HANDOVER MANAGEMENT STRATEGIES IN LTE-ADVANCED HETEROGENEOUS NETWORKS

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Durban, South Africa,

By

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DECLARATION

The research described in this thesis was performed at the University of KwaZulu-Natal under the supervision of Prof. (Dr.) Viranjay M. Srivastava. I hereby declare that all materials incorporated in this thesis are my own original work except where acknowledgement is made by name or in form of reference. The work contained herein has not been submitted in part or whole for a degree at any other university.

Signed:

Olusegun Oladosu Omitola

Date: 23 March 2020

As the candidate's Supervisor, I agree to the submission of this thesis.

Signed: ______________

Prof. (Dr.) Viranjay M. Srivastava

Date: 23 March 2020

DECLARATION – 1: PLAGIARISM

I, **OLUSEGUN OLADOSU OMITOLA** with Student Number 216073471 with the thesis entitled **HANDOVER MANAGEMENT STRATEGIES IN LTE-ADVANCED HETEROGENEOUS NETWORKS** hereby declare that:

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Details of contribution to publications that form part and/or include research presented in this thesis (include publications that have been submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication).

I, **Olusegun Oladosu Omitola**, declare that the following publications came out of this dissertation.

Journals:

1. **Olusegun O. Omitola** and Viranjay M. Srivastava, "An improved handover algorithm for LTE-A femtocell network," *Journal of Communications*, vol. 15, no. 7, July 2020.

2. **Olusegun O. Omitola** and Viranjay M. Srivastava, "Channel borrowing admission control scheme in LTE/LTE-A femtocell-macrocell networks," *Journal of Communications*, vol. 14, no. 10, pp. 900-907, October 2019.

3. **Olusegun O. Omitola** and Viranjay M. Srivastava**,** "Group handover strategy for mobile relays in LTE-A networks," *Journal of Communications*, vol. 13, no. 7, pp. 505-511, September 2018.

4. **Olusegun O. Omitola** and Viranjay M. Srivastava, "Handover algorithm based on user's speed and femtocell capacity in LTE/LTE-A networks," *International Journal on Communications Antenna and Propagation*, vol. 7, no. 5, pp. 417-422, October 2017.

5. **Olusegun O. Omitola** and Viranjay M. Srivastava, "An enhanced handover algorithm in LTE-Advanced network". *Wireless Personal Communication*, vol. 97, no. 2, pp. 2925-2938, July 2017.

6. **Olusegun O. Omitola** and Viranjay M. Srivastava. "A robust speed-based handover algorithm for dense femtocell/macrocell LTE-A network and beyond," *Journal of*

Telecommunication, Electronic and Computer Engineering, vol. 8, no. 9, pp. 121-129, December 2016.

Conferences:

7. **Olusegun O. Omitola** and Viranjay M. Srivastava, “A channel borrowing CAC scheme in two-tier LTE/LTE-Advance networks,” *4th IEEE International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, India. 6-7 January 2017, pp. 1-5.

8. **Olusegun O. Omitola** and Viranjay M. Srivastava, “An effective CAC scheme in two-tier LTE-A macrocell/femtocell networks,” *3rd IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics Engineering (UPCON),* Varanasi, India. 9-11 December 2016, pp. 323-327.

Olusegun Oladosu Omitola

Date: 23 March 2020.

DEDICATION

To God the Father, the Son and the Holy Spirit

To my late Father, Pa Edward Olatunde Omitola

To my loving and caring Mother for her numerous sacrifices and prayers

To my loving, caring and beautiful Wife for being so supportive

To my beautiful Daughter and wonderful Son

To all my wonderful Siblings

And to all those striving to achieve their goals in life.

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ABSTRACT

Meeting the increasing demand for data due to the proliferation of high-specification mobile devices in the cellular systems has led to the improvement of the Long Term Evolution (LTE) framework to the LTE-Advanced systems. Different aspects such as Massive Multiple-Input Multiple Output (MIMO), Orthogonal Frequency Division Multiple Access (OFDMA), heterogeneous networks and Carrier Aggregation have been considered in the LTE-Advanced to improve the performance of the system. The small cells like the femtocells and the relays play a significant role in increasing the coverage and the capacity of the mobile cellular networks in LTE-Advanced (LTE-A) heterogeneous network. However, the user equipment (UE) are faced with the frequent handover problems in the heterogeneous systems than the homogeneous systems due to the users' mobility and densely populated cells.

The objective of this research work is to analyse the handover performance in the current LTE/LTE-A network and to propose various handover management strategies to handle the frequent handover problems in the LTE-Advance heterogeneous networks. To achieve this, an event driven simulator using C# was developed based on the 3GPP LTE/LTE-A standard to evaluate the proposed strategies.

To start with, admission control which is a major requirement during the handover initiation stage is discussed and this research work has therefore proposed a channel borrowing admission control scheme for the LTE-A networks. With this scheme in place, resources are better utilized and more calls are accepted than in the conventional schemes where the channel borrowing is not applied. Also proposed is an enhanced strategy for the handover management in two-tier femtocell-macrocell networks. The proposed strategy takes into consideration the speed of user and other parameters in other to effectively reduce the frequent and unnecessary handovers, and as well as the ratio of target femtocells in the system. We also consider scenarios such as the one that dominate the future networks where femtocells will be densely populated to handle very heavy traffic. To achieve this, a Call Admission Control (CAC)-based handover management strategy is proposed to manage the handover in dense femtocell-macrocell integration in the LTE-A network. The handover probability, the handover call dropping probability and the call blocking probability are reduced considerably with the proposed strategy.

Finally, the handover management for the mobile relays in a moving vehicle is considered (using train as a case study). We propose a group handover strategy where the Mobile Relay Node (MRN) is integrated with a special mobile device called “*mdev*” to prepare the group information prior to the handover time. This is done to prepare the UE’s group information and services for timely handover due to the speed of the train. This strategy reduces the number of handovers and the call dropping probability in the moving vehicle.

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LIST OF ABBREVIATIONS

ADSL	Asymmetric Digital Subscriber Line
AMPS	Advanced Mobile Phone System
ARQ	Automatic Repeat Request
BDMA	Beam Division Multiple Access
BS	Base Station
BW	Bandwidth
CA	Carrier Aggregation
CAC	Call Admission Control
CBP	Call Blocking Probability
CDP	Call Dropping Probability
CC	Component Carrier
CDMA	Code Division Multiple Access
CoMP	Co-ordinated Multi-Point
CN	Core Network
CP	Cyclic Prefix
C-RAN	Cloud-based Radio Access Network
CS/CB	Coordinated Scheduling/Coordinated Beamforming
CSG	Closed Subscriber Group
DBS	Database Server
DeNB	Donor Evolved Node B
DFT	Discrete Fourier Transform
DFTS-OFDM	Discrete Fourier Transform Spread
DL	DownLink
DoC	Data only Carrier

DoS	Denial of Service
DRB	Data Radio Bearers
DSL	Digital Subscriber Line
DTMM	Discrete Time Markov Model
DVB	Digital Video Broadcasting
EDGE	Enhanced Data GSM Environment
eICIC	Enhanced Inter-Cell Interference Cancellation
eNB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EVDO	Evolution Data Optimized
FAP	Femtocell Access Point
FBMC	Filter Band Multi-Carrier
FDD	Frequency-Division Duplex
FFT	Fast Fourier Transform
FGW	Femtocell Gateway
FRN	Fixed Relay Node
FSHO	Fractional Soft Handover
GBR	Guaranteed Bit Rate
GPRS	General Packet Radio System
GRP-HO	Group Handover
GTP-U	GPRS Tunneling Protocol User Plane
GSM	Global System for Mobile communications
HARQ	Hybrid Automatic Repeat Request
HDN	High Dense Network

HDTV	High Definition Television
HDR	Handover Drop Rate
HeNB	Home E-node B
HeNB-GW	Home E-node B Gateway
HetNets	Heterogeneous Networks
HHT	Handover Hysteresis Threshold
HP	Handover Probability
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ICI	Inter-Carrier Interference
IEEE	Institute of Electrical Electronic Engineering
IMT	International Mobile Telephone
IP	Internet Protocol
IPSec	Internet Protocol Security
ISI	Inter-Symbol Interference
ISP	Internet Service Provider
ITU	International Telecommunication Union
JP	Joint Processing
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advance
LOS	Line-of-Sight
MAC	Medium Access Control
MeNB	Master eNB
MIMO	Multiple Input Multiple Output
M2M	Machine-to-Machine Communications

MMS	Multimedia Messaging Service
MME	Mobility Management Entity
MRN	Mobile Relay Network
MRO	Mobility Robustness Optimization
MS	Mobile Station
MTC	Machine-Type Communications
MUE	Microcell User Equipment
MU-MIMO	Multi-User Multiple Input Multiple Output
NAS	Non-Access Stratum
NGBR	Non-Guaranteed Bit Rate
NGMN	Next Generation Mobile Networks
NMT	Nordic Mobile Telephone
NRT	Non Real-time
OFDM	Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
O&M	Operation and maintenance
PARP	Peak to Average Power Ratio
PDU	Protocol Data Unit
P-GW	Packet data network Gateway
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Control
PHY	Physical Layer
PLMN	Public Land Mobile Network
QAM	Quadrature Amplitude Modulation
QCI	Quality Class Identifier
QoS	Quality of Service

QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RLC	Radio Link Control
RLF	Radio Link Failure
RN	Relay Node
RNC	Radio Network Controller
RS	Received Signal
RSS	Received Signal Strength
RSSI	Receive Signal Strength Indicator
RRC	Radio Resource Control
RT	Real-time
SAP	Service Access Point
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDN	Software Defined Networks
SCTP	Stream Control Transmission Protocol
S-GW	Serving Gateway
SNIR	Signal-to-Noise plus Interference ratio
SON	Self-Organizing Network
S-DeNB	Source-Donor Evolved-node B
SRB	Signaling Radio Bearers
SU-MIMO	Single-User Multiple Input Multiple Output
TACS	Total Access Communication Systems
T-HeNB	Target Home E-node B
TDMA	Time Division Multiple Access Technology
TEIDs	Tunnelling End IDs
RAN	Radio Access Network

RN	Relay Network
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SeNB	Serving Evolved-Node B
SMS	Short Message Service
UMTS	Universal Terrestrial Mobile System
UMTS-HSPA	Universal Terrestrial Mobile System-High Speed Packet Access
UDP	User Datagram Protocol
UE	User Equipment
UP	UpLink
VMS	Voice Mail Services
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code Division Multiple Access
WiFI	Wireless Fidelity
WiMAX	Worldwide interoperability for Microwave Access
WLAN	Wireless Local Area Network
1G	First Generation of Cellular Networks
2G	Second Generation of Cellular Networks
3G	Third Generation of Cellular Networks
3GPP	3rd Generation Partnership Project
4G	Fourth Generation of Cellular Networks
5GPP	5th Generation Partnership Project

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Introduction

Mobile cellular networks are becoming more complex due to the emergence of various technologies and the need to increase the bandwidth to meet the present and future data demands by the ever increasing smart phones around the world. It has been forecast that wireless data traffic will grow from over *190 exabytes in 2018* to over *500 exabytes in 2020* [1]. In addition, with more than 50 billion mobile devices supporting varieties of services envisaged in the future, the present cellular networks will be challenged. In order to support these services and increase achievable data rates in the future, there is need to improve the performance of the present cellular networks. As a step towards meeting future data demand in cellular networks, various emerging technologies have been incorporated into the LTE-A (Long Term Evolution-Advanced) with others suggested proposals for the future cellular networks. For the LTE-Advanced, such technologies include Orthogonal Frequency Division Multiple Access (OFDMA), Multiple Input Multiple Output (MIMO), Co-ordinated Multi-Point (CoMP) transmission, Carrier Aggregation (CA) and heterogeneous networks (HetNets) [2-6]. Technologies and techniques for future cellular networks include full-dimensional massive MIMO, interference cancellation and suppression, massive small cell deployment and mm-wave. Heterogeneous networks offer an important role in delivering high data rate, extended coverage and increased capacities in the LTE-Advanced. Notably, a heterogeneous network is a mix of different network base stations. These include femtocells, microcells, picocells and relays [7].

The goals of cellular network include providing a fast seamless handover from one cell to another. This is very important in maintaining ongoing service during the handover procedure and to prevent service loss due to low signal from a particular base station or due to the mobility of users from one cell or base station to another. Also, performance is degraded if data transfer is delayed during the handover procedure. Therefore, it is important that the handover occurs seamlessly to prevent an ongoing service (or call) from being dropped or experience ping-pong effect [8] that is frequent movement of User Equipment (UE) from one cell or base station to another as a result of the UE's mobility and multiple low power base stations in heterogeneous networks. At present, an important research area in wireless networks which is embodied in this research work is the design of an efficient and reliable handover in the LTE-Advanced networks. A brief overview of the LTE-A network is provided in section 1.3.

1.2 Evolution of wireless and cellular networks

A phenomenal growth has been recorded in the last few decades in the wireless and cellular networks. This is attributed to the rapid increase in the number of users of wireless cellular networks [9] and their increasing demand for more voice and data services caused by advancements in wireless technologies. The quest for better and secure connection, seamless handovers, higher bandwidth, reduced latency, as well as increasing, but useful and sophisticated applications on mobile devices, has prompted organisations such as ITU, 3GPP, IEEE etcetera to design new specifications leading to different evolutions of wireless and cellular networks [10]. The evolution of wireless and cellular networks started (as shown in Figure 1.1) with different generations aiming at providing increased data rate, coverage, spectral efficiency, decrease latency and improving quality of service (QoS) [11]. 1G and 2 G are circuit switch systems providing mainly voice services. 2.5 G and 3 G are both circuit and packet switch systems and provide both voice and data services. From 3.5 G up to the present generation are packet switches.

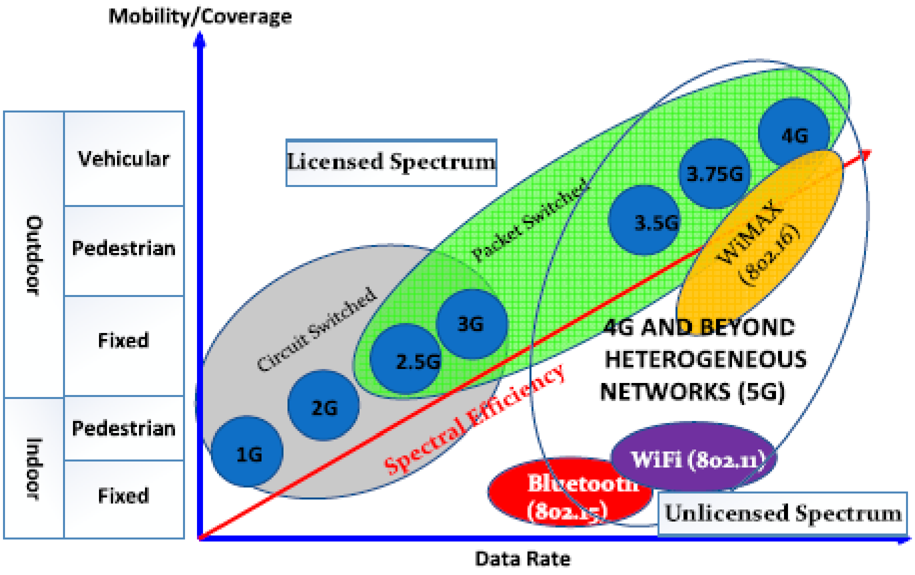

Figure 1.1 Evolution of wireless and cellular networks [11]

Figure 1.1 also shows the difference between wireless systems that use licensed spectrum and those that use unlicensed spectrum. While Bluetooth, Wi-Fi and WiMAX uses unlicensed spectrum, evolving generations use licensed spectrum [11].

1.2.1 First Generation (1G)

Mobile cellular evolution started with the first generation called 1G cellular networks. It was purely an analog system, which was made available in the 1980s and used analog transmission for speech services. The three most popular analog systems were Total Access Communication Systems (TACS), Nordic Mobile Telephones (NMT) and Advanced Mobile Phone System (AMPS) [12]. Although the 1G systems were capable of handover and roaming, they could not operate between different countries. Another shortcoming of these systems was limited capacity, which means that the systems could only accommodate fewer subscribers with a high decrease in performance as subscribers increased. In addition, there were security issues with 1G systems particularly the problem of eavesdropping during communication and inefficient spectrum utilization. To address these shortcomings, considerable efforts were made to develop a new system called second generation of cellular networks.

