widyawan *et al.*, 2007; Zhang & De la Roche, 2010) in which the future position of the UE is given as:

$$(x_t y_t) = \begin{cases} x_{t-1} + v_t \Delta t \cos(\alpha_t) + \mathrm{n}_{t-1} \\ y_{t-1} + v_t \Delta t \sin(\alpha_t) + \mathrm{n}_{t-1} \end{cases} \tag{3.1}$$

where: x_{t-1}, y_{t-1} denotes the previous user position, v_t indicates the user velocity at time t, α_t represents the user direction at time t, n_{t-1} is a noise with Gaussian distribution. Δ_t denotes the period of time between two consecutive updates of the model. The velocity and direction is given by the following equations:

$$v = \left[0, xms^{-1}\right] \qquad v_t = \left| N\left(v_{t-1}, 1ms^{-2}\Delta t\right)\right| \text{(3.2)}$$

$$\alpha = [0, 2\pi] \quad \alpha_t = N\left(\alpha_{t-1}, 2\pi - a\tan\left(\sqrt{\frac{v_t}{2}}\right)\Delta_t\right) \text{(3.3)}$$

N (a, b) indicates the Gaussian distribution of mean (a) and standard deviation (b).

3.2.4 Path Loss Model

The Path loss is described as the reduction or attenuation of signal power, as the radio signal propagates through space. It is characterised by losses incurred from the environment and the distance travelled. The channel model for dense HeNB deployment from(3GPP, 2009) describes the path loss between the LTE FAP and an outdoor UE, the path loss takes into account the free space loss and the exterior wall penetration loss. In this work, single floor houses with no internal walls were assumed. The path loss model implemented in this work is calculated as follows:

$$\mathrm{PL}_{F-U}\,(\mathrm{dB}) = \mathrm{Max}\begin{Bmatrix} 38.46 + 20\log_{10}(\mathrm{R}), \\ 15.3 + 37.6\log_{10}(\mathrm{R}) \end{Bmatrix} + L_{ow} \tag{3.4}$$

Where, R is the distance of separation in meters between the FAP and the UE and L_{ow} is the penetration loss of the exterior wall which is either 10 dB or 20 dB. 20 dB was selected for this work.

3.2.5 Received Signal Strength (RSS)

The RSS is the signal power received from a transmitting femtocell, it describes the average received signal strength at any point as the signal power decays over a distance between the transmitter and receiver. In this work the minimum RSS in which the UE will be able receive is set at -67dBm, below which triggers a handover. In order to obtain the RSS value, the following formula is used:

$$\mathrm{P}_r = P_t - PL_{F-U} \tag{3.5}$$

where

P_r is the received power from the UE

P_t isthe transmitted power from the femtocell or the macrocell

PL_{F-U} is the path loss that occurs between the femtocell and the user.

3.2.6 Candidate Cell List and Neighbour Femtocell List

The candidate cell list and neighbour femtocell list is a profile of all available cells detected by the UE as a handover event is triggered. The neighbour cell lists are ranked in order of signal strength and proximity to the UE. It is updated periodically as the UE is in motion. The Neighbour Femtocell List generated is expressed as:

$$NFL = \left\{ \mathrm{P_r}\left(FAP_i \right) : \mathrm{P_r} \geq P_{th} \right\} \; i \in (0,1,.....,n) \tag{3.6}$$

While the candidate cell list generated is expressed as:

$$CL = \left\{ \mathrm{P'_r}\left(FAP_j \right) : \mathrm{P'_r} \geq P_{th} \right\} \; j \in (0,1,.....,n') \tag{3.7}$$

where $P_r(FAP_i)$ and $P_r'(FAP_j)$ denotes the RSS level of the ith and jth UE from the ith and jth femtocell greater than or equal to the threshold P_{th} and n is a random variable denoting the number of available femtocells $n < N$

When handover is triggered for the inter-femtocell handover algorithm, the handoverscheme uses two cell lists to let the UE choose a femtocell with the least signal strength because the UE is moving very fast and as it quickly approaches the selected cell its RSS from that cell continually improves and the second cell list restricts the UE from selecting the serving cell by eliminating it from that list because the priority of the algorithm is to always select cells with low signal strength and as such, the serving cell would not be selected. When the handover triggering event occurs, the NFL is checked and if it does not include the selected femtocell, the selected femtocell is the target cell. Otherwise the difference between the RSS from the selected cell in the NFL is checked against the cell in the CL. If the RSS of the cell in the NFL is less than that of the CL, then the selected femtocell is the target. Hence, the selected femtocell will be removed from the CL and another femtocell with a minimum RSS from the list is selected as the target femtocell. The flowchart for the inter-femtocell handover scheme is shown in Figure 3.3.

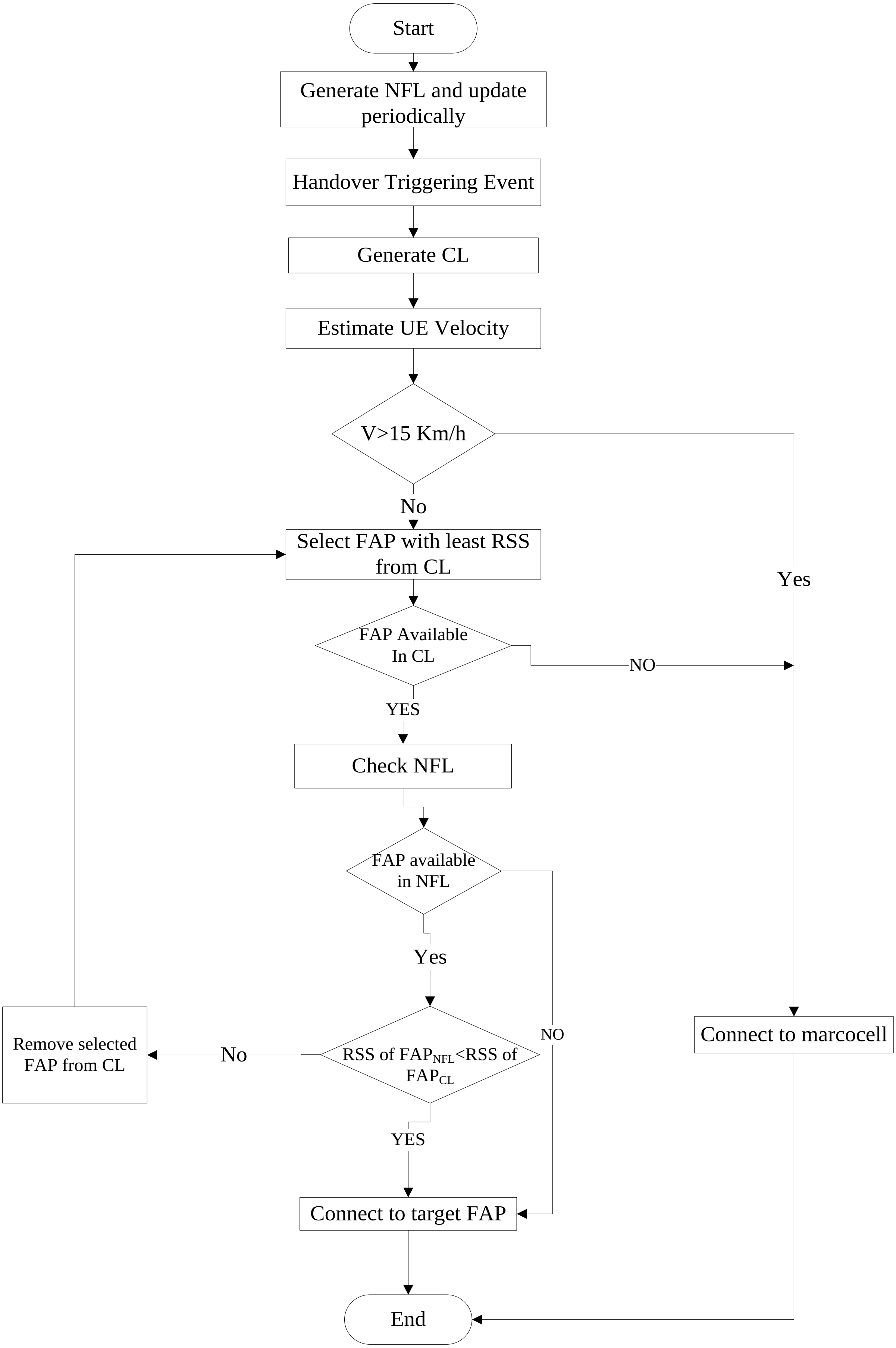


Figure 3.3: Flowchart for Inter-Femtocell Handover Scheme

3.3 Development of the modifiedInter-Femtocell Handover Scheme

From the inter-femtocell handover scheme, the proposed modificationaccommodates a user’s velocity which varies with time. This is achieved using the LET mobility prediction technique. The LET mobility prediction technique, calculates the time for a communication link to expire and having meet a set threshold, re-connects the user to a different link. In this scenario, using the parameters for coordinates of both the UE and the femtocell the LET mobility prediction technique marks the location of the user in relation to the nearest femtocell and connects the user to that cell.

In the proposed scenario, the velocity of the UE is assumed to be V_i while the velocity of the FAP is V_j. However, since the target FAP is not in motion then $V_j = 0$. Also the moving directions θ_i and θ_j for both the UE and FAP is given as:

$$\theta_i = \pi \qquad (3.8a)$$

$$\theta_j = 0 \qquad (3.8b)$$

The FAP is not in motion and the UE is moving in a straight line. From the above assumptions equations (2.7a) and (2.7c) becomes:

$$a = V_i \cos\theta_i \qquad (3.9)$$

$$c = V_i \sin\theta_i \qquad (3.10)$$

Substituting equations (3.9) and (3.10) into equation (2.7), the following is obtained:

$$D_t = \frac{-\left[(\mathrm{V}_i.\cos\theta_i.\mathrm{b}) + (\mathrm{V}_i.\sin\theta_i.\mathrm{d})\right] + \sqrt{\left\{\left(V_i^2\cos^2\theta_i\right) + \left(V_i^2\sin^2\theta_i\right)\right\} r^2 - \left\{\left(V_i.\cos\theta_i.\mathrm{d}\right) - (V_i\sin\theta_i.b)\right\}^2}}{V_i^2\cos^2\theta_i + V_i^2\sin^2\theta_i} \qquad (3.11)$$

Simplifying equation (3.11) results in:

$$D_t = \frac{-b\cos\theta_i - d\sin\theta_i + \sqrt{r^2 - d^2\cos^2\theta_i + 2bd\cos\theta_i\sin\theta_i - b^2\sin^2\theta_i}}{V_i} \tag{3.12}$$

Since the direction of movement of the UE is a straight forward motion, the angle of the UE's motion is given as π.

Therefore:

$$\cos\pi = -1 \tag{3.13a}$$

$$\sin\pi = 0 \tag{3.13b}$$

Equation (3.12) becomes,

$$D_t = \frac{b + \sqrt{r^2 - d^2}}{V_i} \tag{3.14}$$

However, since Rajabizadeh and Abouei's work assumes that call connections were always successful with no failures. Therefore the communication link is assumed not to fail and the time duration (D_t) is assumed to be 1.

From equation (3.14), the velocity of the mobile node (UE) becomes,

$$V_i = b + \sqrt{r^2 - d^2} \tag{3.15}$$

The flowchart for the proposed handover scheme is shown in Figure 3.4. In order to simulate a UE's velocity that is varying, the velocity of the UE is categorised as high velocity (≥ 15 km/hr), low velocity (< 15 km/hr) and very low velocity (≤ 5 km/hr), when its velocity falls within these ranges.

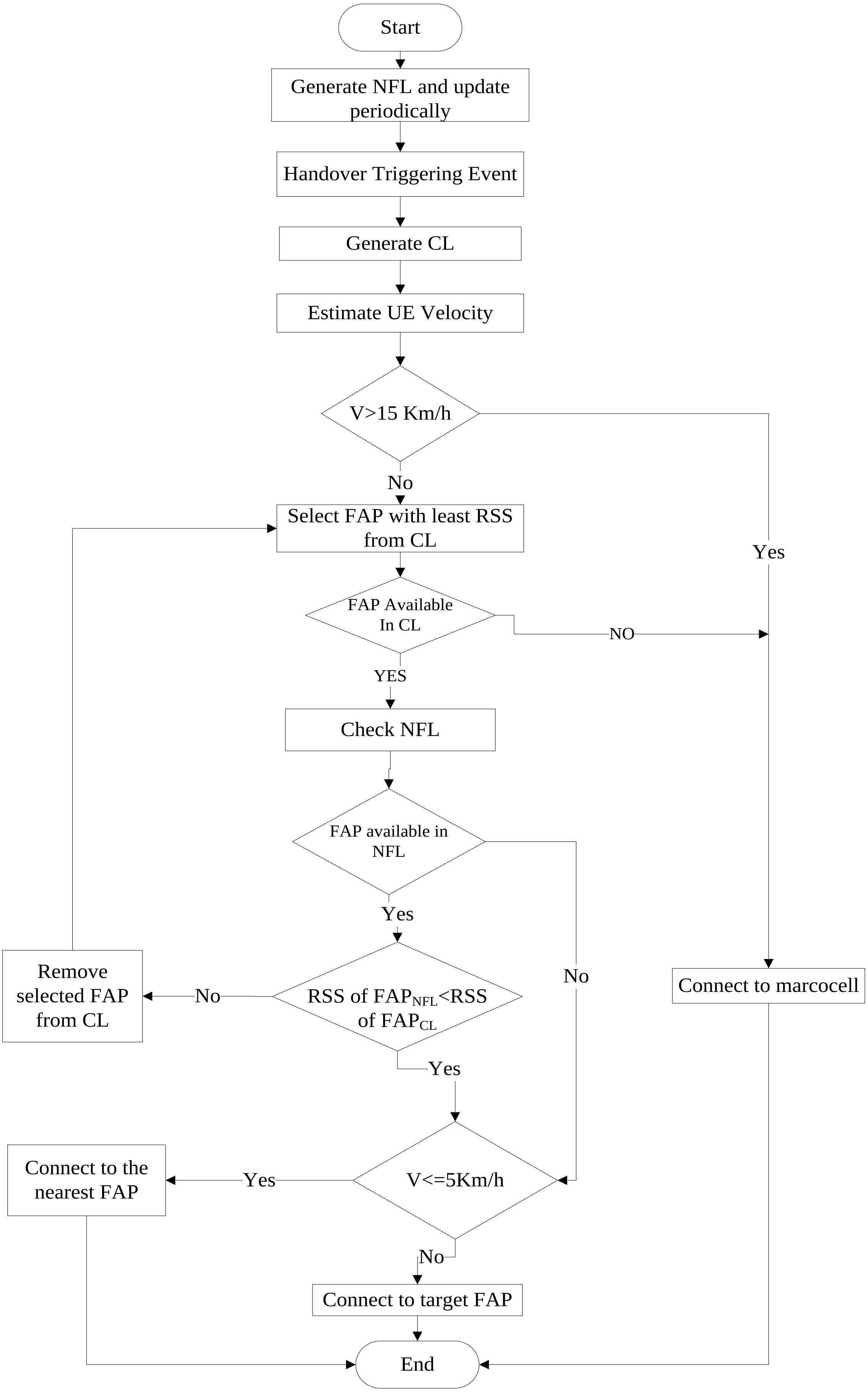
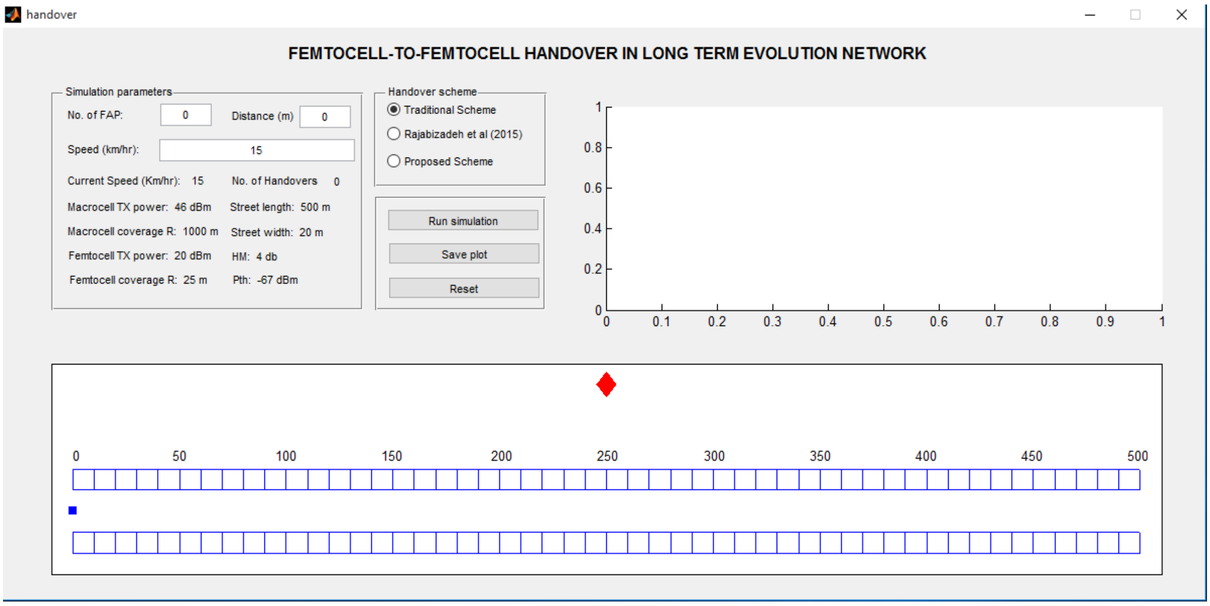