1.2.2 Second Generation (2G)

The second generation (2G) networks were introduced in the late 1980s and were deployed in the early 1990s. Unlike the 1G, the 2G systems were digital systems and addressed the shortcomings in 1G systems. 2G supported low bit rate data services up to *9.6 kbps* and traditional speech voice services. For higher spectrum efficiency, 2G used Time Division Multiple Access Technology (TDMA) and Code Division Multiple Access (CDMA) to provide better performance. Thus, they supported multiple users and more advanced roaming compared with the first generation. 2G primary technologies include CDMA2000 1xRTT and GSM. In GSM, services such as Voice Mail Services (VMS) and the Short Message Service (SMS) were introduced. Although huge success was recorded in 2G compared to 1G in terms of security, enhanced capacity and international roaming; the 2G systems were however, not suitable for data services. As the popularity of internet and multimedia services increased, there was a paradigm shift in the field of mobile communication. Mobile phone users or subscribers wanted to enjoy internet services on the move such as instant messaging, email, internet surfing and other multimedia services while on the move. To meet up with these requirements, the development of a new system becomes imperative.

Against this backdrop, therefore, that more advanced systems such as 2.5G (General Packet Radio Service (GPRS) and Enhanced Data rates in GSM (EDGE)) [13] were developed based on the original 2G systems. These were designed to provide interim protocols and standards for data communication services. GPRS provides data services ranging from *40 Kbps* to *60 Kbps*. In addition, many slots can be set for data communication and be dynamically allocated based on demands by the GPRS. 2.5/2.75G system such as CDMA2000 1xRTT and EDGE are sometimes referred to as 3G as they have attained the *144 kbps* mobile throughput requirement set for 3G [12]. In EDGE, the modulation scheme used in GSM was improved to provide more data rate of about *384 Kbps*.

1.2.3 Third Generation (3G)

The third generation (3G) networks deployment started in the 1990s as International Mobile Telephone (IMT) 2000 project. The requirements described by the International Telecommunication Union (ITU) for third generation included *144 kbps, 384 kbps and 2 Mbps* of throughput for mobile users, pedestrian users and indoor environments respectively. To fulfil these requirements, a group called 3rd Generation Partnership Project (3GPP) was set up. The 3G primary technologies include Universal Terrestrial Mobile System-High Speed Packet Access (UMTS-HSPA) and CDMA2000 EV-DO. 3G technologies supported both circuit and packet switched data transmission. They supported single standard compatible with a variety of mobile devices across the globe to provide global roaming and Internet access anywhere in the world. Other 3G services were the wide-area wireless voice and video calls, broadband wireless data as well as the High Speed Packet Access (HSPA) data transmission capabilities close to *14.4 Mbps* and *5.8 Mbps* downlink and uplink respectively. The major limitation of 3G was that its mobile phone generally required more energy and was more expensive than 2G systems [11, 14, 15]. The intermediate generation between 3G and 4G aimed at improving data rate (that is by *5 Mbs-30 Mbps*) using some of the techniques introduced in the 3G which are referred to as the 3.5G. Examples in this regard include the Evolution Data Optimized (EVDO) and the High Speed Uplink/Downlink Packet Access (HSUPA/HSDPA) [14].

1.2.4 Fourth Generation (4G)

The fourth generation (4G) started as a 3GPP (third Generation Partnership Project) project. The requirement for IMT-Advanced issued by ITU for 4G includes high spectral efficiency which operates at *100 MHz* radio channels with a peak spectral efficiency of *15 bps/Hz* resulting to a total throughput of *1 Gbps* to *1.5 Gbps* [12]. With *1 Gbps* at a stationary position and *100 Mbps* mobile, the goal of 4G could not be met by earlier versions of LTE and WiMAX. New technologies like LTE-Advanced and IEEE 802.16m were thus required to provide the desired capacity. Therefore, the original LTE and WiMAX were not regarded as true 4Gs. 4G applications include MMS, video chat, Digital Video Broadcasting (DVB), Mobile TV as well as High Definition TV [14, 16-18].

1.2.5 Fifth Generation

Although 4G’s (LTE-A) deployment are still on-going, work on the fifth generation of cellular networks which is expected to be deployed by 2020, has been started by various groups such as the 5GPP (5th Generation Partnership Project), the EU’s METIS, the Small Cell Forum, and the NGMN (Next Generation Mobile Networks) etcetera. [19-22]. With 5G, it is expected that the system capacity will be *1,000* times the present capacity and the end-to-end latency will be less than *1* ms [23]. Also, battery life, energy efficiency, data rate, and spectral efficiency are each expected to be *10* times better than the previous generations. To achieve these, 5G will be driven by technologies like massive MIMO, millimetre-wave (mm-wave), densely populated small cells, Cloud-based Radio Access Network (C-RAN), Machine-to-Machine Communications (M2M), Software Defined Networks (SDN) etcetera. Other favourable technologies for 5G include Beam Division Multiple Access (BDMA) and Filter Band Multi-Carrier (FBMC) multiple access [24]. In the BDMA technique, mobile stations communicating with a base station will be allocated an orthogonal beam. The BDMA technique then divides the antenna beam with respect to the mobile station’s location and gives multiple access to the mobile stations [11, 25, 26]. This results in increased network capacity desired by the 5G system. Various challenges expected in 5G, design fundamentals and potential facilitators have been discussed in [11, 27]. Table 1.1 shows the evolution of mobile cellular networks from 1G to 5G.

Table 1.1 Evolution of Mobile Cellular Networks [28-30]

	1G	2/2.5G	3G	4G	Future 5G
Year	1980s	1990s	2000s	2010s	Vision 2020
Frequency	800 MHz	800/900/1800/1900 MHz	800/850/900/1800/1900/2100 MHz	1.8 GHz, 2.6 GHz,	1.8/2.6, 30 – 300 GHz proposed
Technology	AMPS, NMT, FDMA	GSM, TDMA, CDMA, GPRS, EDGE (2.5G)	WCDMA, UMTS, CDMA 2000 HSUPA/HSDPA (3.5G) LTE, OFDMA/SC-FDMA	LTE, OFDMA/SC-FDMA WiMAX LTE, OFDMA/SCFDMA (4.5G)	BDMA/FBMC Massive MIMO, Millimetre-wave, Software Defined Networks (SDN), Machine-to-Machine Communication (M2M)
Feature	Analog voice	Voice, SMS, data (i.e. 2.5)	Voice, data, video, HDTV, security	3D gaming, HDTV, DVB, expanded multimedia, higher bandwidth, high QoS and more security	HDTV, virtual, reality applications, high speed and QoS
Data Rate	2.4 kbps	10 kbps 50/200 kbps	384 kbps, 2 Mbps (stationary), 100 – 200 Mbps (with 3.9G)	Up to 1 Gbps	Up to 20 Gbps expected
Switching	Circuit	Circuit/Packet	Circuit/Packet	Packet	Packet
Limitation	Analog voice, poor voice quality, security issues, limited capacity, no data and roaming between countries difficult	Data rate still very low and too many standards	Infrastructure more expensive, more power is required by 3G handsets, high bandwidth requirements, 3G phones very expensive	High power consumption, implementation very hard, higher data prices for users, cost of buying new devices that support 4G	High cost of developing infrastructure, security and privacy issue yet to be resolved.

1.3 LTE and LTE-Advanced

1.3.1 LTE

LTE started as a project under the Third Generation Partnership Project (3GPP) in 2004 and was first published in 2009 as Release *8* specifications. By using wider bandwidths, system performance was improved in the LTE. LTE as an improvement to the UMTS is an all-IP-flat architecture. It aimed at achieving a *100 Mbps* data rate at peak downlink and *50 Mbps* data rate uplink as well as less than *10 ms* round-trip times for Radio Access Network (RAN) [31]. To increase the overall spectral efficiency in the LTE, MIMO was used. The OFDMA and Single Carrier-Frequency Division Multiple Access (SC-FDMA) were also used for the downlink and the uplink scenarios [32]. The LTE supports hard handover, seamless global roaming as well as high-speed mobile wireless broadband connectivity. Services like VoIP, video streaming and video TV are supported by the LTE.

1.3.2 LTE-Advanced

LTE-A which is regarded as the true 4G is an evolution of the LTE. It is backward compatible with the LTE and operates in the same frequency spectrum with the LTE without affecting the LTE terminals [33]. The LTE-Advanced was designed to meet the ITU standards for IMT Advanced, which is *100 Mbps* data rate for highly mobile users and *1 Gbps* for users with low or no mobility. Other requirements for 4G by ITU include general acceptance of functions with support for advanced cost effective multimedia services and applications, compatibility of services with fixed network, internetworking, high quality service for user devices, universal user equipment acceptability [34], user-friendly applications and services, and global roaming capabilities. In order to meet these requirements, various functionalities have been added to the previous releases of the LTE by 3GPP in the LTE-A framework [7]. These include heterogeneous network enhancement; that is, enhanced Inter-cell Interference Cancellation (eICIC) and mobility management, full dimension MIMO for the Uplink (UL) and the Downlink (DL), bandwidth extension through CA, and CoMP transmission for allowing different cells to cooperate and serve users better. The combination of these features increases the capacity and improves the performance in the LTE-A. HetNet enhancement reduces the implementation cost and improves the overall system capacity and throughput per-user [35].

1.4 Motivation

The previous generations of cellular networks are homogeneous whereas the LTE-A systems are heterogeneous systems with different base stations. With heterogeneous systems, higher capacity and better network performance can be achieved. User equipment due to user’s mobility and densely populated cells in heterogeneous systems face frequent handover problems than homogeneous systems. Since maintaining continuous connectivity without any service interruption is desirable of any cellular network, much still needs to be done to address the handover issues in the heterogeneous LTE-Advanced networks compared to homogeneous system where so much research has been done. It is pertinent to mention that there are interesting works that have already addressed handover issues in heterogeneous networks. However, no study has specifically considered handover problems in different network deployment scenarios such as femtocell/macrocell deployment, multi-tier networks, densely populated femtocell deployments and in an extremely fast moving vehicles environment in LTE-A heterogeneous network. Different network scenarios of the LTE-Advanced need to be investigated so as to understand and analyse handover problems better. Therefore, considering handover issues as regards the above research gaps is of the utmost importance in this research work.

1.5 Problem Statement

Achieving a seamless and robust handover operation in the LTE-A heterogeneous network is a serious issue. Studies have shown that the frequency of handover in the heterogeneous environment is greater compared to the homogeneous environment. This can be attributed to the following factors:

(a) High number of smaller cells such as femtocells in the heterogeneous environment.
(b) Small cell lower coverage and capacity,
(c) Various small cell signals detection, and
(d) Lack of efficient handover management scheme for heterogeneous environment.

Small cells such as femtocells and relay as part of the LTE-A heterogeneous network are often deployed in large quantity to improve and increase the network capacity. As a result, the UE detects many of the femtocell signals and because the femtocell coverage and capacity is low, mobile UE tries to move from one femtocell to another and thus causes the ping-pong effect. In many cases, there is a lack of an effective handover management strategy to handle frequent handovers resulting from the large femtocell deployment and fast moving UEs. Therefore, this research work aimed to provide various handover management strategies that will reduce the number of handovers in LTE-A networks.

1.6 Objectives of the Research Work and It's Contributions

The objective of this research work is to analyse the handover performance in LTE-Advanced heterogeneous networks and then propose different strategies for handover management in LTE-Advanced heterogeneous networks. The thesis had the following objectives:

(a) To propose Call Admission Control strategy for handover decisions. Admission control is required during handover initiation stage to manage the available radio resources at the target base station. One of the contributions of this thesis is to propose an efficient strategy to manage the radio resources in LTE-A femtocell-macrocell networks.

(b) To propose an enhanced handover management algorithm for two-tier macrocell-femtocell LTE-A networks. To propose an efficient handover algorithm based on the speed of the UEs and other parameters in the LTE-A macrocell-femtocell integration.

(c) To propose a handover management strategy for densely deployed femtocell in the LTE-A networks. To propose a robust CAC-based handover management strategy to reduce frequent handovers and ping-pong effects associated with densely femtocell deployments.

(d) To propose group handover management strategy for mobile relays in the LTE-A networks.

1.6.1 Methodology

The standardization of the LTE-A was done in 3GPP release 10 to release 12. These 3GPP standardization documents and drafts were useful in addition to the previous studies, articles, and textbooks that discussed handover challenges and management in the LTE-A heterogeneous networks. Since the LTE-A is an improvement on the LTE, a preliminary study of the LTE has been done to provide adequate background for this research work. This has provided the required information on the various aspects of the LTE-A technology such as architecture, deployments, protocols as well as network components. The literature review, which gives sufficient information regarding different handover methods proposed in the previous studies, has been reviewed. The LTE-A network was designed and simulation scenarios were investigated using event driven simulator designed for this research work. By using MATLAB, performance analysis of various metrics was done. The flowchart in Figure 1.2 describes the step-by-step approach used in carrying out this research work.

1.6.2 Simulation Tools

An event-driven simulator implemented in C# using Microsoft Visual Studio environment was developed for this research work. The simulator was designed according to the LTE/LTE-A specification and standards. An object oriented C# programming was chosen because of its many advantages. These include its object oriented nature which makes it more user friendly, that is, easy to use, availability of many functions for computation of complex mathematical equations and better integration of the components with other languages. In addition, redundancy and replication of the software modules can be eliminated. The simulation script for each scenario consists of standard specification and configuration for the design of LTE/LTE-A. After several simulation scenarios, the expected results are achieved. The results are first displayed in the excel sheet and then transferred to the MATLAB code for graph presentation and easy analysis.

1.7 Thesis Outline

This research aimed to analyse handover problems in the LTE-A network with the view of providing different handover management strategies different from the existing ones and to improve the overall system' performance. To achieve this, an in depth knowledge of various technologies, standards, specifications and functional requirements related to handover in the LTE/LTE-A system was required. The research work includes the standards and specifications provided by the 3GPP. An extensive overview of the wireless cellular concept and detailed study of handover management in femtocell/macrocell and heterogeneous LTE-A networks have been made. The thesis is organised as follows:

Chapter two presents the background as well as the literature review of previous studies on LTE/LTE-A handover management. The various enhancements made to the previous LTE

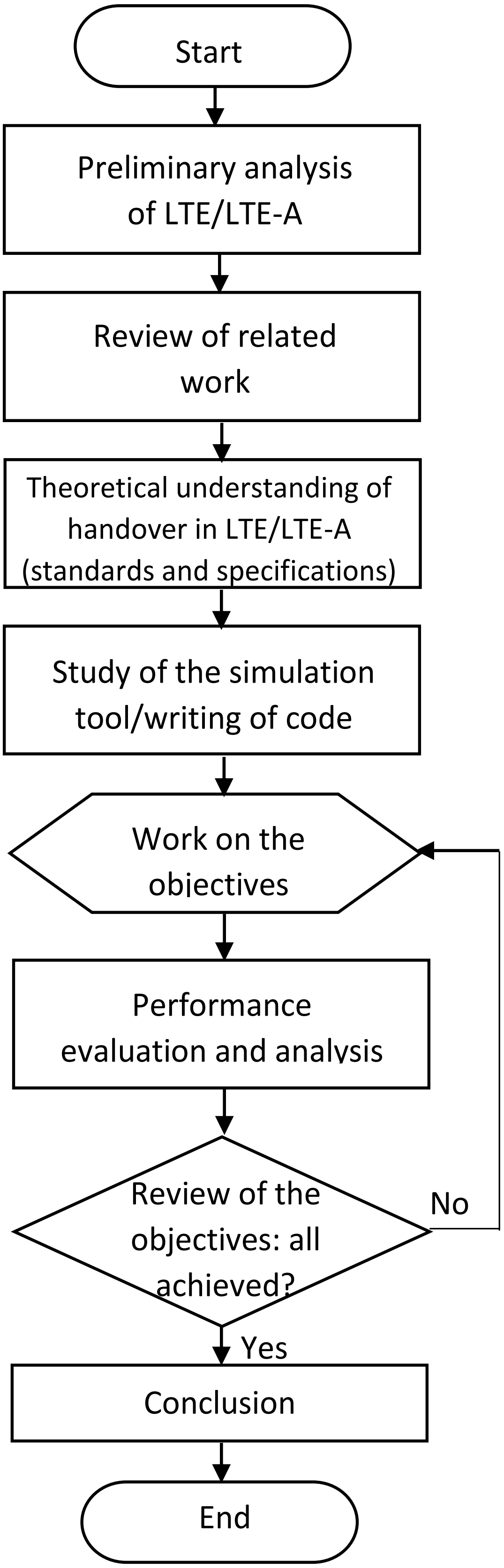

Figure 1.2 Flowchart for the procedure of this work

releases have been explained in this chapter. The chapter also presents the general architecture of the LTE/LTE-A system as well as the handover types used.

Chapter three discusses the call admission strategy for the handover decision in the LTE-A system. During the handover initiation stage, admission control is required to determine the availability of resources before handover can occur. Therefore, a channel-borrowing strategy has been proposed for the admission procedure in the femtocell-macrocell integration. The system model for the femtocell-macrocell integration and the different femtocell access modes have been explained in this chapter.

Chapter four proposes handover management based on the UE's speed and other parameters. The simulation environment for the femtocell-macrocell integration has been presented in this chapter. The traffic of calls has also been analysed in this chapter.

Chapter five presents handover management in dense femtocell deployment in the LTE-A networks. In order to meet the future demand for data, huge femtocell deployment is required, however, this often leads to more handover among many femtocells in the densely populated femtocell environment. In providing a solution to this problem, the CAC scheme has been proposed and applied to the different call types while modelling the proposed scheme using the Markov chain.

Chapter six proposes a group handover management strategy for the mobile relays in the LTE-A. In our strategy, we have introduced a device called "*mdev*" to forecast the location and direction of the target base station and then prepare the mobile relay for timely handover to the target base station.

Finally, *Chapter seven* provides a brief summary of the previous chapters and the conclusion of this research work. We also made future recommendations concerning handover in the LTE-A and future networks.

1.8 Resulting peer reviewed publications

The following are the peer-reviewed publications derived from this research work. The publications make up the topic of the chapters in this dissertation.

1. **Olusegun O. Omitola** and Viranjay M. Srivastava, “An improved handover algorithm for LTE-A femtocell network,” *Journal of Communications*, vol. 15, no. 7, July 2020. (Chapter 4)

2. **Olusegun O. Omitola** and Viranjay M. Srivastava, “Channel borrowing admission control scheme in LTE/LTE-A femtocell-macrocell networks,” *Journal of Communications*, vol. 14, no. 10, pp. 900-907, October 2019. (Chapter 3)

3. **Olusegun O. Omitola** and Viranjay M. Srivastava**,** “Group handover strategy for mobile relays in LTE-A networks," *Journal of Communications*, vol. 13, no. 7, pp. 505-511, September 2018. (Chapter 6)

4. **Olusegun O. Omitola** and Viranjay M. Srivastava, “Handover algorithm based on user’s speed and femtocell capacity in LTE/LTE-A networks,” *International Journal on Communications Antenna and Propagation*, vol. 7, no. 5, pp. 417-422, October 2017. (Chapter 4)

5. **Olusegun O. Omitola** and Viranjay M. Srivastava, “An enhanced handover algorithm in LTE-Advanced network,” *Wireless Personal Communication*, vol. 97, no. 2, pp. 2925-2938, July 2017. (Chapter 4)

6. **Olusegun O. Omitola** and Viranjay M. Srivastava. “A robust speed-based handover algorithm for dense femtocell/macrocell LTE-A network and beyond,” *Journal of Telecommunication, Electronic and Computer Engineering*, vol. 8, no. 9, pp. 121-129, December 2016. (Chapter 5)

7. **Olusegun O. Omitola** and Viranjay M. Srivastava, “A channel borrowing CAC scheme in two-tier LTE/LTE-Advance networks,” *4th IEEE International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, India. 6-7 January 2017, pp. 1-5. (Chapter 3)

8. **Olusegun O. Omitola** and Viranjay M. Srivastava, “An effective CAC scheme in two-tier LTE-A macrocell/femtocell networks,” *3rd IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics Engineering (UPCON),* Varanasi, India. 9-11 December 2016, pp. 323-327. (Chapter 3)

CHAPTER TWO

LITERATURE REVIEW AND BACKGROUND OF STUDY

2.1 Introduction

Previous studies aiming at efficient handover management in LTE networks have been discussed in various literatures in section 2.2 and 2.3. Research on LTE started before the first release of standards by 3GPP and further research thereafter. To increase the capacity and for better quality of service, enhancements have been made to the LTE in the LTE-Advanced framework. Careful consideration is required in designing LTE-Advanced involving macro and smaller nodes to reduce associated handovers. The technical background on LTE-Advanced and its related technologies are provided in this chapter. This chapter consists of five sections as follows. Section 1 outlines previous studies on handover management for two tier femtocell-macrocell integration as well as dense femtocell deployment in LTE-Advanced network. Section 2 gives an overview of previous studies on handover management in mobile relay network. Section 3 explains key features of LTE-Advanced systems. Section 4 discusses LTE/LTE-A general architecture, interfaces and protocol layers. Also discussed in this section are the LTE-Advanced physical layer descriptions. Brief studies on handover techniques are discussed in section 5.

2.2 Handover in femtocell-macrocell LTE/LTE-Advanced

The procedure for handover and mechanism supporting user’s mobility in 4G LTE networks have been described in [36, 37]. *Ulvan et al.* [38] studied these procedures and introduced the user equipment mobility prediction to achieve a more optimized procedure. This mobility prediction is based on Markov chain probabilities in order to determine the present position and the velocity as well as the direction of the UE. To reduce the frequent and unnecessary handovers, these authors proposed reactive and proactive handover strategies. In [39], the reactive handover decision strategy and mobility prediction proposed in [38] were used to investigate the handover procedure in both the horizontal and the vertical handovers. The authors explained that proactive handover can occur before the current base station RSSI level reaches the Handover Hysteresis Threshold (HHT) while the reactive handover postpones the handover to as long as possible until the UE fully loses the signal from the source base station. To determine the distance of the next position of the UE in advance, direct movement mobility model was adopted. It was shown that the reactive handover produces the lowest number of handovers and latency because of its principle of postponing the handover until the signal is lost. A new criterion like the base station capacity estimation was introduced to the handover procedures in [40]. With this, the base station utilization and type can be determined. This helps in preventing the base station from being overloaded. It also results in better load balancing and improved Quality of Service (QoS) for the users. An optimized handover management algorithm in [41] uses a call admission control to reduce the handover and the Handover Drop Rate (HDR) in a two-tier macrocell-femtocell LTE network. This algorithm, however, only considers one macro-base station within many femtocell base stations.

To improve the handover performance in a densely populated environment with many macrocells and femtocells such as the one by *Lee et al*. [42], new mobility strategies were introduced in [43, 44]. With the new strategies, which separate control plane and the user plane, the authors discussed that the Data only Carrier (DoC) network performed better in a network of densely deployed femtocells with very low handover failure and high-energy efficiency than the current LTE systems. From the literature above, it is noticed that more work needs to be done in the area of handover management for LTE/LTE-A femtocell-macrocell system especially now that users' equipment requires more data and femtocell being deployed massively to boost the capacity and thus increase coverage. In addition, the admission control can be enhanced and introduced to handover management to handle calls effectively in such an environment and thereby reduce handover call dropping and blocking probabilities.

2.3 Handover in mobile relay network

Previous studies in this area indicate that by deploying supportive and coordinated relays on train tops, user's Quality of Service (QoS) in a train can be improved significantly [45-47]. Dedicated MRN in [48, 49] were compared with the existing solutions such as layer 1 repeaters, WiFi access points and dedicated macro eNBs serving the vehicular UEs and were found to offer great improvement in the vehicular user experience. To reduce the number of signalling messages in the network nodes, *Chen and Lagrange* [50] propose fixed relay architecture with global tunnel concept and extends it to mobile relay. With the X2 and S1 global tunnels concept, several tunnels were gathered and used to transmit data traffic for vehicular UEs served by a Mobile Relay Node (MRN). This results in the reduction of signalling messages and allows the possibility of grouping several handovers in mobile relays.

To reduce handover failure in moving cells, *Luo et al*. [51] propose a Co-ordinated Multipoint Transmission (CoMP)-based handover strategy which allows the train to receive multiple signals from adjacent base stations, thus acquiring diversity gain whenever it passes through those base stations. *Hwang and Shin* [52] presented moving cell architecture as well as protocol stacks of control and user planes. They argue that the LTE-A fixed relay architecture is not suitable for mobile relay. This is because in mobile relay, all UEs communicate with a MRN which in turn communicates with the Donor E-UTRAN Node B (DeNB) as the vehicle moves. For better handover performance, all UEs handovers can be congregated into a single handover of one MRN which then performs the handover to the DeNB. This is, however, not supported by the fixed relay architecture of LTE-A. In [53], the architecture to support mobile relay and the key techniques to support mobile relay were presented albeit an effective handover management strategy is required to support this architecture. Based on this architecture, a group handover management strategy is proposed later in this research work for mobile relay such that MRN attached to a high-speed train effectively handovers all UEs related communications from the source donor eNB (DeNB) to the target DeNB.

2.4 Key technologies for LTE-Advanced

LTE-Advanced primarily is an air interface enhancement to LTE. It is an evolution of LTE aimed at meeting the increasing demand for improved service, bandwidth, quality of service at low cost as well as meeting the requirements set for the IMT-Advanced. Initial enhancements were made to 3GPP LTE Release 8 in Release 9 which were followed by more significant enhancements in Release 10 (LTE-Advanced). Beyond Release 10, further enhancements were made to the initial releases while the naming continues as LTE-Advanced.

Some of the important enhancements mentioned in chapter one include Enhanced Carrier Aggregation, Enhanced MIMO for uplink and downlink, Coordinated Multi-point (CoMP) Transmitter and Receiver, Relay, Self-Organising Network (SON), Machine-to-Machine communications (M2M), Enhanced Inter-Cell Interference Coordination for Heterogeneous Network and relaying [54]. The importance of the enhancements in LTE-Advanced include enabling more efficient use of spectrum, increase the data rate for UEs and providing more coverage and capacity to system. Short notes on each of these enhancements are as follows:

2.4.1 Enhanced Carrier Aggregation (CA)

To achieve the LTE-Advanced goal of supporting maximum bandwidth of *100 MHz*, LTE-Advanced allows a mobile equipment to transmit and receive using five Component Carriers (CCs) that is *1.4 MHz*, *3.5 MHz*, *10 MHz*, *15 MHz* and *20 MHz* with each having a maximum of *20 MHz* bandwidth [55]. This method of utilizing more than one carrier to achieve an increased transmission bandwidth (i.e. data rate) is referred to as Carrier Aggregation. CA also makes it possible to use fragmented spectrum efficiently. With LTE-Advanced CA, different arrangements of CCs can be aggregated. These include adjacent or non-adjacent component carriers in the same or different frequency bands. Each CC can take any of *6*, *15*, *25*, *50*, *75* or *100* Resource Blocks (RBs) equivalent to *1.4*, *3*, *5*, *10*, *15* and *20* MHZ channel bandwidths respectively [56].

Another reason for CA is the support for heterogeneous networks. In heterogeneous networks where low-power layer small cells and high-power layer macrocells co-exist, CA allows one carrier instead of two to be used by both layers. CA allows the use of multiple carriers for a given layer and avoids interference through cross-carrier scheduling [57].

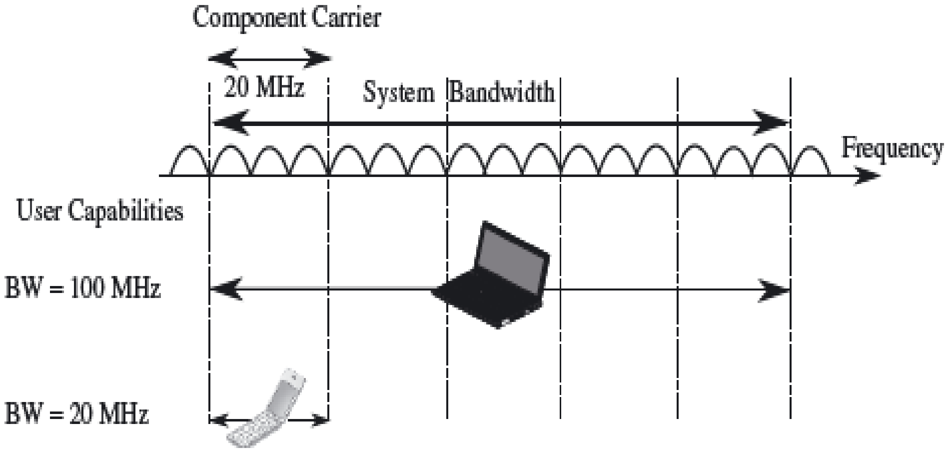

Figure 2.1 Carrier Aggregation in LTE-A [58]

With Carrier Aggregation, a spectrum can be used more efficiently as shown in Figure 2.1. For instance, UE can transmit or receive from multiple component carriers at *100 MHz* maximum bandwidth [58]. Without carrier aggregation, UE can transmit or receive from a single component carrier only.

2.4.2 Coordinated Multi-point (CoMP)

Coordinated Multi-point (CoMP) enables dynamic coordination of transmission and reception over many separated base stations or eNBs. The purpose of CoMP in LTE systems is to enhance the system performance or cell edge throughput [59] by using the resources more effectively. CoMP can also improve the user service quality. By using CoMP, separated eNBs are dynamically coordinated to deliver joint scheduling and transmission and joint processing of the received signal [60]. Thus, the users at the cell edges are provided with improved signal reception/transmission and increased throughput. The two types of CoMP technologies in LTE-Advanced are: Joint Processing (JP) and Coordinated Scheduling/Beamforming (CS/CB). With JP, multiple data transmission points can be provided for each UE amid multiple cooperated eNBs. Notably CS/CB supports single data transmission point for each UE with scheduling/beamforming decisions [61]. In CS/CB, the sharing of user data among cells is not required. An example of CoMP architecture in a distributed network is depicted in Figure 2.2 [62].

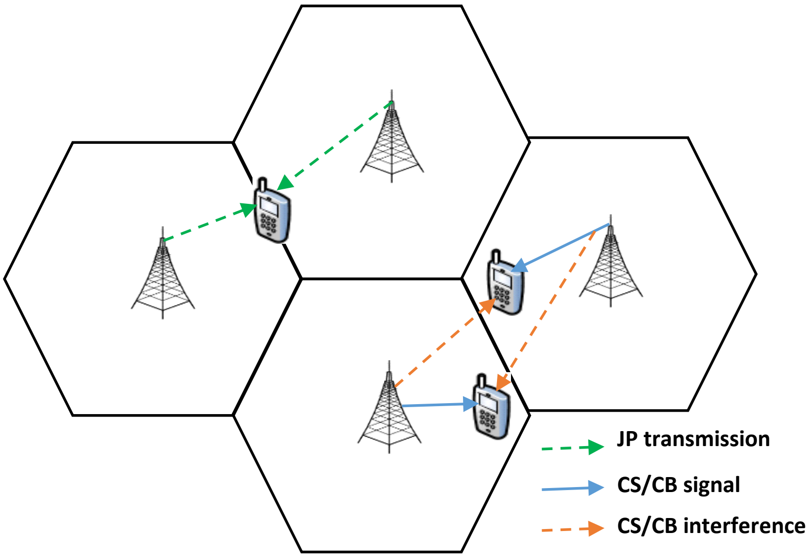

Figure 2.2 CoMP in a distributed network architecture [62]

2.4.3 Enhanced Multiple Input Multiple Output (MIMO) Antenna Techniques

MIMO is a default technology of the LTE system for boosting the overall data rates. MIMO offers high data rates without the need for additional bandwidth and transmission power [63]. It allows for the use of multiple antennas at both transmitting and receiving sides of the system. Unlike the traditional cellular systems where Line-of-Sight (LoS) is required for best performance, MIMO provides best performance under rich scattering conditions. Additionally, MIMO provides high data rates in the LTE systems using multipath characteristics of wireless channels. Also by leveraging on spatial dimensions, several signals from different antennas can be combined at both the transmitter and the receiver leading to high data rates [63, 64]. In LTE-A, enhanced MIMO features that is spatial multiplexing and transmission diversity can together achieve an improved coverage and enhanced peak data rate.

In LTE-A, the 3GPP propose two techniques: high-order Single-User MIMO (SU-MIMO) for higher data rates and Multi-User MIMO (MU-MIMO) for higher spectral efficiency. For better performance, 4x4 SU-MIMO is used in the uplink and transmit diversity is used for the control signalling [57]. In the downlink, higher order 8x8 SU-MIMO is used.