Figure 3.4: Flowchart for Proposed Handover Scheme

3.4 Graphical User Interface (GUI)

Figure 3.5represents the developed GUI and its menu. The GUI receives input parameters from the user and generates a graphical output of the RSS from serving FAP against time as the simulation is carried out. The MATLAB code used in implementing the GUI can be seen in appendix F.



No. of FAP: 0

Distance (m) 0

Speed (km/hr): 15

Current Speed (Km/hr): 15

No. of Handovers 0

Macrocell TX power: 46 dBm

Street length: 500 m

Macrocell coverage R: 1000 m

Street width: 20 m

Femtocell TX power: 20 dBm

HM: 4 db

Femtocell coverage R: 25 m

Pth: -67 dBm

● Traditional Scheme

○ Rajabizadeh et al (2015)

○ Proposed Scheme

Figure 3.5: Graphical User Interface for Simulation

3.4.1 Simulation parameters

This section describes the values and parameters adopted for the simulation. The values and parameters were adopted from the work of (Rajabizadeh & Abouei, 2015).

3.4.1.1 Number of Femtocell Access Points (FAP)

This indicates the number of femtocells used during the simulation run. The number of femtocells was randomly placed on either side of the direct street, inside the houses. A green marker was used to indicate the cell in which the UE was currently connected as it moves.

3.4.1.2Distance

The distance, the mobile user would travel in the simulation runs was tied to the number of femtocells to be selected. This is to ensure that the randomly deployed femtocells weren't too far apart from each other. A maximum range of 10 meters for every 1 femtocell deployed was set for the simulation. For example in a scenario where 25 femtocells were to be deployed, the mobile user would travel a total distance of 250m.

3.4.1.3Speed/ Current Speed

This indicates the selected speed of the mobile user during the simulation run. It is given in km/hr. When the users speed varies, the current speed indicates the current speed of the mobile user at that period of time. When speeds of varying limits are set, the mobile users motion is uniformly distributed based on the distance to be travelled.

3.4.1.4Number of Handovers

The number of handovers gives the amount of handovers per unit time as the mobile user is in motion and experiences a degrading signal quality. Thus thereby triggering a handover event when the signal threshold has been reached. The expected number of handovers is given as(Huamin & Kyung Sup, 2006):

$$NO_{ho} = \sum_{k=1}^{N} P_{ho}(\mathrm{k}) \qquad (3.16)$$

where the probability of handovers $P_{ho}(\mathrm{k})$ is given as:

$$P_{ho}(\mathrm{k}) = p_1(k)\,p_{1\to2}(k) + p_2(k)\,p_{2\to1}(k) \qquad (3.17)$$

$p_1(k)$ and $p_2(k)$ are the assigned probabilities of BS1 and BS2, $p_{1\to2}(k)$ and $p_{2\to1}(k)$ are the transition probabilities as the UE performs handovers at time instant k.

3.4.1.5Macrocell and FemtocellTransmission Power and Coverage

The maximum transmission power of the macrocell is given as 46dBm, and the transmission range of the macrocell was set at 1000m. In cases when the mobile user is connected to the macrocell, a green marker indicates that the user is currently connected to the macrocell. The femtocell transmission power was given as 20dBm, while the transmission range of the femtocell was given as 25m.

3.4.1.6Hysteresis Margin

The hysteresis margin is a commonly used parameter for avoiding frequent handover. The hysteresis margin is used with the received signal strength, and the signal threshold power. Handover to a new base station occurs only if the current signal level drops below the set threshold and the target base station, is stronger than the current one by a given hysteresis margin. The value of the hysteresis margin used in this work is 4dB(Yusof *et al.*, 2013).

3.5 Simulation Setup and Assumptions

The GUI was written in MATLAB version R2013a. The following steps are required to make use of the simulator:

(i) Ensure that the current directory of MATLAB is set.

(ii) Type handover in the command window or, open **handover.m file** and click the 'run' button in the MATLAB Script Editor menu.

(iii) When the GUI window appears, provide inputs for the desired number of femtocells, in the field shown.

(iv) Choose a Handover scheme of your choice, then click **'Run Simulation'**

(v) Click on **'Save Plot'** in order to save the plot of the generated graph.

(vi) If interested in another handover scheme. Click **'Reset'** for a new setup.

Assumptions made in order to carry out this work include:

(i) Single floor houses without internal walls.

(ii) Femtocells operating in open access mode.

(iii) All handovers were assumed to perform successfully

(iv) Femtocells have the same distances from the street

The parameters considered for the simulation are shown in Table 3.2. The pseudocode for the proposed handover scheme is givenas follows:

```
//Pseudo-code for simulation
generate_scenario_architecture ( );
generate_femtocells ( ); //based on user input
generate_distance ( ); //based on user input
generate_Speed ( ); //based on user inputs
select_handover_Scheme ( );
//based on user mobility, calculate RSS forevery point (x,y)
calculate_RSS (x,y); //based on equation 3.5
end
generate_NFL ( ); //based on equation 3.6
generate_CL ( ); //based on equation 3.7
  estimate user velocity;
        if $V>15km/h$;
  connect to macrocell;
 else
  Select FAP with least RSS from CL;
 end
 Check NFL;
        if selected FAP is available in NFL;
  Check RSS of selected $FAP_{NFL}$ and RSS of $FAP_{CL}$;
 elseif
  $V \leq 5Km/h$
 end
```

```
if RSS $FAP_{NFL}$< RSS $FAP_{CL}$;
  V ≤ 5Km/h;
else
  Remove selected FAP from CL;
elseif
  connect to target FAP;
end
  if V ≤ 5Km/h;
  connect to nearest FAP;
else
  connect to target FAP;
end
```

Table 3.2: Simulation of Modified Parameters From(Rajabizadeh and Abouei, (2015))

Parameters	**Value**
Frequency	2 GHz
Macrocell TX Power	46 dBm
Femtocell TX Power	20 dBm
Macrocell Coverage radius	1000m
Femtocell Coverage radius	25m
Street Length	500m
Street Width	20m
External Penetration loss (L_{ow})	20 dB
Hysteresis Margin (HM)	4 dB
Threshold Power (P_{th})	-67 dBm
d	10 m
Velocity (v)	(15-5-11-3)km/h

3.6 Performance Evaluation

The performance of the developed handover algorithm was validated using the number of handovers and the time between handovers as the performance metrics. The number of handovers is the the amount of handovers performed per unit time as the user is in motion. The time between handovers is the amount of time that elapses before the handover eventually occurs. It was taken throughout the simulation run as the user is in motion.

3.7 Summary

This chapter provides detailed information on the step-by-step approach adopted in replicating and carrying out this work. The flowcharts, the adopted equations and assumptions are explained. Also the performance metrics adopted in evaluating the performance of the developed work is treated.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the performance of the proposed handover decision algorithm and the traditional handover algorithm, based on the number of handovers and the time interval between handovers. The results gotten from the simulation are presented and discussed.

4.2 Results

The results obtained from the simulation setup are discussed in this chapter. The following results are based on the number of handovers, handover count per velocity, and the average time interval between handovers.

4.2.1 Number of Handovers

In Figure 4.1, the number of handovers was plotted against the number of femtocells deployed.From the plot it can be observed that there is a linear correlation between the number of handovers and the number of femtocells deployed. The proposed handover schemeperformed fewer handovers than the 3GPP handover scheme.This was achieved as the speed of the user increases, the handover algorithm extends the time for successive handovers by selecting an adjacent femtocell that is the furthest possible, thus reducing the number of handovers. Furthermore, as can be observed from the plot,the number of handovers for the proposed handover scheme experiences a sudden decrease from 11 handovers to 10 handovers when going from 30 femtocells to 35 femtocells. The cause of this sudden decrease is the placing of femtocells.The femtocells were randomly placed, thus affecting the way handovers were performed. The proposed handover scheme achieved a 24.17% reduction in terms of the number of handovers performed as against the 3GPP handover scheme.

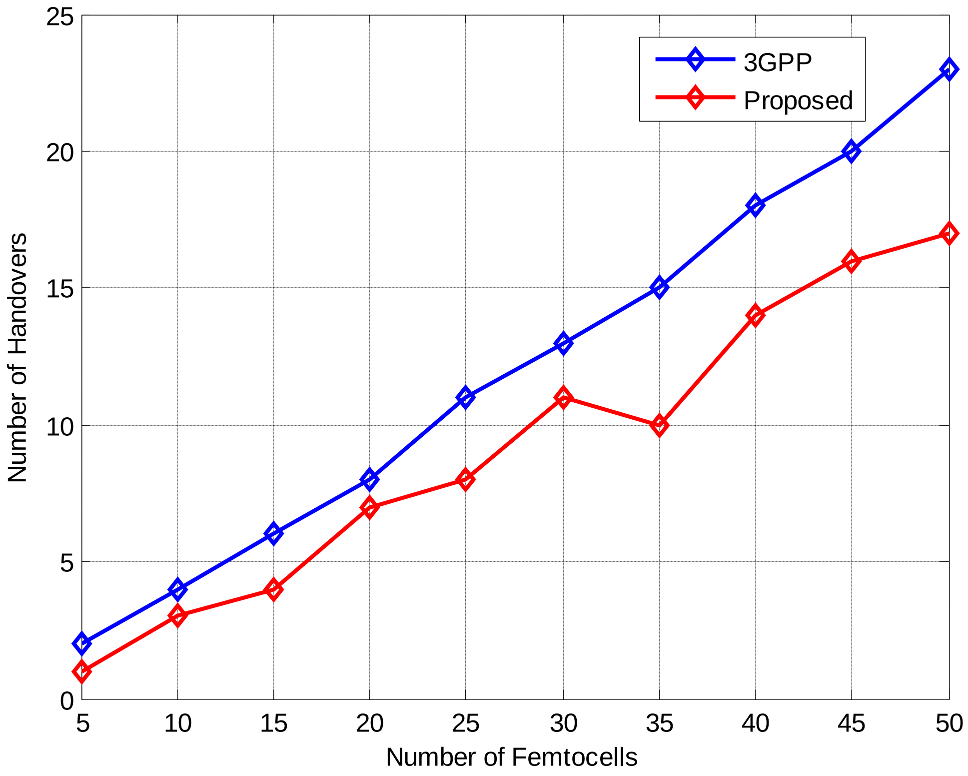


Figure 4.1: Number of Handovers to Number of Femtocells

4.2.2 Handover Count per Velocity

In Figures 4.2 and 4.3, the plots shows the number of handovers performed for different velocity rates, when 45 and 50 femtocells were deployed.From the plots, it can be observed that the proposed handover scheme performed fewer handovers when the speed of the user was high (15 and 11 km/hr) as compared to when the speed of the user was lower (5 and 3 km/hr). This is because, as the speed of the user increases the time to trigger a handover is extended, leading to fewer handovers and as the speed of the user reduces, the time contracts, leading to more handovers at lower speeds. The performance of both the 3GPP and proposed handover schemes were similar for lower speeds.From the foregoing, it implies that the faster the user moves, the fewer the handovers performed will be in comparison to the traditional handover.