2.4.4 Heterogeneous Networks (HetNets)

The rapid increase in internet-connected mobile applications and devices has necessitated that the network providers increase their network capacity [65]. Heterogeneous network provides new paradigm cost effective approaches by increasing the network capacity and thus deliver uniform connectivity experience to the users. HetNets involves overlaying low power small cell nodes like pico cells, femtocells and relay nodes etcetera. on the existing macrocell layer [7]. In HetNet deployments, the macrocell provides a wider coverage as shown in Figure 2.3 while the smaller cells are deployed in a way that reduces the coverage of dead zones. The capacity offered by the macrocells in the macro-only network is not distributed evenly across the network, that is, UE in the centre tends to experience higher throughput compared to the UE at the cell edges. The HetNets provide a solution to the capacity needs in hotspot areas as well as pervasive user experience [52].

HetNets can also provide huge improvement to the network and service connectivity by dynamically offloading traffic from the macrocell for reasons such as network load balancing and coverage extension. Picocells and relays are used for outdoor deployments whereas femtocells are usually deployed for indoor use in residential, cafeteria or enterprise buildings. In an enterprise deployment, femtocells are deployed in a well-coordinated manner by allowing self-organising and adapting to optimize transmission parameters.

In HetNets, the small cells can operate at the same or different frequencies and thus transmit with less power than the macro cells. The small cells can be accessed in three different modes, namely, open mode, closed mode and hybrid mode.

A. **Open Access**: In open access, all the network subscribers can access the femtocell resources without any restriction. To extend coverage to the macrocell UEs with reduced threat to adjacent channel and co-channel interferences, [66] the network operators generally adopt this mode. In the public access mode, a macrocell UE has the opportunity to choose the femtocell that offers best service quality [67, 68]. This leads to macrocell UEs enjoying continuous connection to the core network. Open access femtocell is generally found in public places like malls, railway stations, cafeteria, airports and universities to improve the overall network throughput. One of the challenges with this access mode is service degradation due to the sharing of limited resources among large numbers of UEs [66]. Other challenges include increased handover between macrocell and femtocell open access, non-guaranteed QoS to femtocell UEs and privacy and security issues.

B. **Closed Access**: In the closed access mode, only registered users have access to the femtocell services. In other words, it monopolizes the backhaul to the advantage of femtocell UEs [69] and prevents unregistered UEs from using the femtocell resources. The closed access femtocells are used privately by homes, offices, and small businesses to provide privacy and security to the information of the femtocell UEs [35]. Subscribers in this mode also enjoy high quality coverage, high rate multimedia services and high rates of success [70]. The closed access mode has lower network overhead and is more secure than the open access mode [71]. Since the closed access mode does not accept unregistered UEs, difficult handover mechanism is not required. The closed access mode, however, suffers from co-tier and cross-tier co-channel interference that are explained later in this study [66]. Therefore, good knowledge of frequency planning is required in closed access femtocell deployments to prevent co-channel interference.

C. **Hybrid Access**: The hybrid access mode evolved to provide solutions to the inflexible access in the open and the closed access modes. It permits a particular number of macrocell UEs to access the limited amount of femtocell backhaul without affecting the quality of service provided to femtocell UEs. This method of deploying femtocells to allow macrocell UEs to access the resources of femtocell leads to overall increase in network throughput compared to the macrocell only deployment. In the hybrid access modes, though the macrocell or public UEs can access the femtocell service, however; priority is ideally be given to the registered users. The interfering Macrocell UEs can be readily selected and served in a way that minimizes adjacent channel and co-channel interferences [72]. However, like in the open access, the hybrid access mode challenges include privacy and security issues, complex signalling overheads and large billing amount resulting from traffic bottlenecks [73]. Most of the current deployment of femtocell allow users to select the type of mode of the femtocell to be used [74].

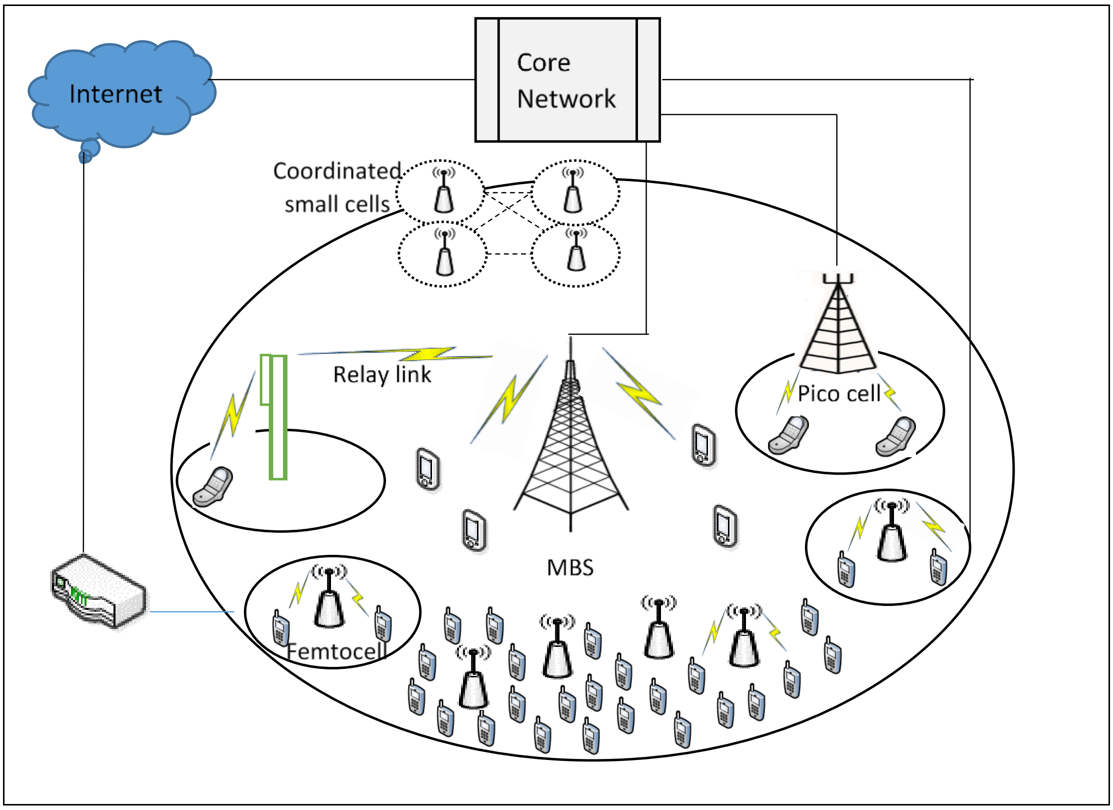

Figure 2.3 Heterogeneous LTE-A networks

2.4.5 Enhanced Inter-Cell Interference Coordination (eICIC) for Heterogeneous

The small cells overlaid by the macrocell provide higher spectral reuse due to cell splitting. It also leads to an improved system capacity for localized high traffic densities (that is hotspots) [57]. However, this also brings about sharing of the spectrum between macrocells and the small cells due to the limited availability of the spectrum, thereby causing more interference in HetNets than in homogeneous macrocellular networks. In 3GPP LTE-A, Enhanced-ICIC is a standardized time domain in the ICIC scheme for addressing the co-channel deployment issues. With the eICIC, certain sub-frames in one layer of cell can be muted to reduce the interference in other layers [75]. Enhanced ICIC is due to common knowledge about protected resources, that is, sub-frames blanked by the strongest neighbour. The strongest neighbour corresponds to the surrounding macrocell in the picocell scenario with a bias-based cell range extension [76]. In a femtocell single carrier deployment with CSG, the HeNB blanks a fraction of sub-frames to eventuate protected resources necessary to schedule the macrocell UEs in the downlink (DL).

2.4.6 Dual Connectivity and Inter-site Carrier Aggregation

Dual connectivity is similar to CA but with a little difference. Dual connectivity occurs between different sites. It enables a UE to be connected simultaneously to at least two different nodes, that is, the master eNB (MeNB) of the macrocell and the secondary SeNB of the small cells with non-ideal backhaul [77]. This method of inter-node radio resource aggregation can be across different frequencies and locations and across different radio access technologies such as WLAN and cellular network. Dual connectivity is introduced to heterogeneous networks for robust UE mobility, improved data rate, and signalling of the overhead reduction [78, 79]. With dual connectivity, UEs can separate data and control planes by sending user data to the SeNB and control messages to the master eNB. Dual connectivity also reduces handover failures in the LTE-A heterogeneous network.

Figure 2.4 shows the dual connectivity scenario where two SeNBs are connected to one MeNB through non-ideal backhaul links. In this scenario, three UEs are connected as follows; UE-1 and UE-2 are singly connected to MeNB and SeNB-2 respectively. UE-3 is connected to both MeNB and SeNB-1 using dual connectivity. By utilizing the radio resources from both MeNB and SeNB-1, increased throughput is noticed in UE-3 [80].

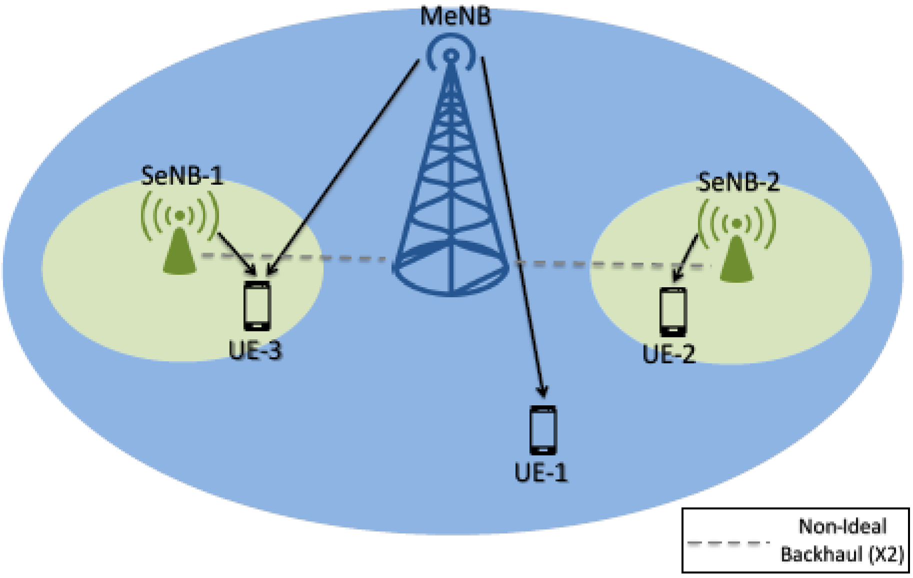

Figure 2.4 Dual connectivity deployment scenario [80]

2.4.7 Self-Organising Network (SON) Enhancements

Self-organizing networks are aimed at optimizing radio resource usage, network management simplification and operational cost reduction for the network operators [81]. This enhancement enables the network to automatically notice changes in the network and thus make intelligent decisions based on the changes and then take the required actions [82]. With SON, the systems are aware of their location and present situation(s) and can be configured dynamically in a distributed fashion. In terms of resource management, SON aids in automatic coordination of resources at the cell's border and thereby improves the performance and services at the cell-edges. In the initial LTE release, SON was associated with equipment installation (referred to as eNB self-configuration) such as Automatic Inventory, Automatic Software Download, Automatic Neighbour Relation and Automatic PCI Assignment [83]. Enhancements made to SON have resulted in various procedures for the covering of network optimization. Additional functionalities provided in the latest release to manage heterogeneous networks include [84]:

(a) Capacity and Coverage Optimization.
(b) Cell Outage Detection and Compensation.
(c) Enhanced Inter-Cell Interference Coordination.
(d) Energy Saving.
(e) Drive Test Minimization.

(f) Self-healing Functions.
(g) Mobility Robustness Optimization (MRO).

The aim of SON-MRO feature includes detecting and preventing connection failures due to the mobility of the UEs. These failures include the following:

(a) Too late handover causing failure in connection in the serving cell.
(b) Coverage hole causing failure in connection in the serving cell.
(c) Too early handover causing failure in connection in the target cell.
(d) Inappropriate handover to a wrong target cell causing connection failure in the cell.

Generally, the connection failure occurred because of the Radio Link Failures (RLFs) and the handover failures [85]. Respective solutions to the aforementioned failures have been provided by *Sesia et al*. [57].

2.4.8 Macrocell

The macrocell base station (MBS) provides close to *40 Km* wide area coverage at about *40W* to *100W* transmission power to users. The number of users in the MBS, though, depends on the deployed cell and the environment is usually around *200* users to *1000* users [86]. The macrocell can also act as an overlay layer to the smaller cells in the LTE systems although this usually increases interference if there is no proper network planning. For example, macrocells can be made to operate on the same frequency with the smaller cells (that is co-channel deployment) or on different frequencies. In the LTE-Advanced, co-channel deployment is preferred for both indoor and outdoor applications because of its many advantages which include channel optimisation. With channel optimization, more frequency channels can be saved leading to reduced network implementation cost and better spectral efficiency. However, co-channel deployment often leads to co-channel interference. To avoid co-channel interference and other interference problems, proper frequency planning is required during the deployment of the macrocells and the smaller cells. Resource allocation techniques for the frequency can be used to handle associated interference challenges [87].

2.4.9 Picocell

Picocell transmission is considerably lower compared to the macrocell. They are usually deployed in an ad-hoc manner which results in a lower Signal-to-Noise plus Interference ratio

(SNIR) and challenging RF channel for transmission of the control channel to the users at the cell edges. Picocells can cover up to *200 m* and their base stations can be deployed indoor or outdoor with careful planning to extend the coverage of the macrocell thereby providing support for additional UEs. In the macrocell-picocell deployment, there is a large dissimilarity between the transmission power of both cells which leads to smaller downlink coverage of a picocell against a larger downlink coverage of the macrocell. For the uplink, the same transmission power strength is used by the UE to all base stations because the uplink depends solely on the UEs' transmission power [88]. Figure 2.5 shows picocell deployment within the coverage of the macrocell, extending the coverage of the macrocell and providing additional supports to the UEs.

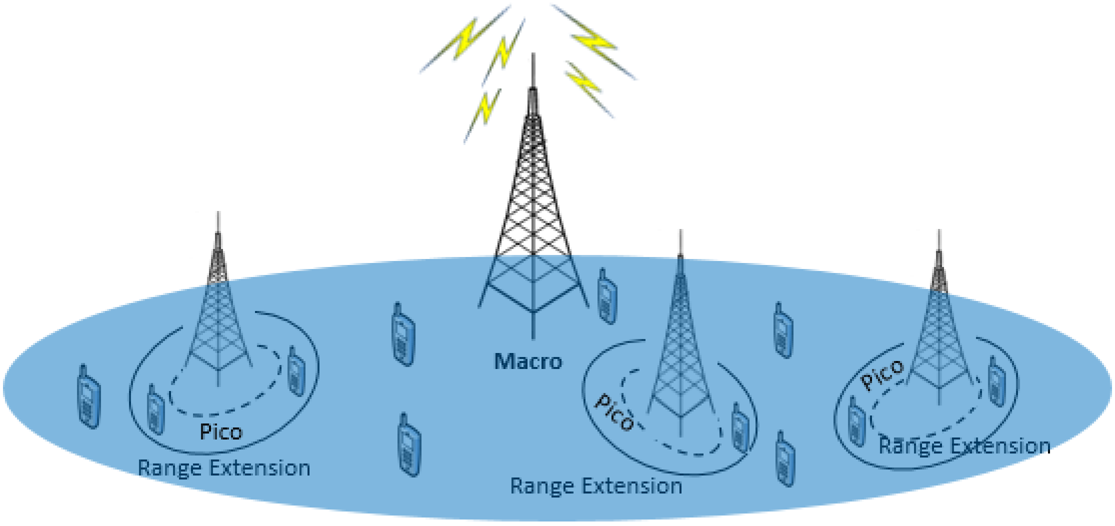

Figure 2.5 Macrocell-picocell range extension

2.4.10 Relay

The LTE-A includes another feature known as the relay nodes (RNs) which support the LTE deployment in areas where a wired backhaul is not available or too costly in order to expand the coverage or increase the network capacity. The RN first appears in the LTE Release 8 where the UEs receive and transfer all the control and data signals to and from the RN whereas in the LTE-A, the RN separately transmits control and data to and from a donor cell (eNodeB) [57]. Unlike the repeaters (used in UMTS) which only amplifies the signal and interference received, thus degrading the quality of signal received, the RN first processes the received signal and then forwards it to the appropriate UE [89]. Also unlike the repeaters which are operated independent of the RAN, the RNs are under the full control of the RAN for easy monitoring and remote control functionalities. Figure 2.6 represents the processed signal of the RN against the simple amplification of a repeater. The 3GPP LTE-A defined type 1 (non-transparency) and type 2 (transparency) as the two RN types. Type 1 enables a remote UE to have access to the macrocell eNB. In order to extend the signal coverage and other services to the UE, the RN transmits common reference signal and control information from the eNB to the remote UEs. Type 2 enables a local UE within the macrocell and with direct communication to the eNB to experience an improved link capacity and better service quality. Details about the relay node and the other types are explained in chapter 6 of this work.