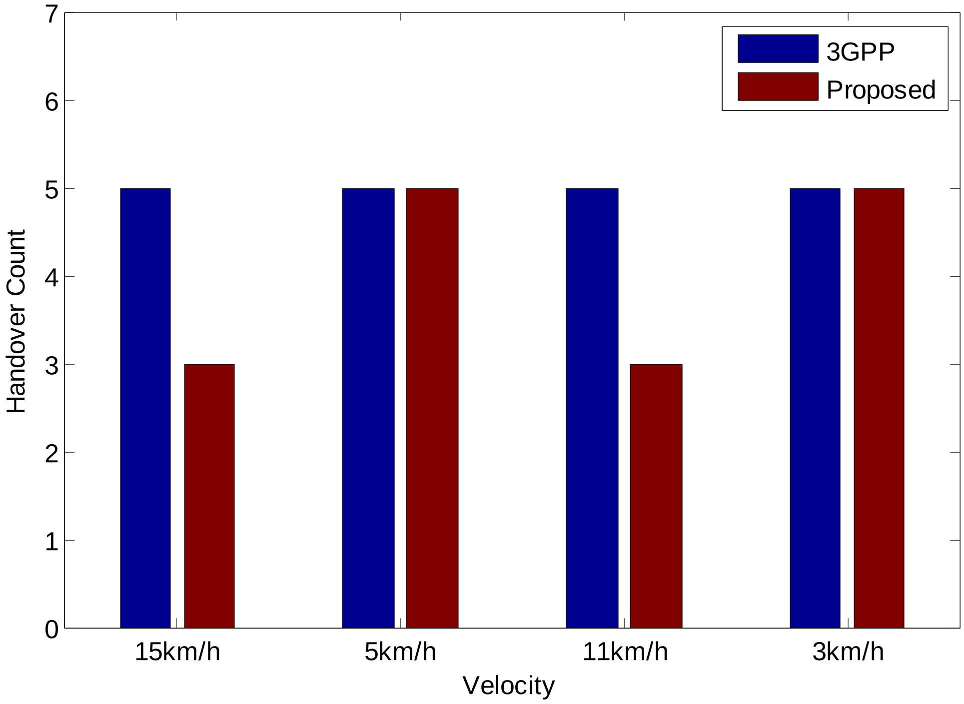


Figure 4.2: Handover Count per Velocity for 45 Femtocells

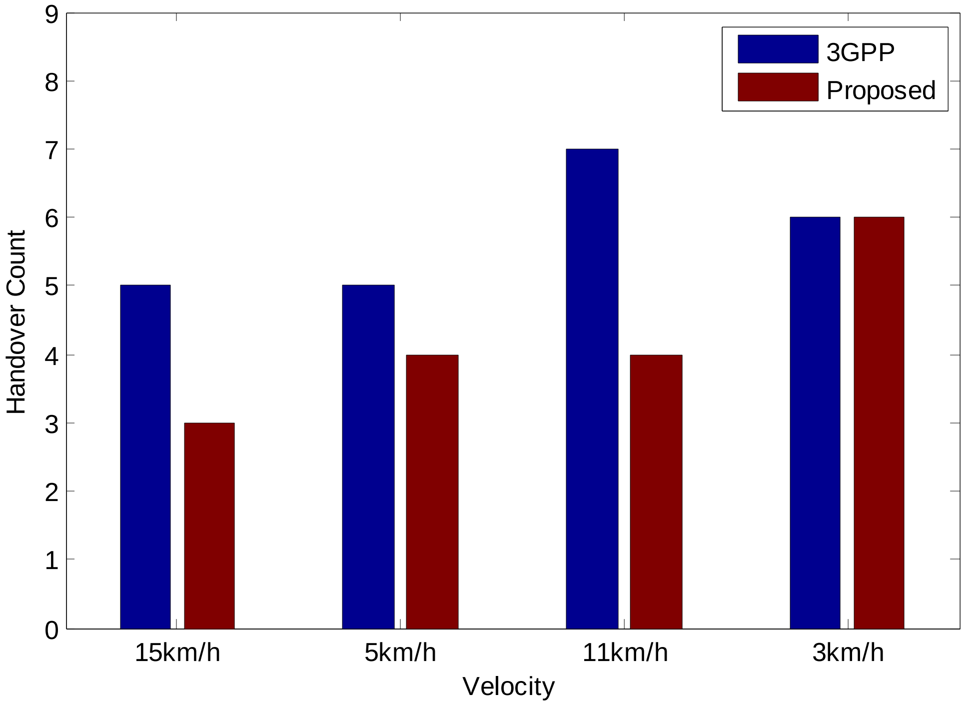


Figure 4.3: Handover Count per Velocity for 50 Femtocells

4.2.3 Average Time between Handovers

In Figure 4.4, the plot shows the average time between handovers for the number of femtocells deployed. From the plot, it can be observed that the proposed handover scheme generally had an increased average time due to its tendency to extend handover when the velocity of the user is high. However for much lesser femtocell deployments (5 and 10 femtocells) the 3GPP handover scheme has a slightly higher average time because it performed more handovers in comparison to the proposed handover scheme and in doing so, more time was incurred in carrying out these handovers. The observed increase for the proposed handover scheme was approximately 24.51%.

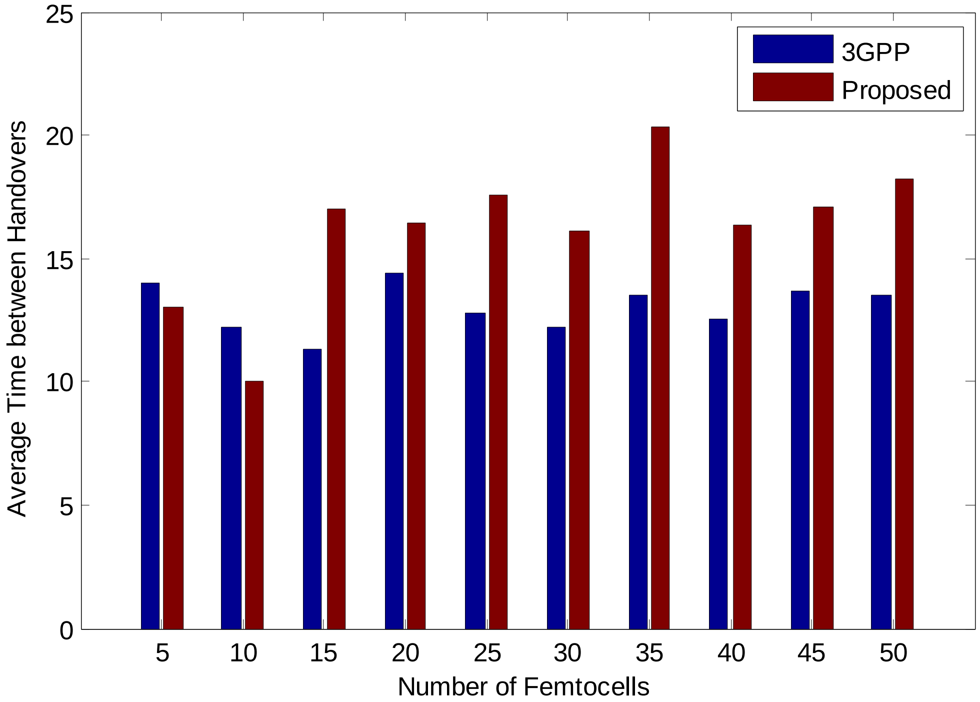
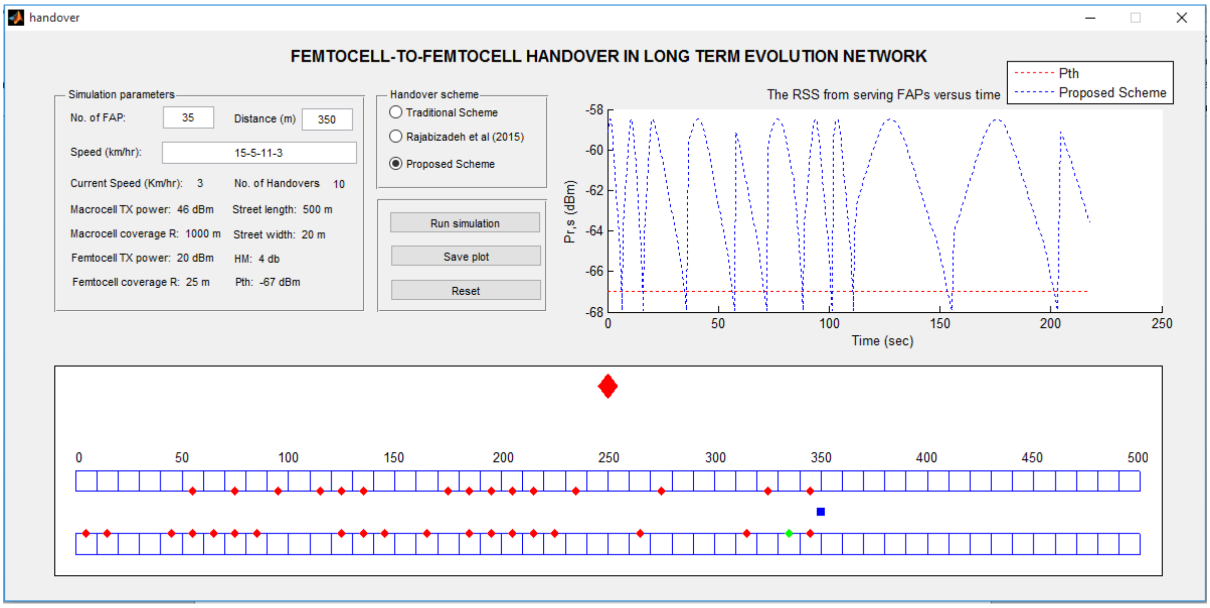