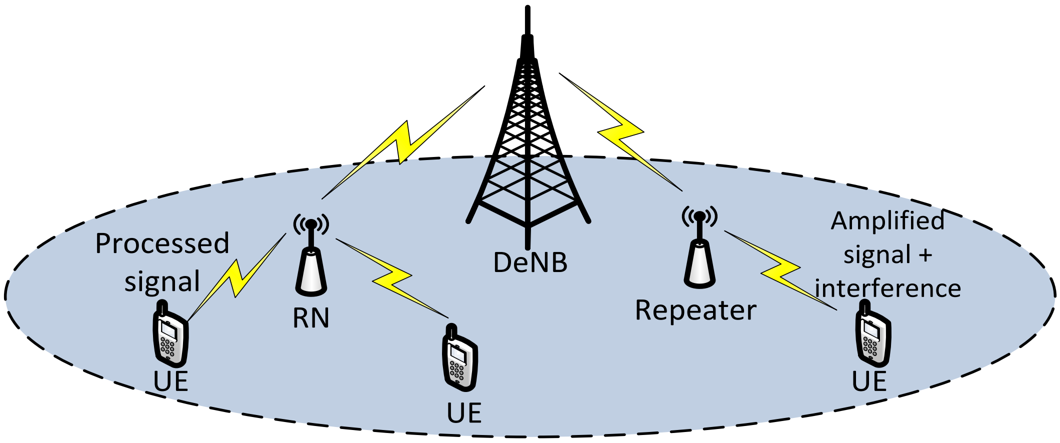

Figure 2.6 Comparison of RN signal and Repeater signal

2.4.11 Machine-To-Machine (M2M) Communications

The M2M communications also referred to as Machine-Type Communications (MTC), are communication types involving entities with no human interaction [58]. To explain the communication scenarios between the entities, the 3GGP has provided transport and communication services support for the three scenarios described in Figure 2.7:

(a) Scenario A – In this scenario, M2M application interacts directly with the UE.

(b) Scenario B – In this scenario, M2M application interacts directly with the M2M server located outside the operator area.

(c) Scenario C – In this scenario, M2M application interacts with the M2M server located inside the operator area.

The 3GPP services include bearer services, Short Message Service (SMS) and IP Multimedia Subsystem. Besides, the following M2M problems have been addressed in 3GPP:

(a) Small data transmission – In M2M communications, high peak data rates, sophisticated channel estimations or advanced MIMO is not required.

(b) Addressing – IP addressing is a big problem in M2M communication due to large number of devices. Therefore, common devices are grouped to share a common identifier.

(c) Congestion and overloading of the CN – Delays, packet loss due to overloading, or service failure can result when a large number of MTM communication devices are deployed in certain areas. Load control mechanisms can be implemented based on different priorities in M2M devices to minimize this problem. Other methods that have been used are discussed in [58].

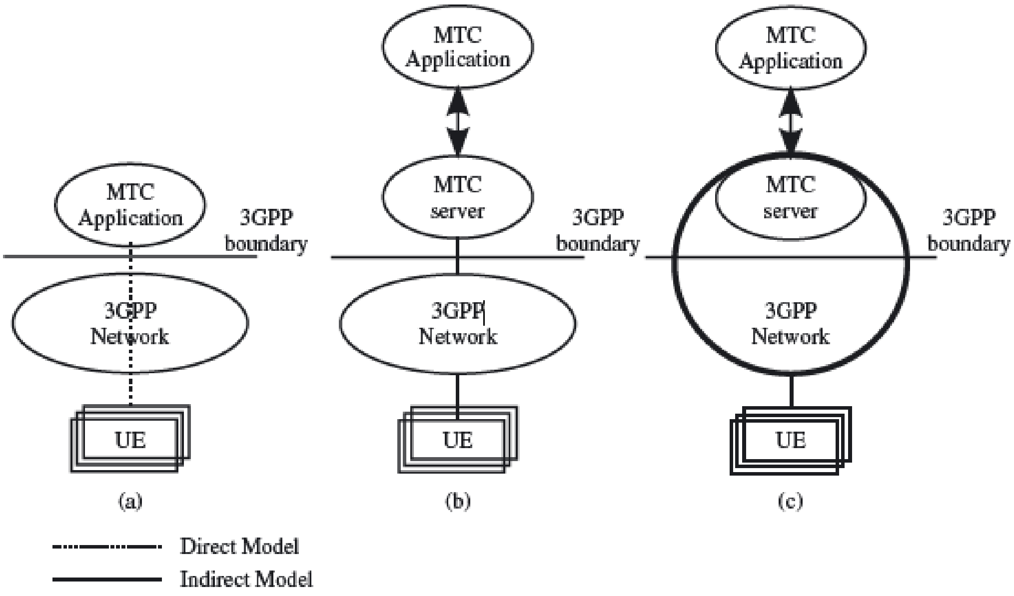

Figure 2.7 M2M scenarios [58]

2.5 General Architecture of LTE-Advanced

The LTE-Advanced architecture is similar to the LTE system except the introduction of smaller low power nodes in the LTE-Advanced. In the system architecture of the LTE-A with support for femtocell, the femtocell node, that is, HeNB can be plugged-in/off as the occasion requires. This LTE-A system architecture shown in Figure 2.8 consists of the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC).

The E-UTRAN is a radio interface and comprises of eNBs which functions as the macrocell base stations, mobile stations UEs and HeNBs which are femtocell base stations. The eNB performs radio resource management such as radio bearer control, radio admission and resource allocation to the UEs. It also performs data security and encryption over the radio interface.

The EPC consists of Mobility Management Entity (MME), Packet data network Gateway (P-GW) and Serving Gateway (S-GW) [90]. The protocol layer planes manage the UE mobility shown in Figure 2.9 and 2.10 respectively. The user-plane serves as a protocol stacked between the UE and the connected eNB and it is layered from the physical layer (PHY) at the bottom followed immediately by the Medium Access Control (MAC), then to the Radio Link Control (RLC) and Packet Data Convergence Protocol (PDCP) at the top [90]. The control plane consists of a radio resource control (RRC) which is also layered between an UE and an eNB [90]. Furthermore, a non-access stratum (NAS) protocol is located between the UE and the MME in the control plane. The MME manages the UE mobility and performs UEs tracking and paging in idle-mode. It also selects S-GW/P-GW for an UE during its first attachment to the network. Moreover, the MME performs UE's authorization to the network service provider such as the Public Land Mobile Network (PLMN) required in roaming. S-GW functions include routing and forwarding of user data packets, accounting and charging and anchor point for different handovers. The P-GWs are responsible for the IP address allocation to the UEs. It also provides the UE connectivity to external networks such as non-3GPP. It filters the downlink user IP packets and executes policy enhancement.

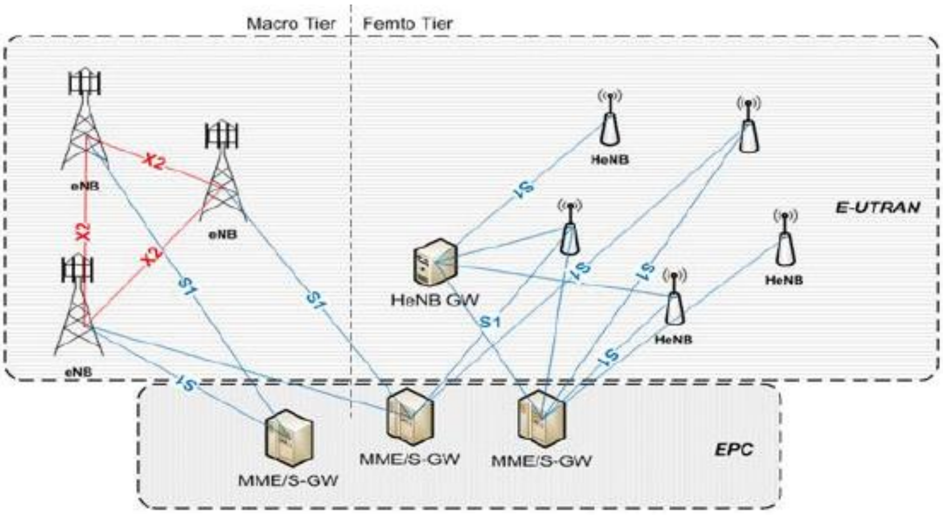

Figure 2.8 LTE-A system architecture with femtocell base station [91]

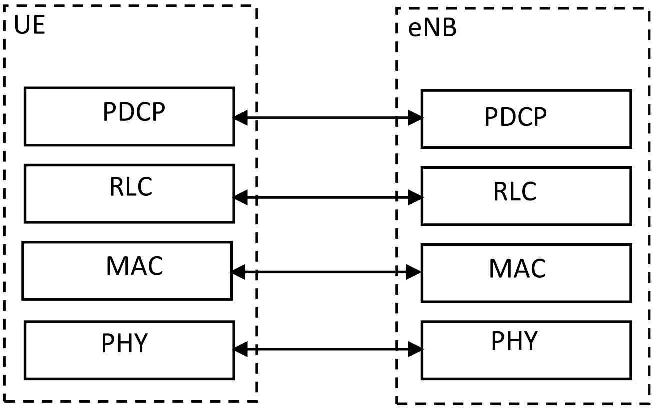

Figure 2.9 LTE-A user-plane protocol stack

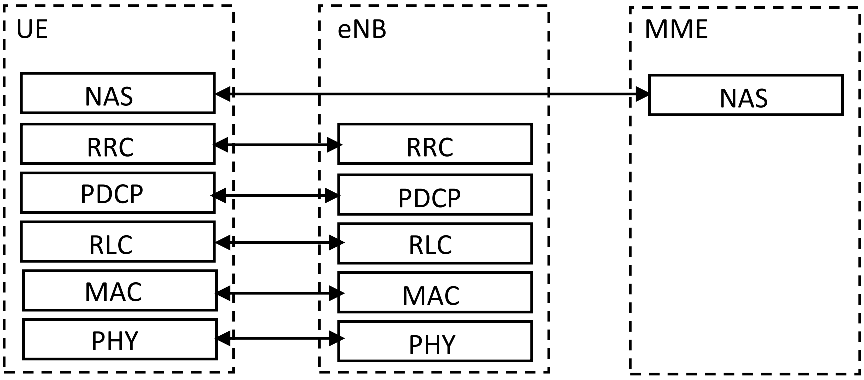

Figure 2.10 LTE-A control-plane protocol stack

2.5.1 LTE-A Protocol Layers

The LTE-Advanced protocol stack consists of a control plane and a user plane. Figures 2.9 and 2.10 show LTE-A user and control planes protocol stacks. The user plane comprises of PHY, MAC, RLC and PDCP layers [92]. The control plane consists of these four (4) layers in addition to the Non Access Stratum (NAS) and Radio Resource (RRC) layers. The function of these layers can be explained as follows.

A. **Non Access Stratum (NAS)**: NAS is situated at the uppermost layer of the control plane protocol stack that directly connects the UE to the MME and is used for control purposes [93]. Its function includes mobility management and session management functions such as establishing and maintaining the IP connectivity of the UE to the PDN. The NAS protocol also performs other functions including the Public Land Mobile Network (PLMN) selection, paging, authentication and tracking of the area update.

B. **Radio Resource (RRC) Layer**: The RRC protocol layer only appears at the control plane. It is responsible for conveying information regarding dedicated and common NAS. Dedicated NAS information concerns specific UE whereas common NAS information has to do with every UE. It also renders services like paging establishment, Signaling Radio Bearers (SRB) and handover services. In addition, the RRC can perform modification and connection release. It manages UEs' information in the RRC-IDLE such as incoming calls notification and information in the RRC-CONNECTED like channel configuration and handover information. Moreover, the RRC provides measurement configuration and Inter-RAT mobility [94].

C. **Packet Data Convergence Protocol (PDCP)**: The PDCP is found at the user and the control planes. It deals with the IP packet messages in the user plane and processes the radio resource control messages in the control plane. It provides services to both the lower layer and the upper layer. The major roles performed by the PDCP layer include header compression/decompression, ciphering and integrity protection [95]. The PDCP also provides procedures for data retransmission and reordering during handover [96].

D. **Radio Link Control (RLC)**: The RLC is a layer located between the PDCP layer and the MAC layer. It communicates with the PDCP above it via Service Access Point (SAP), and beneath with the MAC layer via logical channels [57]. This layer function includes organizing upper layer packets into different sizes for transmission over the radio interface, recovering packets losses through re-transmitting radio bearers to avoid errors and reordering packets received out of order as a result of the HARQ functionality in the layer below the RLC [97]. The RLC provides three reliability modes for data transmission; Acknowledge Mode (TM), Unacknowledged Mode (UM) and Transparent Mode (TM) [93, 98].

   1) Acknowledge Mode (AM): This is the most complex mode and the only mode for providing bi-directional data transfer. It is used for transmitting Non-Real Time (NRT) services like file downloads. It performs all the functions performed by UM and additionally retransmission of data to support error-free transmission i.e. ARQ (Automatic Repeat Request).

2) Unacknowledged Mode (UM): This mode is used for transmitting delay sensitive services that cannot wait for retransmissions such as Real Time (RT) services. However, the sequence number (SN) in the RLC packet header can be used to detect packet loss and provides packet re-ordering and re-assembling.
3) Transparent Mode (TM): This is the simplest mode because it does not tamper with the upper layer data and can be used when the size of Protocol Data Unit (PDU) is known to broadcast system information. In RLC TM, data received from the upper layers are forwarded to the underlying MAC layer and there is no additional RLC header required.

E. **Medium Access Control (MAC)**: This layer is located between the RLC and the PHY layer. In the MAC, physical and logical channels are connected to allow data transmission between the physical layer and the MAC layer. The functions of the MAC layer include multiplexing and de-multiplexing of data between the RLC and the physical layer. The function of the MAC layer also includes radio resource and information transfer scheduling between the UEs, uplink timing alignment, random access procedure and discontinuous reception [99].

F. **Physical Layer (PHY)**: The physical layer functions include frame formation, the TDD or the FDD topology and the OFDMA structure based on the BW/FFT. It is responsible for modulation and coding of different traffic and control channels. The physical layer functions also include scrambling and code-word to layer mapping. It incorporates appropriate reference signals into uplink and downlink for the channel estimation and equalization.

2.5.2 LTE-Advanced Physical Layer Descriptions

In the LTE-Advanced, different radio access technologies are used for uplink and downlink communications. In this section, we will look at the physical layer characteristics briefly. A detailed explanation of the LTE/LTE-A physical layer can be found in [100].

A. **Orthogonal Frequency Division Multiplexing (OFDM)**: The OFDM is simply a multi-carrier modulation technique used for providing high bandwidth efficiency. The OFDM was chosen in the LTE/LTE-A downlink mainly because of its simple implementation and good performance. In this technique, the frequency selective wide band channel is separated into non-frequency selective narrowband sub-channels orthogonal to each other [57]. Modulation is carried out on each sub-carrier using modulation scheme (such as QPSK, 16-QAM or 64-QAM). Orthogonality simply implies that the maximum of one sub-carrier is at the minimum of the next sub-carrier thus removing inter-symbol interference (ISI) [63]. The division also makes each sub-carrier nearly flat fading. The OFDM suffers from high Peak to Average Power Ratio (PAPR). The OFDM time domain symbols are taken as Gaussian waveform leading to a very high amplitude variation. This resulted in distorted signal from non-linear power amplifiers. Power amplifiers with large operating point are required to remove this distortion. The OFDM is also sensitive to carrier frequency offset and time varying channels. Loss of orthogonality causes blurring of information signals and degrades communication.

B. **Orthogonal Frequency Division Multiple Access (OFDMA)**: The OFDMA is defined as an access scheme which is based on the OFDM principle to organise and distribute scarce radio resources among several UEs at the same time thus enabling multi-user communication [101]. The OFDM carriers with different frequencies and Discrete Fourier Transform (DFT) are applied to create orthogonal subcarriers. In the LTE/LTE-A, the OFDMA as a downlink access technology, can be used in the downlink to deliver high data rate and high spectrum efficiency [102]. It divides the bandwidth into multiple narrow, mutually orthogonal subcarriers and then transmits the data in parallel streams. With the OFDMA, fading and interference are improved. The OFDMA like the OFDM, however, suffers from high Peak to Average Power Ratio (PAPR) that reduces the efficiency of transmitter RF power amplifier. Thus, to save the UE battery, the OFDMA is not used in uplink direction.