Figure 4.4: Number of Femtocells and Average Time between Handovers

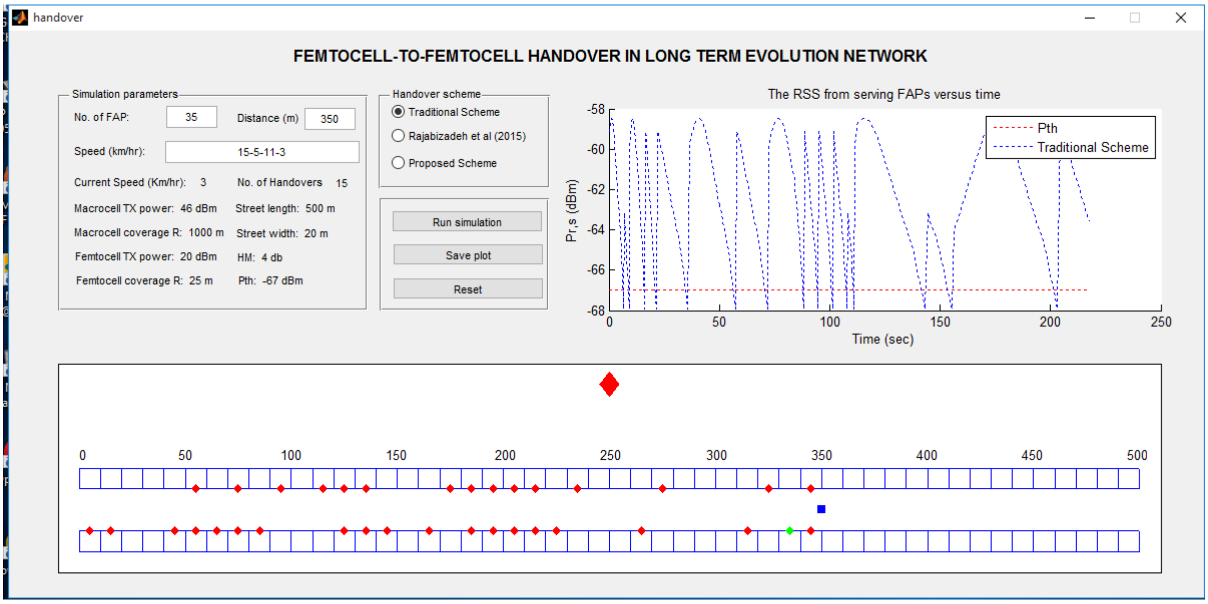
Figures 4.5 and 4.6 show snapshots of the simulation runs, when 35 femtocells were deployedforthe proposed and 3GPP handover scheme with the same outlay of femtocells. From the figures, the users handover profile is shown with respect to time against a threshold (P_{th}). From figure 4.5 the user made fewer handovers when compared to figure 4.6, where the user made more handovers.


FEMTOCELL-TO-FEMTOCELL HANDOVER IN LONG TERM EVOLUTION NETWORK

Simulation parameters
No. of FAP: 35
Distance (m) 350
Speed (km/hr): 15-5-11-3
Current Speed (Km/hr): 3
No. of Handovers 10
Macrocell TX power: 46 dBm
Street length: 500 m
Macrocell coverage R: 1000 m
Street width: 20 m
Femtocell TX power: 20 dBm
HM: 4 db
Femtocell coverage R: 25 m
Pth: -67 dBm

Handover scheme
○ Traditional Scheme
○ Rajabizadeh et al (2015)
● Proposed Scheme

Figure 4.5: Simulation Run for Proposed Handover Scheme with35 Femtocells


FEMTOCELL-TO-FEMTOCELL HANDOVER IN LONG TERM EVOLUTION NETWORK

Simulation parameters
No. of FAP: 35
Distance (m) 350
Speed (km/hr): 15-5-11-3
Current Speed (Km/hr): 3
No. of Handovers 15
Macrocell TX power: 46 dBm
Street length: 500 m
Macrocell coverage R: 1000 m
Street width: 20 m
Femtocell TX power: 20 dBm
HM: 4 db
Femtocell coverage R: 25 m
Pth: -67 dBm

Handover scheme
● Traditional Scheme
○ Rajabizadeh et al (2015)
○ Proposed Scheme

Figure 4.6: Simulation Run for 3GPPHandover Scheme with 35 Femtocells

4.3 Summary of Results

From the results discussed, it can be observed that the proposed handover scheme was able to perform fewer handovers than the 3GPP handover scheme. The proposed handover scheme achieved a 24.17% reduction in the number of handovers compared to the traditional handover scheme. This reduction in the number of handovers was achieved as the average time for a handover to occur was increased. The proposed handover scheme increased the average time by approximately 24.51%.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research work developed an adaptive handover decision algorithm based on mobility prediction using the Link Expiration Time (LET) method. The number of handovers performed and the average time between handovers was used to evaluate the performance of the handover scheme. The developed handover scheme achieved a 24.17% reduction in the number of handovers when compared to the traditional algorithm, and there was a 24.51% increase in the average time between handovers. This increase in the average time enabled the proposed handover scheme to reduce the number of handovers.

5.2 Significant Contributions

The contributions of this dissertation are as follows:

(i) The developed handover scheme using the LET mobility prediction technique with varying speeds of a mobile user,achieving a 24.17% reduction in the number of handovers when compared with the standard handover scheme

(ii) The developed scheme also achieved a 24.51% increase in the average time between handovers when compared with the standard handover scheme.

(iii) The adaptive nature of the proposed handover scheme out performed that of Rajabizadeh and Abouei at lower speeds.

5.3 Recommendations for Further Study

In view of the current results obtained thus far, the following are recommended for further study;

(i) This work can be extended by considering scenarios arising from call drops due to loss of connection. This is in order to solve problems that may arise due to user mobility.

(ii) Subsequent researchers can also consider a direct street scenario having adjoining street junctions and not only a direct street.

(iii) Other researchers can look into the aspect of incorporating Self Organising Network (SON) features in order to have an optimised performance in terms of time to trigger and signal level.

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APPENDIX A

MATLAB m-File “CreateLayout”

```
function createLayout(hObject, uePos)
cla(hObject)
pos = [10, 20, 40, 50];
hold(hObject, 'on')
for i=1:4
   plot(hObject, [10 510], [pos(i) pos(i)])
end

for i=10:10:510
    plot(hObject, [i i], [10,20])
    plot(hObject, [i i], [40,50])
end

scatter(hObject, uePos, 30, 'fill', 's', 'b')
scatter(hObject, 260, 90, 250, 'fill', 'd', 'r')


% for d=10:50:510
%     text(d, 55, num2str(d-10), 'HorizontalAlignment', 'center')
% end

xlim(hObject, [0, 520])
ylim(hObject, [0, 100])

set(hObject, 'XTick', [])
set(hObject, 'YTick', [])

set(hObject, 'XTickLabel',{})
set(hObject, 'YTickLabel',{})
hold(hObject, 'off')

end
```

APPENDIX B

MATLAB m-File “CreateTripData”

```
function tripMat = createTripData(handles)

% dat = get(handles.figure1, 'UserData');
% speedVector = [10 15 10 15];
% totalDist = 100;
speedVector = str2double(strsplit(get(handles.edit2,'String'), '-'));
totalDist = str2double(get(handles.edit3,'String'));

speedVectorLen = length(speedVector);
dist = (totalDist/speedVectorLen);

distVector = (totalDist/speedVectorLen)*[1:speedVectorLen];
timeVector = dist./(speedVector *  0.2778);
speedDistMat = [speedVector', distVector'-dist, distVector',
cumsum(timeVector)'];

totalTime = sum(speedDistMat(:,4));
tripMat = [];
for distCovered = 1:totalDist
    ind =ceil((distCovered/totalDist)*speedVectorLen);
    currentSpeed = speedVector(ind);
    currentDist = distCovered - speedDistMat(ind, 2);
    timeSpent = currentDist / (currentSpeed*0.2778);
if ind > 1
        timeSpent = timeSpent + speedDistMat(ind-1, 4);
end
    tripMat = vertcat(tripMat, [currentSpeed, distCovered, timeSpent]);
end
% dat.tripMat = tripMat;
% set(handles.figure1, 'UserData', dat);

end
```