C. **Single Carrier Frequency Division Multiple Access (SC-FDMA)**: The LTE/LTE-A uses the SC-FDMA technology in the uplink because it enables the power amplifier in the transceiver antenna to be used efficiently [101]. This prolongs the battery life of the UEs. Another advantage of using the SC-FDMA for uplink transmission is its lower PAPR which reduces power amplifier cost for mobile users [103]. It also provides all the benefits of the OFDM. Like in the OFDM, the bandwidth in the SC-FDMA can be divided into multiple parallel sub-carriers and by using the Cyclic Prefix (CP), orthogonality between the subcarriers can be maintained thereby, eliminating Inter-Symbol Interference (ISI) in the SC-FDMA information blocks. It should be noted that in the OFDM, each subcarrier is modulated individually by data symbols to represent the amplitude of each sub-carrier at a time by each constellation point of digital modulation whereas in the SC-FDMA, all the data symbols are combined linearly, transmitted and modulated to a given subcarrier at the same time through a process called single carrier scheme of the SC-FDMA [57]. Implementation of the SC-FDMA is done in time and frequency domains. Implementation in the frequency domain is preferred in the LTE because it is more bandwidth efficient than implementing in the time domain [104]. Figure 2.11 shows the frequency domain implementation of the SC-FDMA. Details on the SC-FDMA signal generation in the frequency domain using the Discrete Fourier Transform Spread-OFDM (DFTS-OFDM) can be found in [57, 105].

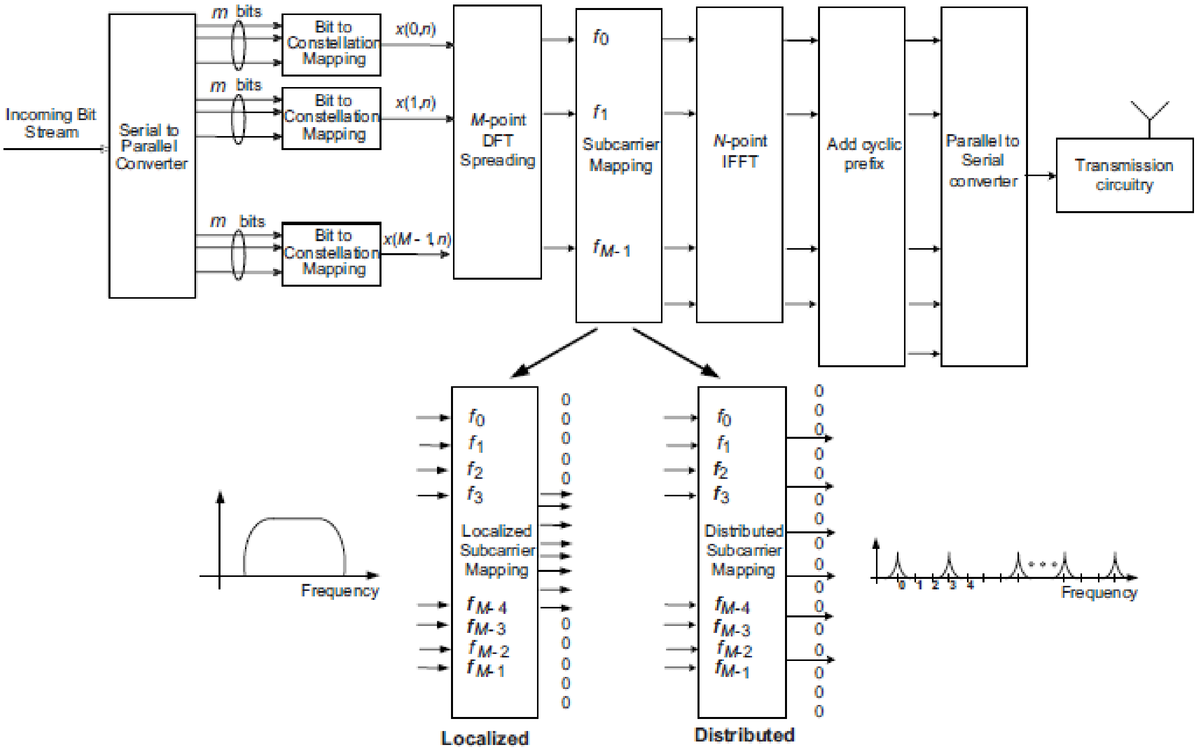

Figure 2.11 SC-FDMA Implementation in frequency domain [57]

2.6 Handover Techniques

Handover is required to maintain seamless connectivity during the UE transitioning from one cell or base station to another [106]. Handover involves transferring an ongoing voice or data call from one base station (BS) to another due to user mobility or when the signal received from the serving base station becomes low. The call transfer can also occur between two sectors belonging to the same BS. The handover algorithm or strategy is required to handle the handover decision in such cases. Generally, a handover will be executed based on the handover' procedure or statement specified in the algorithm. Like in most wireless networks, the handover algorithm with multiple data transmission points as per each UE is a necessity in the LTE-A networks [59]. Handover can be classified into: "intra cell and inter cell" handover; and "hard and soft handover".

2.6.1 Intra cell vs inter cell handover

For the intra cell handover, the source and the target base stations belong to the same cell. In this way, there is no change of the cell during the process of transferring calls. Inter cell handover on the other hand, requires that the source and the target base stations be located on the different cells. They can, however, be located on the same cell-site [91]. These handovers are sometimes called horizontal (intra technology) and vertical (inter technology) handovers. Horizontal handover occurs between the same radio access technology, that is, handover of the UE from one cell to another cell within an LTE system. Whereas vertical handover takes place between different radio access technologies, that is, between the WiMAX network and the LTE network [107].

2.6.2 Soft vs Hard Handover

Handover can also be classified as soft and hard handover as depicted in Figure 2.12 and Figure 2.13 respectively. In the soft handover also referred to as make-before-break, the UE continues using the resources in the source base station together with the resources in the target base station. This is to ensure that the connection to the target base station has been established before breaking from the source base station. The soft handover can be said to be a state in the ongoing communication rather than an event [91]. Some parallel connections can exist where by signals from each connection are coalesced to provide a stronger one for transmission. In the hard handover, the UE first releases the channel with the source base station completely before engaging the channel in the target base station [108]. Thus, the UE initial connection with the source base station is broken before making connection to the target base station. Unlike the soft handover, the hard handover is referred to as an event in ongoing communication which requires the least processing by the network [91].

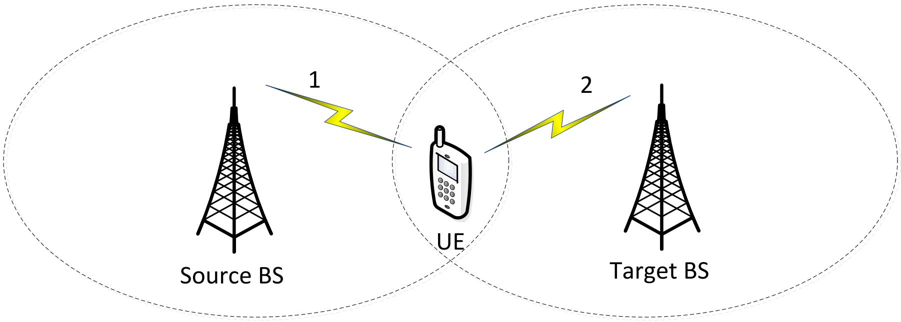

Figure 2.12 Soft handover

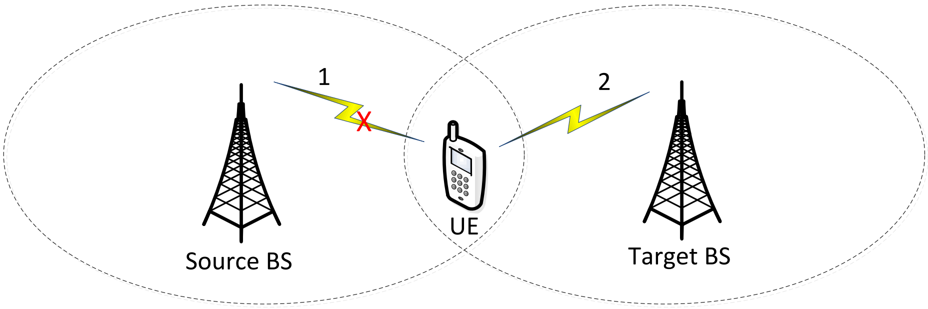

Figure 2.13 Hard handover

The handover type in the LTE-Advanced network is purely the hard handover. It is very simple compared to the soft handover. However, the hard handover usually experiences high data loss, frequent disruption and high outage probability as well as carrier interferences which lead to unpredictable handover procedures more especially for the broadband applications and multimedia services [109]. In addition, maintaining the QoS requirements in the hard handover is very difficult. Therefore, to provide fast and seamless access to the broadband applications and multimedia services with very little delay required by the LTE-Advanced network, several other handover techniques like the Fractional Soft Handover techniques (FSHO), semi-soft handover and multicarrier handover have been proposed in the literature for the LTE-A [109]. All these techniques were introduced to the LTE-A to increase the reliability of handover in the LTE-A systems.

Since the focus of this research work is on the handover management strategies for the LTE-Advanced, in the next chapter we will discuss the admission control strategy that can be used at the handover initiation stage to determine the availability of the resources in the LTE-A femtocell-macrocell integration.

2.7 Chapter Summary

This chapter discussed the theoretical background of this work. The key approaches available in literature to reduce frequent handovers and a number of target cells in the LTE-Advanced heterogeneous networks were reviewed. Enabling technologies such as Enhanced Carrier Aggregation, Enhanced MIMO, CoMP Transmitter and Receiver, Relay, Self-Organising Network, Enhanced ICIC for HetNets for LTE-Advanced as well as LTE-Advanced architecture were presented. The handover technique, which is a key operation in the LTE-Advanced for UE to maintain connectivity during communication was also presented. Brief introduction to the heterogeneous network and the different access modes of smaller cells was given. Important contributions of macrocell, picocell, femtocell and relay as constituents of heterogeneous network were noted in this chapter. Other important areas in this research work have also been introduced in this chapter.

CHAPTER THREE

HANDOVER INITIATION AND ADMISSION CONTROL

3.1 Introduction

The handover Initiation is the first stage of the three stages of handover procedure in LTE-Advanced network. Handover execution and handover completion are the other two stages. In this chapter, our focus is on the admission control during the handover initiation stage. We examine how the resources are determined at the handover initiation stage and thus propose an efficient CAC strategy to allocate resources to the UEs during handover. At the handover initiation stage, the source SeNB/HeNB makes handover decision to transfer UE's calls (or services) to target T-HeNB/eNB based on certain measurement reports and available radio resource information. Based on the reports, the SeNB/HeNB requests handover to the T-HeNB/eNB. This is followed by the exchange of necessary signalling information between the SeNB/HeNB and the T-HeNB/eNB via X2 interface. To guarantee that the resource is available to the UE, the T-HeNB/eNB performs admission control. After determining that the resource is available, the T-HeNB/eNB sends the handover response to the SeNB/HeNB.

At the handover execution stage, the SeNB/HeNB issues a handover command message to the UE to start the handover execution. The UE starts synchronizing with the T-HeNB/eNB for radio connection establishment. At this time, an uplink data path is created between the T-HeNB and the UE. To indicate the completion of radio connection set up, the UE sends a handover (HO) confirmation message to the T-HeNB/eNB.

The handover completion stage concludes the handover procedure. This stage involves the T-HeNB/eNB sending path switch request messages to the HeNB-GW [110], which forwards the messages to the MME/S-GW for downlink data path set up completion. The MME on receiving the message sends path switch acknowledgement to the HeNB-GW which forwards it to T-HeNB/eNB. The T-HeNB/eNB upon receiving the path switch acknowledgement sends a resource release message to the HeNB-GW. The HeNB-GW notifies the MME/S-GW about the resource release which also informs the SeNB/HeNB. This signifies the end of the handover procedure and the SeNB/HeNB completely releases the UE resources as shown in Figure 3.1.

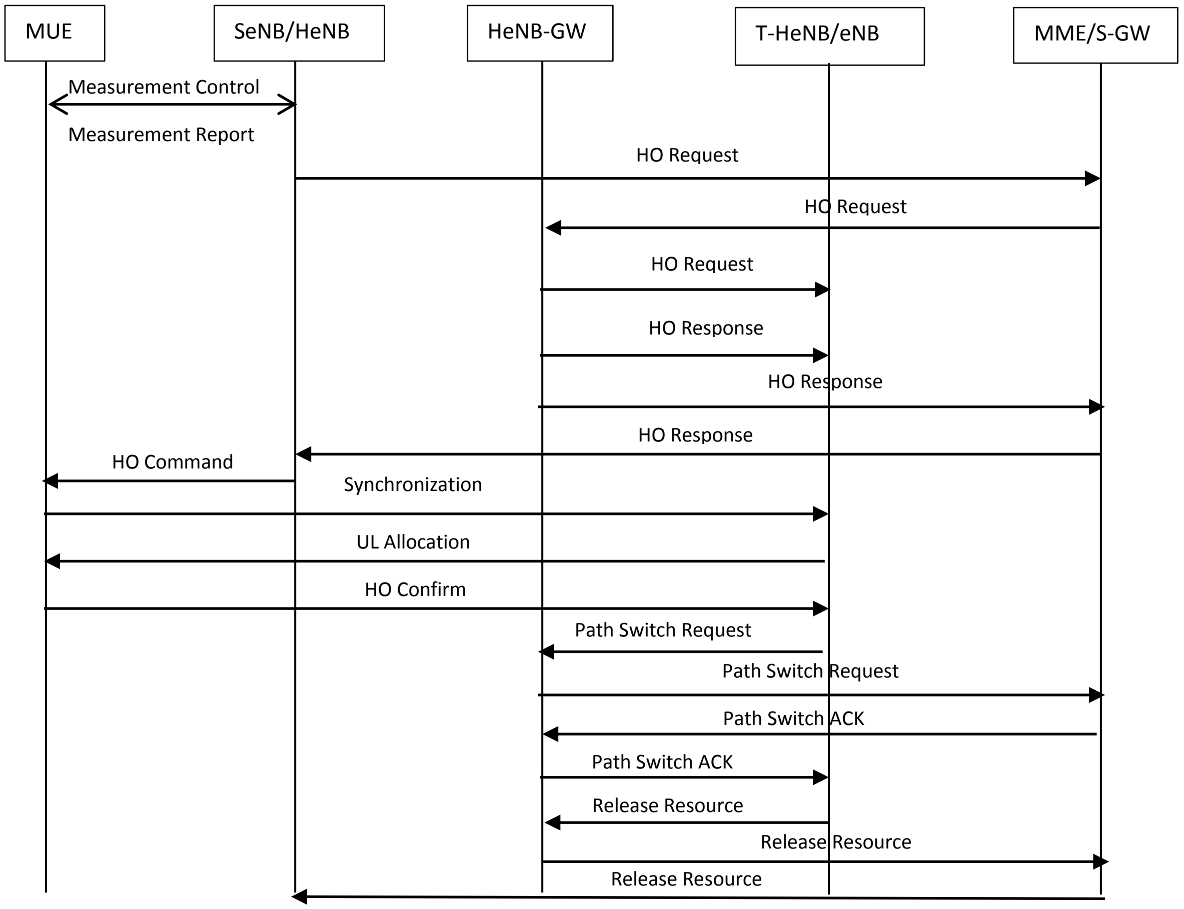

Figure 3.1 LTE-A femtocell-macrocell handover procedure [111]

3.2 Admission Control in Handover Initiation Stage

Admission control is required to know if a UE's call or service will be admitted or rejected, to know the amount of resources to allocate to the UE in the target cell and to determine whether existing sessions need to be stopped or not to admit new calls. Calls (new or handover) can be accepted only if there are enough bandwidth resources available in the target cell. Because of its importance during handover, we will first examine how the admission control can provide QoS to user equipment (UE) in the LTE-A. Admission control is needed to achieve load balancing across the different cells in LTE-A networks. This is especially so for small cells with different access modes where regulation of incoming calls plays an important role in achieving QoS to the UEs served by the small cells. The different access modes explained in chapter two can serve the different UE types. For example, the open access mode can serve the mobile UEs within its range. Closed access mode can serve pre-registered UEs while hybrid access can provide registered UEs with higher priority (that is, high QoS) and then non-registered UEs with the resources remaining after traffic transmissions scheduling of the registered UEs [111]. With an efficient admission control strategy in place, more UE calls can be admitted into the network with good QoS. Different traffic types can be assigned different priority levels to accommodate more calls with stringent QoS. To achieve this, a channel borrowing admission control scheme for femtocell-macrocell in the LTE-A networks are proposed in this chapter.