APPENDIX C

MATLAB m-File “PlaceFAP”

```
function [connectedFap, currentPr] = placeFap(handles, posOfFap, uePos, 
oldConnectedFap, speed)
Low = 20;
Pt = 20;
Pth = -68;
HM = 4;
R=[];
PL=[];
Pr=[];
CL = [];
currentI = 0;
currentPr = nan;
for i=1:size(posOfFap,1)
        Ri=norm(uePos - posOfFap(i,:));
        PLi=max([38.46 + 20*log10(Ri), 15.3 + 37.6*log10(Ri)]) + Low;
        Pri=Pt - PLi;
        R=[R Ri];
        PL=[PL PLi];
        Pr=[Pr Pri];

if all(posOfFap(i,:) == oldConnectedFap)
       currentPr = Pri;
       currentI = i;
end
if  i > currentI && (Pri > Pth)
        CL = [CL; i];
end
end

hold(handles.layout_axes, 'on')
scatter(handles.layout_axes, posOfFap(:,1), posOfFap(:,2), 'fill', 'd', 
'r')
dat = get(handles.figure1, 'userData');
scheme = dat.scheme;

if strcmp(scheme, 'Proposed Scheme')
if speed <= 5;
        scheme = 'Traditional Scheme';
else
        scheme = 'Rajabizadeh et al (2015)';
end
end

if currentPr < Pth || isnan(currentPr)
switch scheme
case'Traditional Scheme'
             [maxPr, ind] = max(Pr);
if maxPr > Pth + HM
                connectedFap = posOfFap(ind,:);
                currentPr=maxPr;
                scatter(handles.layout_axes, connectedFap(1), 
connectedFap(2), 'fill', 'd', 'g')
else
                connectedFap = [260 90];
                Pt = 46;
                R=norm(uePos - connectedFap);
                PL=max([38.46 + 20*log10(R), 15.3 + 37.6*log10(R)]);
```

```
                currentPr=Pt - PL;
                scatter(handles.layout_axes, connectedFap(1),
connectedFap(2), 250, 'fill', 'd', 'g')
end
case'Rajabizadeh et al (2015)'
if ~isempty(CL)
                connectedFap = posOfFap(CL(end),:);
                currentPr=Pr(CL(end));
                scatter(handles.layout_axes, connectedFap(1),
connectedFap(2), 'fill', 'd', 'g')
else
                connectedFap = [260 90];
                Pt = 46;
                R=norm(uePos - connectedFap);
                PL=max([38.46 + 20*log10(R), 15.3 + 37.6*log10(R)]);
                currentPr=Pt - PL;

                scatter(handles.layout_axes, connectedFap(1),
connectedFap(2), 250, 'fill', 'd', 'g')
end
case'Proposed Scheme'
end

else
    connectedFap=oldConnectedFap;
    scatter(handles.layout_axes, connectedFap(1), connectedFap(2), 'fill',
'd', 'g')
end

hold(handles.layout_axes, 'off')

end
```

APPENDIX D

MATLAB m-File “SetupPrAxes”

```matlab
function setupPrAxes(handles, noOfFap, totalTime)

cla(handles.axes2)
hold(handles.axes2, 'on')

% totalTime = tripMat(end,end);

% [totalTime, speedMps] = timeSec(speedKmph, totalDist);

plot(handles.axes2, [0 totalTime], [-67 -67], 'r:')
hold(handles.axes2, 'off')
% xlim(handles.axes2, [0, time+10])
% ylim(handles.axes2, [-70, -58])

title('The RSS from serving FAPs versus time')
xlabel('Time (sec)')
ylabel('Pr,s (dBm)')

end
```

APPENDIX E
MATLAB m-File “timeSec”

```matlab
function [time, speedMps] = timeSec(speedKmph, dist)
speedMps = speedKmph * 1000 / 3600;
time = dist / speedMps;
end
```

APPENDIX F

MATLAB m-File “handover”

```
function varargout = handover(varargin)
% HANDOVER MATLAB code for handover.fig
%      HANDOVER, by itself, creates a new HANDOVER or raises the existing
%      singleton*.
%
%      H = HANDOVER returns the handle to a new HANDOVER or the handle to
%      the existing singleton*.
%
%      HANDOVER('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in HANDOVER.M with the given input
arguments.
%
%      HANDOVER('Property','Value',...) creates a new HANDOVER or raises
the
%      existing singleton*.  Starting from the left, property value pairs
are
%      applied to the GUI before handover_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property
application
%      stop.  All inputs are passed to handover_OpeningFcn via varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help handover

% Last Modified by GUIDE v2.5 27-Dec-2016 15:33:11

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
'gui_Singleton',  gui_Singleton, ...
'gui_OpeningFcn', @handover_OpeningFcn, ...
'gui_OutputFcn',  @handover_OutputFcn, ...
'gui_LayoutFcn',  [] , ...
'gui_Callback',   []);
if nargin && ischar(varargin)
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:};
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
% --- Executes just before handover is made visible.
function handover_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to handover (see VARARGIN)
dat=[];
dat.scheme = 'Traditional Scheme';
```

```
set(handles.figure1, 'userData', dat)
% Choose default command line output for handover
handles.output = hObject;
% Update handles structure
guidata(hObject, handles);

% UIWAIT makes handover wait for user response (see UIRESUME)
% uiwait(handles.figure1);

 % --- Outputs from this function are returned to the command line.
function varargout = handover_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes during object creation, after setting all properties.

function layout_axes_CreateFcn(hObject, eventdata, handles)
% hObject    handle to layout_axes (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: place code in OpeningFcn to populate layout_axes

createLayout(hObject, 10)

function edit1_Callback(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit1 as text
%        str2double(get(hObject,'String')) returns contents of edit1 as a
double
dat=get(handles.figure1, 'UserData');

set(handles.text5, 'String','0')
createLayout(handles.layout_axes, 10)
for d=10:50:510
    text(d, 55, num2str(d-10), 'HorizontalAlignment', 'center')
end

noOfFap = str2double(get(hObject,'String'));
totalDist = noOfFap*10;
set(handles.edit3, 'String', num2str(totalDist))

 tripMat = createTripData(handles);
dat.tripMat = tripMat;
setupPrAxes(handles, noOfFap, tripMat(end,end))
set(handles.text18, 'String', num2str(tripMat(1,1)))

coord=[[[15:10:totalDist+5]' 20*ones(noOfFap,1)]; [[15:10:totalDist+5]'
40*ones(noOfFap,1)]];
posOfFap=sortrows(coord(randperm(2*noOfFap, noOfFap),:), 1);

uePos=[10, 30];
```

```matlab
oldConnectedFap = posOfFap(1,:);
[connectedFap, currentPr] = placeFap(handles, posOfFap, uePos,
oldConnectedFap, tripMat(1,1));

dat.posOfFap=posOfFap;

set(handles.figure1, 'UserData', dat);


% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

dat=get(handles.figure1, 'UserData');

enable(handles, 'off')

set(handles.text5, 'String','0')

posOfFap=dat.posOfFap;
noOfFap = str2double(get(handles.edit1,'String'));

tripMat = createTripData(handles);
dat.tripMat = tripMat;
setupPrAxes(handles, noOfFap, tripMat(end, end))
set(handles.text18, 'String', num2str(tripMat(1,1)))

p=11;
uePos=[p, 30];
[connectedFap, currentPr] = placeFap(handles, posOfFap, uePos,
posOfFap(1,:), tripMat(1, 1));
oldConnectedFap = connectedFap;
count = 0;
Pr=[];

totalDist = str2double(get(handles.edit3,'String'));

tripMat = dat.tripMat;

while p<=totalDist+10

createLayout(handles.layout_axes, p)
```