Admission control is more complex in a mobile environment than in a fixed environment because in a mobile environment some bandwidths are reserved to admit handover calls. In a fixed network, admission control is simply based on the resources available and the new calls quality of service requirements. However, in the mobile network, if there are fewer handover calls compared to the reserved bandwidths, then the reserved resources are underused or wasted. If there are more calls than the reserved bandwidth, the handover may be dropped. The system’s resources are distributed to the UEs using a minimum and a maximum threshold value. The following parameters can be considered when designing the call admission control.

A. **Resource availability**: New call and handover call can be accepted into the system based on the resources available. The network load is considered when designing the call admission control scheme. Some decisions can be made to admit certain calls using the resource reservation method.
B. **Network parameters quality**: The quality of network connection is very important in establishing interference free connection. Usually, the link between the network components is evaluated using received signal strength (RSS). Each element in the network is tested to know their quality requirements. This is taken into consideration during the design of the call admission scheme.
C. **Quality policies**: Resource utilization, throughput and delay are some of the examples of parameters used to determine the QoS of a network. Traffic can be analysed to determine the parameters which leads to network performance degradation. In addition, network traffic conditions can be predicted to meet up with service requirements.
D. **Call prioritization**: Calls can be classified into new and handover calls with the handover call having higher priority to the new call. Each of this calls can be further divided into the real time and non-real time calls. The highest priority is given to real

time calls while the non-real time receives the lowest priority. Reservation and queuing schemes can be employed to prioritise different call types.

E. **Mobility management**: Mobility of the UEs (that is, speed of UEs) is put into consideration to lower call dropping and call blocking probabilities. This is useful in predicting the UE’s movement towards a particular base station. It also helps to determine the call request type (that is, new call or handover call), thereby leading to efficient resource allocation.

F. **Optimization methodologies**: Optimization can be performed to enhance the performance of the call admission process. The complexity in the call admission procedure and in determining parameters for every call request given the threshold value can be reduced by the optimization method.

Generally, admission control schemes in cellular networks can be classified into: prioritized and non-prioritized admission control schemes as illustrated in Figure 3.2. In the prioritized admission control, priority is given to the calls with stringent QoS by allocating a guard (fixed or dynamic) channel to them. This scheme can be further broken down into reservation, call queuing and channel borrowing scheme. In contrast, in the non-prioritized admission control, no priority is given to any call, that is, new calls and handover calls are handled exactly the same way [112]. More discussion on prioritized and non-prioritized admission control has been given in [113].

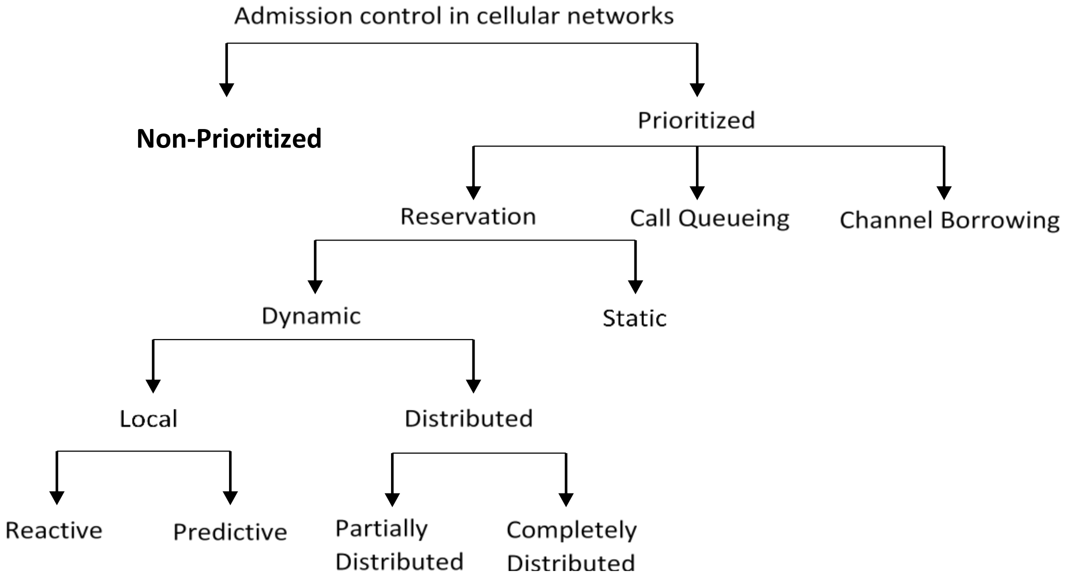

Figure 3.2 Call admission control [113]

Various CAC strategies in literature favoured allocating more channels to the UE calls with high priority such as the handover calls and guaranteed bit rates. A dynamic guard channel [114] prioritized different services to reduce probability of the dropping handover calls. Similarly, the QoS of handover calls was guaranteed in [112] by using a priority-based resource reservation scheme. A scheduler algorithm proposed by *Kosta et al*. [115] assigned the highest priority to the guaranteed bit rate (GBR) services to improve their performance. The performance of non-guaranteed bit rate (NGBR) services was also improved. The QoS of some real-time services like videoconference, multimedia traffic was guaranteed using a reserved CAC scheme based on the account balance of the customer.

Chowdhury et al. [116] reveal that the fixed guard channel scheme can reduce the dropping probability of prioritized calls and services. However, this was at the expense of the system's utilization and blocking probability. This proved further that the fixed guard channel scheme generally results in inefficient use of the network resources. To utilize the network resources better, dynamic schemes have been proposed in literatures. For instance, *Vergados, and Cruz-Perez et al*. [117, 118] propose strategies to reclaim some of the bandwidth resources of already admitted less priority calls for the high priority calls to utilize. However, these strategies can disrupt the ongoing handover call, as there was no means of differentiating handover calls from the new calls. *Alagu and Meyyappan* [119, 120] introduced the channel borrowing idea to the guard channel to admit more new calls but like [117, 118], the schemes did not differentiate the different call types.

In this chapter, we propose a channel borrowing admission control strategy for femtocell-macrocell integrated in the LTE-A networks. The uniqueness of this strategy is that first: the strategy differentiates handover calls from the new calls; secondly, real time (RT) call is differentiated from the non-real time (NRT) call. Finally, NRT new calls can make use of the reserved channel for handover calls when it is not being used by the handover calls. In addition, the pre-emptive method was employed so that the reserved channel can be used by handover calls at any time.

3.3 System Model

The system model for femtocell access point (FAP) deployment in the LTE-A network is shown in the Figure 3.3. The UE located within the macrocell coverage is equipped with a dual interface so that it can communicate with both macrocell and the femtocell respectively. Femtocells are also located within the coverage of the macrocell. The UE initially connected to FAP are represented by the FUE and the ones connected to the macrocell initially by the MUE. The femtocell and macrocell coverage areas are given as A_f and A_m respectively. Calls are generated randomly within the macrocell coverage area. A call placed within the femtocell coverage has a probability of $P = A_f/A_m$ since the femtocells are located within the macrocell coverage. A call placed outside the femtocell coverage has a probability of $1-P$.

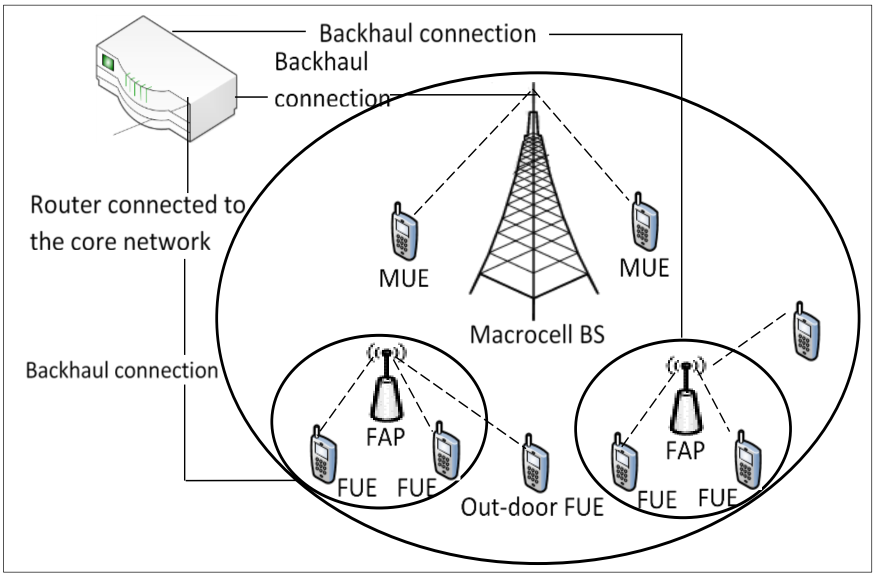

Figure 3.3 System Model for FAP deployment in LTE-A Network

We assumed that the LTE-A operates at 2 GHz and uses a frequency-division duplex (FDD) with 10 MHz bandwidth for the uplink and downlink. The new call arrival rate λ_n, and handover call arrival λ_h follows Poison distribution. The macrocell total channel capacity C_T is divided into different channels in bandwidth units. Where C_T represents the physical resource blocks in LTE/LTE-A networks allocated to the calls in a cell [121].

3.3.1 Proposed CAC with borrowing strategy

We assumed that there are two types of UE calls: (i) new originating calls and (ii) handover (HO) calls. The new originating calls can be further divided into: Real Time (RT) and Non-Real Time (NRT) calls or services. The RT services can include real time gaming and video conferencing while NRT services include web browsing and non-real time video. Since it is more desirable for ongoing calls to be maintained than the new ones, the handover call is given the highest priority by allocating a dynamic reserved channel to it as shown in the Figure 3.4. Also, since the QoS of NRT services are less stringent compared to the RT services, the NRT services can be delayed for a considerable time as opposed to RT services that requires very little or no delay [121]. Therefore, we employed the channel borrowing strategy to the reserved channel such that whenever the reserved channel is not being used or fully used, the new originating NRT services can make use of it. However, when the handover services are available, the new originating NRT services are pre-empted by the handover services thus forcing it to wait in the queue until the bandwidth resource is available.

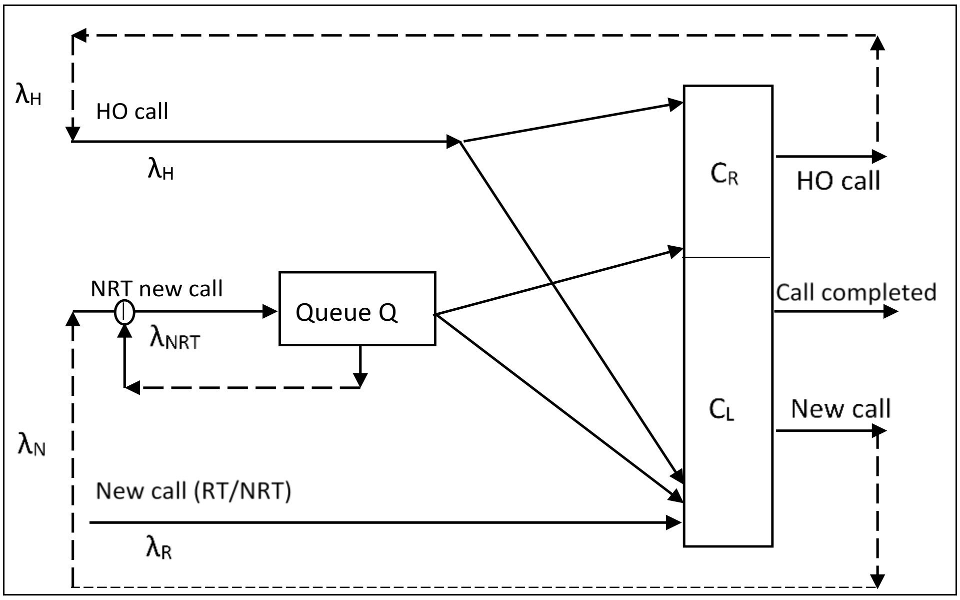

Figure 3.4 Channel borrowing CAC strategy

3.3.2 Procedure for the Proposed CAC scheme

Whenever a new originating call (RT/NRT) arrives in the LTE/LTE-A macrocell coverage area A_f, the new call first checks if the femtocell resources are available. If the resources are available, the call is accepted into the femtocell. If not, the call tries to connect to the macrocell if the bandwidth resources are available in the macrocell unreserved channel (C_L). The proposed strategy for accepting calls into the macrocell illustrated in Figure 3.4 can be described as follows. If the bandwidth resources are not available in the unreserved channel $C_{L,}$ the traffic type is determined. If the new originating call is NRT and the reserved channel C_R is not fully utilized, then this channel will be borrowed and used by the NRT new originating call; otherwise, the call is blocked. For the handover calls, we have: femtocell-to-femtocell, femtocell-to-macrocell, macrocell-to-femtocell and macrocell-to-macrocell handover calls. When the call (RT/NRT) is femtocell-to-femtocell/macrocell-to-femtocell handover call, the call is connected to the femtocell if there are available resources in the femtocell. Otherwise, the call is dropped. However, the operation differs from femtocell to macrocell or macrocell-to-macrocell handovers. It is more difficult to perform handover from femtocell/macrocell to femtocell due to the large number of target femtocells whereas in femtocell/macrocell to macrocell, only one or few macrocells are involved.

The handover calls from the femtocell or macrocell can be connected to the unreserved channel C_L or to the reserved channel C_R. If the C_R is being used by the NRT new originating call and the C_L is fully occupied, the HO call pre-empts the service of NRT call to make use of the C_R. The connected NRT new calls are kept in the queue and make use of the C_R again whenever it is free. The NRT new originating call operation can be delayed for some time since it is not delay sensitive. The size of the queue at time, 't' is denoted as $X(t)$ and the NRT new call will be blocked if $X(t) > 0$. The essence of this proposed strategy is that it will utilize the network resources efficiently which eventually leads to reduced total blocking probability of the new originating calls. In the same vein, the reservation of the channel for handover calls is crucial for a good QoS of handover calls.

Since the total channel (in terms of bandwidth) is C_T, the reserved bandwidth for the handover calls is C_R and the remaining bandwidth for both new calls and handover calls is C_L, let the number of HO calls, new RT and new NRT calls be denoted as N_h, N_r and N_n respectively, then we have the following:

(a) A HO call will be dropped if $N_h + N_r + N_n \geq C_T$ and $N_h \geq C_R$

(b) A HO arrival will be accepted if $N_h + N_r + N_n \geq C_T$ and $N_h < C_R$ by pre-empting nRT call.

(c) An RT arrival will be blocked if $N_h + N_r + N_n \geq C_T$ or $N_r + N_n \geq C_T - C_R$ (i.e. C_L)

(d) An NRT will be blocked if $x(t) \geq 0$ and $N_h + N_r + N_n \geq C_T$

3.4 Performance Evaluation of the Proposed CAC Strategy

As shown in the Figure 3.4, of all the three types of calls, only the pre-empt NRT calls can be in the queue. The proposed model is a mixed loss-queuing system which is very difficult to analyse mathematically. Consequently, we propose two estimation methods which can be analysed mathematically by solving the global balance equation for each method.

3.4.1 System Estimation 1 (SE1)

In this estimation method, it is assumed that the pre-empt NRT calls return to make use of the reserved channel after they have been displaced by the HO calls. If *p(N_h, N_r, N_n)* is the steady-state probability of state (N_h, N_r, N_n) in the proposed CAC strategy, then the arrival rate to the queue can be given as follows:

$$\lambda_h \sum_{\substack{N_h+N_r+N_n=C_T \\ N_h<C_R}} p\left(N_h, N_r, N_n\right) \tag{3.1}$$

where $\sum_{N_h < C_R} N_h + N_r + N_n = C_T\, p\left(N_h, N_r, N_n\right)$ is the probability that the system is in the state that all the channels used by the HO calls is less than C_R. λ_h is the HO calls arrival rate. If the queue is removed, then the arrival rate of the NRT calls (λ_{NRT}^{new}) can be modified as:

$$\lambda_{NRT}^{new} = \lambda_{NRT} + \lambda_h \sum_{\substack{N_h+N_r+N_n=C_T \\ N_h<C_R}} p\left(N_h, N_{r,} N_n\right) \tag{3.2}$$

Where λ_{NRT}^{new} is determined by the state probabilities and the arrival rate λ_h of HO calls.