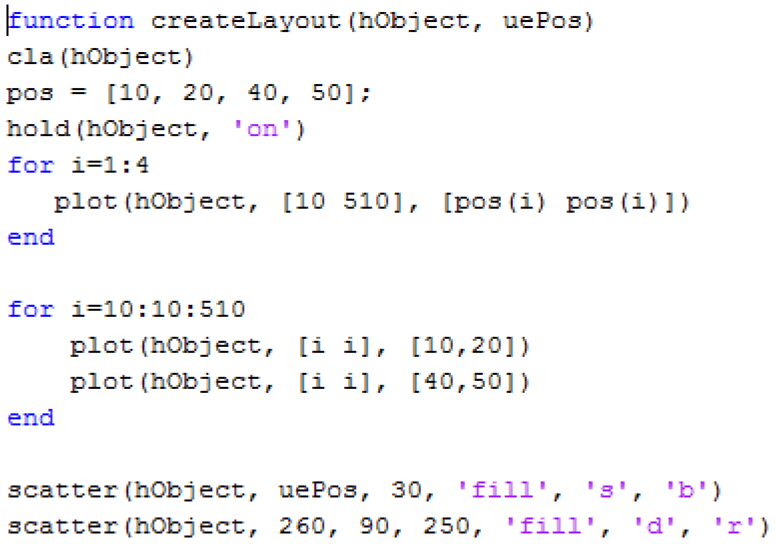
```
uePos=[p, 30];

dist = p-10;

speed = tripMat(dist, 1);
set(handles.text18, 'String', num2str(speed))
[connectedFap, currentPr] = placeFap(handles, posOfFap, uePos,
oldConnectedFap, speed);

if ~isequal(connectedFap, oldConnectedFap)
%       if ~isequal([260 90], connectedFap) && ~isequal([260 90],
oldConnectedFap)
        count=count+1;
        set(handles.text5, 'String', num2str(count));

%       end
    oldConnectedFap=connectedFap;
end

% speedKmph = str2double(get(handles.text18,'String'));
dist = p-10;
% [time, speedMps] = timeSec(speedKmph, dist);

time = tripMat(dist,3);
Pr=[Pr; [time, currentPr]];

hold(handles.axes2, 'on')
plot(handles.axes2, Pr(:,1), Pr(:,2), 'b:')
hold(handles.axes2, 'off')
legend('Pth', dat.scheme)
drawnow

p=p+1;
end


dat.Pr = Pr;
enable(handles, 'on')

set(handles.figure1, 'userData', dat)


% --- Executes on button press in pushbutton2.
function pushbutton2_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

dat=get(handles.figure1, 'userData');

Pr = dat.Pr;
uisave('Pr', 'rss')

set(handles.figure1, 'userData', dat)


% --- Executes on button press in pushbutton3.
function pushbutton3_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton3 (see GCBO)
```

```
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
dat=get(handles.figure1, 'userData');
set(handles.edit1, 'String', 0)
set(handles.edit2, 'String', 15)
set(handles.edit3, 'String', 0)
set(handles.text5, 'String', 0)
cla(handles.axes2)
legend off
dat.Pr=[];
dat.dat.posOfFap = [];
createLayout(handles.layout_axes, 10)
set(handles.figure1, 'userData', dat)


% --- Executes when selected object is changed in uipanel1.
function uipanel1_SelectionChangeFcn(hObject, eventdata, handles)
% hObject    handle to the selected object in uipanel1
% eventdata  structure with the following fields (see UIBUTTONGROUP)
%   EventName: string 'SelectionChanged' (read only)
%   OldValue: handle of the previously selected object or empty if none was
selected
%   NewValue: handle of the currently selected object
% handles    structure with handles and user data (see GUIDATA)

dat = get(handles.figure1,'userData');
dat.scheme=get(hObject, 'String');
set(handles.figure1,'userData', dat);


function edit2_Callback(hObject, eventdata, handles)
% hObject    handle to edit2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit2 as text
%        str2double(get(hObject,'String')) returns contents of edit2 as a
double
dat = get(handles.figure1, 'UserData');
totalDist = str2double(get(handles.edit3,'String'));
tripMat = createTripData(handles);
dat.tripMat = tripMat;
setupPrAxes(handles, totalDist/10, tripMat(end, end))
set(handles.text18, 'String', num2str(tripMat(1,1)))
set(handles.figure1, 'UserData', dat)
% --- Executes during object creation, after setting all properties.
function edit2_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit3_Callback(hObject, eventdata, handles)
% hObject    handle to edit3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
```

```
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit3 as text
%        str2double(get(hObject,'String')) returns contents of edit3 as a
double
dat=get(handles.figure1, 'UserData');

set(handles.text5, 'String','0')
createLayout(handles.layout_axes, 10)
noOfFap = str2double(get(handles.edit1,'String'));
totalDist = str2double(get(hObject,'String'));

tripMat = createTripData(handles);
dat.tripMat = tripMat;
setupPrAxes(handles, totalDist/10, tripMat(end,end))
set(handles.text18, 'String', num2str(tripMat(1,1)))

coord=[[[15:10:totalDist+5]' 20*ones(totalDist/10,1)];
[[15:10:totalDist+5]' 40*ones(totalDist/10,1)]];
posOfFap=sortrows(coord(randperm(2*totalDist/10, noOfFap),:), 1);

uePos=[10, 30];
oldConnectedFap = posOfFap(1,:);

[connectedFap, currentPr] = placeFap(handles, posOfFap, uePos,
oldConnectedFap, tripMat(1,1));

dat.posOfFap=posOfFap;
set(handles.figure1, 'UserData', dat);

% --- Executes during object creation, after setting all properties.
function edit3_CreateFcn(hObject, eventdata, ~)
% hObject    handle to edit3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
% --- Executes during object creation, after setting all properties.
function uipanel1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to uipanel1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
```

APPENDIX G

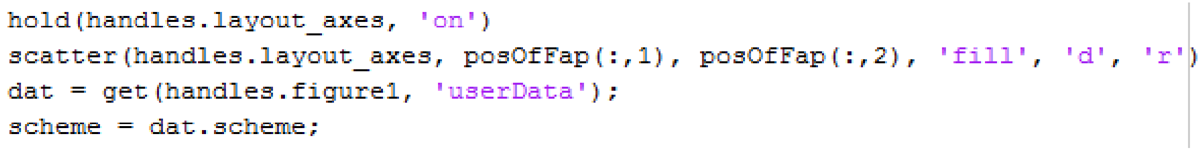
MATLAB CODE SNIPPET FOR FEMTOCELL BLOCK



```
function createLayout(hObject, uePos)
cla(hObject)
pos = [10, 20, 40, 50];
hold(hObject, 'on')
for i=1:4
   plot(hObject, [10 510], [pos(i) pos(i)])
end

for i=10:10:510
    plot(hObject, [i i], [10,20])
    plot(hObject, [i i], [40,50])
end

scatter(hObject, uePos, 30, 'fill', 's', 'b')
scatter(hObject, 260, 90, 250, 'fill', 'd', 'r')
```

APPENDIX H

MATLAB CODESNIPPET FOR MARCROCELL-FEMTOCELL ARCHITECURE



```
hold(handles.layout_axes, 'on')
scatter(handles.layout_axes, posOfFap(:,1), posOfFap(:,2), 'fill', 'd', 'r')
dat = get(handles.figure1, 'userData');
scheme = dat.scheme;
```

APPENDIX I

LIST OF TABULATED RESULTS

Table I.1: Number of Handovers against Number of Femtocells Deployed

Velocity (km/h)	Femtocells	Number of Handovers	
		3GPP	Proposed
15-5-11-3	5	2	1
	10	4	3
	15	6	4
	20	8	7
	25	11	8
	30	13	11
	35	15	10
	40	18	14
	45	20	16
	50	23	17

Table I.2: Handover Count per Velocity for 45 Femtocells

No. of Femtocells	Velocity (km/hr)	Handover Scheme	
		3GPP	Proposed
45 femtocells	15	5	3
	5	5	5
	11	5	3
	3	5	5

Table I.3: Handover Count per Velocity for 50 femtocells

No. of Femtocells	Velocity (km/hr)	Handover Scheme	
		3GPP	Proposed
50 femtocells	15	5	3
	5	5	4
	11	7	4
	3	6	6

Table I.4: Number of Femtocells and the Average Time between Handovers

Femtocells	Average Time between Handover (s)	
	3GPP	Proposed
5	14.00	13.00
10	12.25	10.00
15	11.33	17.00
20	14.38	16.43
25	12.80	17.60
30	12.19	16.09
35	13.53	20.30
40	12.56	16.36
45	13.65	17.06
50	13.48	18.24