From the system estimation method above, a three-dimensional Markov chain can be obtained as follows:

$$S = \left\{\left(N_h, N_r, N_n\right) \mid N_h, N_n \geq 0{,}0 \leq N_r \leq C_T - C_R, N_h + N_r, N_n \leq C_T\right\} \tag{3.3}$$

The transition rates for the Markov chain of this estimation can be given as follows [122]:

$$
\begin{aligned}
&q\left(N_h, N_r, N_n; N_h, N_r, N_n - 1\right) = N_n \mu_n \left(0 \leq N_h < C_T, N_n > 0{,}0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n \leq C_T\right)\\
&q\left(N_h, N_r, N_n; N_h, N_r, N_n + 1\right) = \lambda_{NRT}^{new} \left(0 \leq N_h < C_T, 0 \leq N_r \leq C_T - C_R, N_h + N_r + N_n < C_T\right)\\
&q\left(N_h, N_r, N_n; N_h, N_r - 1, N_n\right) = N_r \mu_{RT} \left(0 \leq N_h, < C_T, 0 < N_r \leq C_T - C_R, N_h + N_r + N_n \leq C_T\right)\\
&q\left(N_h, N_r, N_n; N_h, N_r + 1, N_n\right) = \lambda_{RT} \left(0 \leq N_h, < C_T, 0 \leq N_r, + N_n, < C_T - C_R, N_h + N_r + N_n < C_T\right)\\
&q\left(N_h, N_r, N_n; N_h - 1, N_r, N_n\right) = N_h \mu_h \left(0 < N_h, \leq C_T, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n \leq C_T\right)\\
&q\left(N_h, N_{r,} N_n; N_h + 1, N_r, N_n\right) = \lambda_h \left(0 \leq N_h < C_T, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n < C_T\right)\\
&q\left(N_h, N_r, N_n; N_h + 1, N_r, N_n - 1\right) = \lambda_h \left(0 \leq N_h < C_R, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n = C_T\right)
\end{aligned}
$$

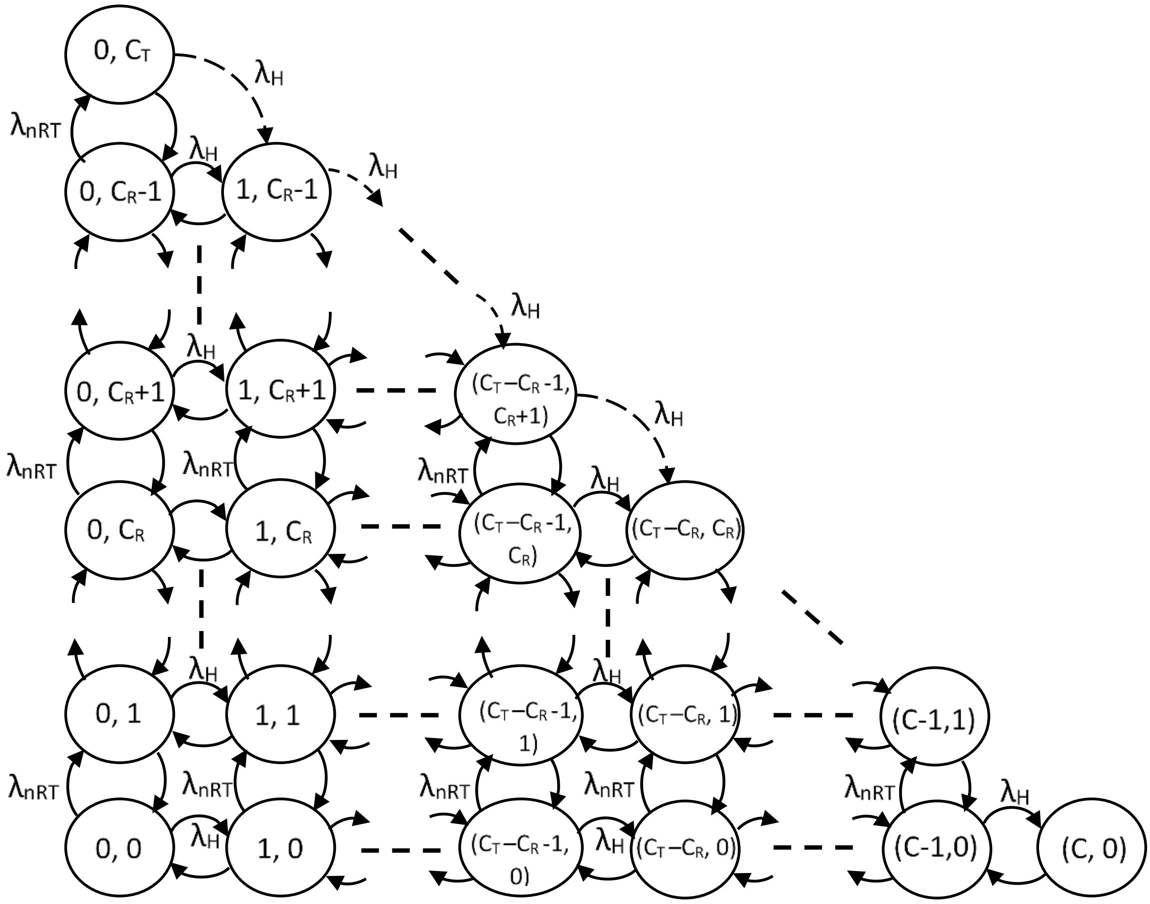

Figure 3.5 Markov chain for the channel-borrowing strategy

A three dimensional Markov chain can be used to model a three state system. For instance, the HO calls, RT new calls and the NRT new calls represent the three systems we are dealing with in this research work. It is, however, difficult to mathematically solve a three-dimensional Markov chain like this. Hence, a two-dimensional Markov chain which is easy to analyse, is used in this research work to model a two-state system. We assume our system to be two-state (that is, NRT new calls and HO calls) as against the original three state. The Markov chain for this system (that is, two-state system) is time-reversible and can be solved using global balance equations. However, our assumption of the two-state system will not affect the channel borrowing idea as it can be applied without the RT calls. The state diagram of the two-dimensional Markov chain for the system estimation 1 is illustrated in Figure 3.5. The arrival rate of the NRT calls is represented by λ_{NRT} and the handover calls as λ_H. By using the global balance equations method in [122], the two-dimensional Markov chain can be solved numerically. Since λ_{NRT} is a function of the system's state, therefore, we use new NRT arrival rate instead of the normal NRT value in the global balance equations. This resulted into non-linear equations that can be solved using non-linear solvers.

To substantiate this fact, the new NRT arrival rate is represented by $\lambda^{new}_{NRT,}$ and is used in the global balance equations of the state (0, C_T) as follows:

$$p(0,C_T)(\lambda_H + C_{T\,\mu H}) = p(0,C_T - 1)\lambda^{new}_{NRT} = \lambda_{NRT}\,p(0,C_T - 1) + \lambda_H \sum_{n_1+n_2=C_T\,(n_1<C_R)} p(0,C_T - 1)p(n_1,n_3) \tag{3.4}$$

The term $p(0,C_T - 1)p(n_1,n_3)$ contains multiplicative terms which made the above equation non-linear. For example, the size of this equation increases rapidly as C_T increases. In other to resolve the equation into linear equations, the system's estimation 2 is used.

3.4.2 System Estimation 2 (SE2)

In this estimation, $\lambda^{new}{}_{NRT} = \lambda_{NRT.}$ Unlike the system estimation 1, it is assumed that the pre-empt NRT calls are dropped and will not return to make use of the reserved channel. The output of this estimation method yielded linear balance equations because the arrival rate of the pre-empt calls determine the accuracy of the system. Since system estimation 2 resulted in linear equations, which can be solved efficiently within a smaller time, it can, therefore, be useful in large systems with high number of channels.

The performance evaluation of the proposed CAC with the channel strategy is compared with the existing strategy without channel borrowing using the following metrics: call-blocking probability (CBP), call dropping probability (CDP) and resource utilization. The CBP is defined as the probability of rejecting new calls due to little or non-availability of the radio resources. The call dropping probability (CDP) is defined as the chances that an ongoing call will be dropped due to insufficient radio resources or handover failure. The resource utilization is the ratio of the number of resource blocks used in a cell (that is, macrocell) during the whole system's operations to the maximum load capacity of the cell.

We first show the comparison in the results of the two estimation methods using global balance equations. For the two system estimations, the global balance equations can be solved mathematically to obtain CBP and CDP as follows:

$$CBP = \Bigg(\sum_{(N_h, N_r, N_n): N_r + N_n \supseteq C_t - C_r} \frac{\lambda_{RT}}{\lambda_{RT} + \lambda_{NRT}^{new}} + \sum_{(N_h, N_r, N_n): N_r + N_n \supseteq C_T - C_R} \frac{\lambda_{NRT}^{new}}{\lambda_{NRT}^{new} + \lambda_{RT}} + \sum_{\substack{(N_h, N_r, N_n): N_r + N_n \subset C_T - C_R \\ N_h + N_r + N_n = C_T}} \Bigg) p(N_h, N_r, N_n) \quad (3.5)$$

$$CDP = \sum_{\substack{(N_h, N_r, N_n): N_r + N_n \subset C_T - C_R \\ N_h + N_r + N_n = C_T}} p(N_h + N_r + N_n) \quad (3.6)$$

These global balance equations can be solved using MATLAB with C_T and C_R assumed to be *16* and *8* respectively. The parameter used for the numeric analysis of the two estimations is indicated in Table 3.1.

Table 3.1 Parameter for Numerical Analysis

Parameter	**Value**
Total number of channels (C_T)	16
Reserved channels (C_R)	8
Service rate (μ_H, μ_R, μ_N)	1
λ_{RT}	0.5
λ_H	0.5 * i
λ_{NRT}	0.5* i (i.e. i = 1,2…..10)

The obtained results for CBP and CDP are shown in Figure 3.6 and Figure 3.7 respectively. It is noticed that the system estimation 2 performs better than the system estimation 1 with reference to both CBP and CDP because the pre-empted NRT calls are dropped in system estimation 2. This lowers the NRT load as well as the overall load in the system. Consequently, fewer numbers of calls can be blocked and dropped in the system estimation 2.

The system estimations were used to obtain values for CBP and CDP in the mixed loss queueing system used in the proposed channel borrowing strategy because the CBP and CDP cannot be easily obtained through analytic means from the mixed loss queueing model. We have also employed simulations to obtain CBP, CDP as well as resource utilization and then compared the results in the following sections.

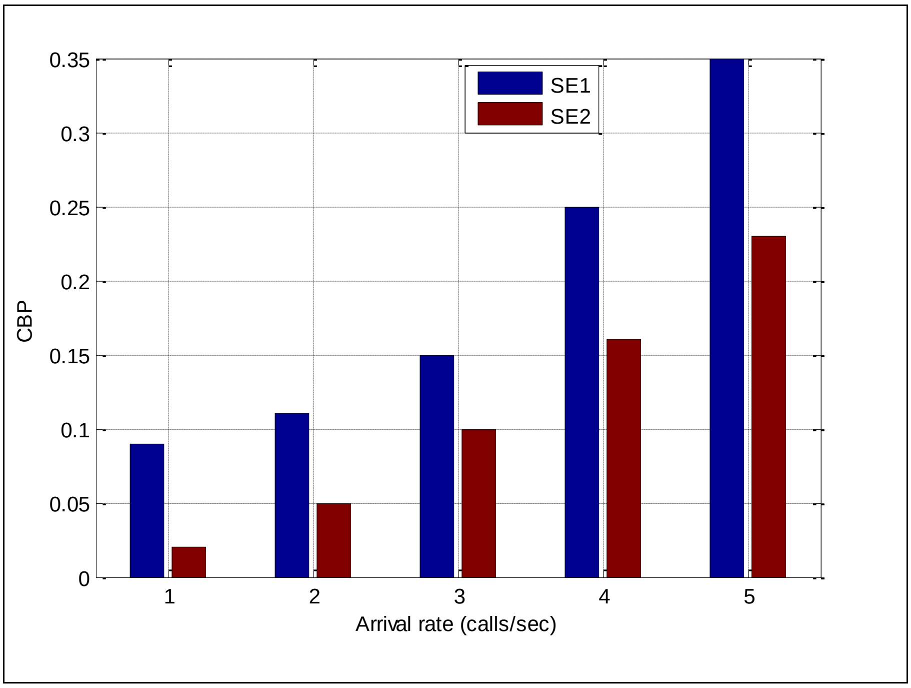

Figure 3.6 Total Call blocking probability for system estimations

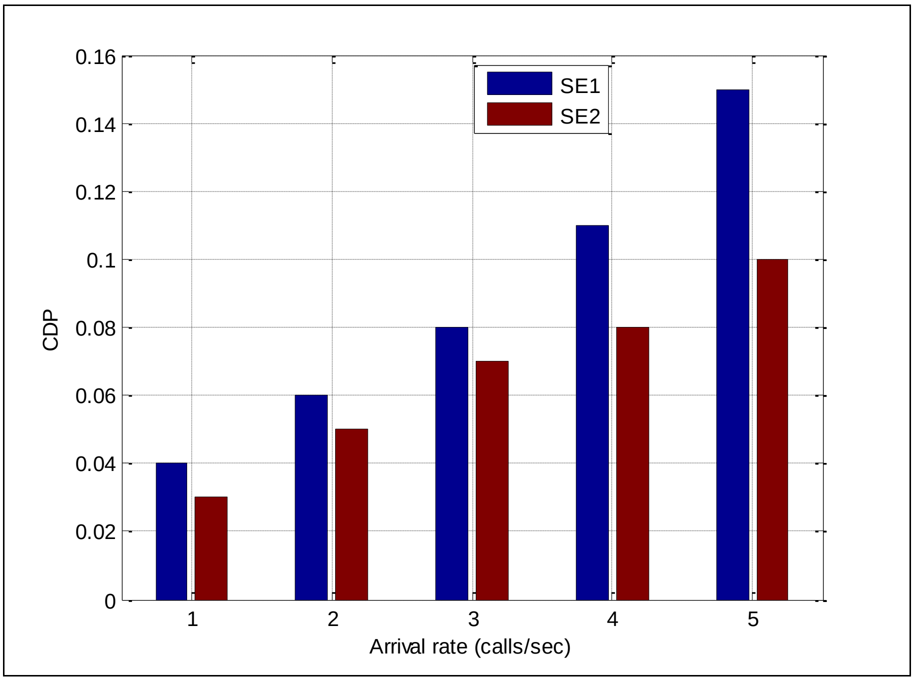

Figure 3.7 Total Call dropping probability for system estimations

3.5 Results and Discussion

The proposed CAC with channel borrowing strategy is evaluated and compared with the existing strategy without the channel borrowing scheme. The simulation parameters are as shown in the Table 3.2.

The simulation result of call blocking probability for both the existing strategy and the proposed strategy is as shown in Figure 3.8. We assumed that the existing strategy is the one without channel borrowing scheme as discussed in reference [114]. This strategy is simulated and evaluated together with our proposed strategy. In the existing strategy where channel borrowing is not employed, to admit more handover calls, part of the channel is reserved for the handover calls to guarantee a reduced handover blocking probability. New originating calls, therefore, suffered in the process as the resources are not being utilized effectively. The new originating calls (RT and NRT) only have access to the remaining non-reserved channels. In the proposed strategy, however, the channel borrowing strategy has been employed to increase the number of new originating calls while also guaranteeing reserved resources for the handover calls.

For instance, more NRT calls will be accepted into the unused reserved channel while keeping the pre-empted ones in a queue. The pre-empted NRT calls resume making use of the channel as soon as it is available. Therefore, the overall call blocking probability of the new calls is considerably reduced. In Figure 3.8, the proposed strategy reduces the call blocking probability by about 10% of the existing strategy for every traffic load. The proposed strategy was able to accept newer NRT calls while allowing handover calls to use the resources anytime.

The simulation result of the call dropping probability is presented in Figure 3.9 for both the existing strategy and the proposed strategy. The CDP though initially lower in the proposed strategy than the existing strategy owing to the lower traffic, however, as the traffic increases CDP becomes a bit higher in the proposed strategy than in the existing strategy. This is because fewer handover calls can now use the unreserved channel. Here, the increase in CDP is very insignificant compared to the high performance gain recorded in terms of CBP with the proposed strategy. The difference in CDP, which is only noticeable as the traffic increases, is less than 1%.

Table 3.2 Simulation Parameters

Parameter	**Value**
Radius of the Enb	500 m
Radius of HeNB	15 m
Power of Enb	46 mW
Power of HeNB	20 mw
Macrocell Bandwidth capacity	10 Mbps
Number of users	Varies
Initial number of users in a femtocell	4
Mode access of femtocell	Open/closed
Ues mobility model	Random WayPoint
UE speed	Varies
Average call duration	150 seconds

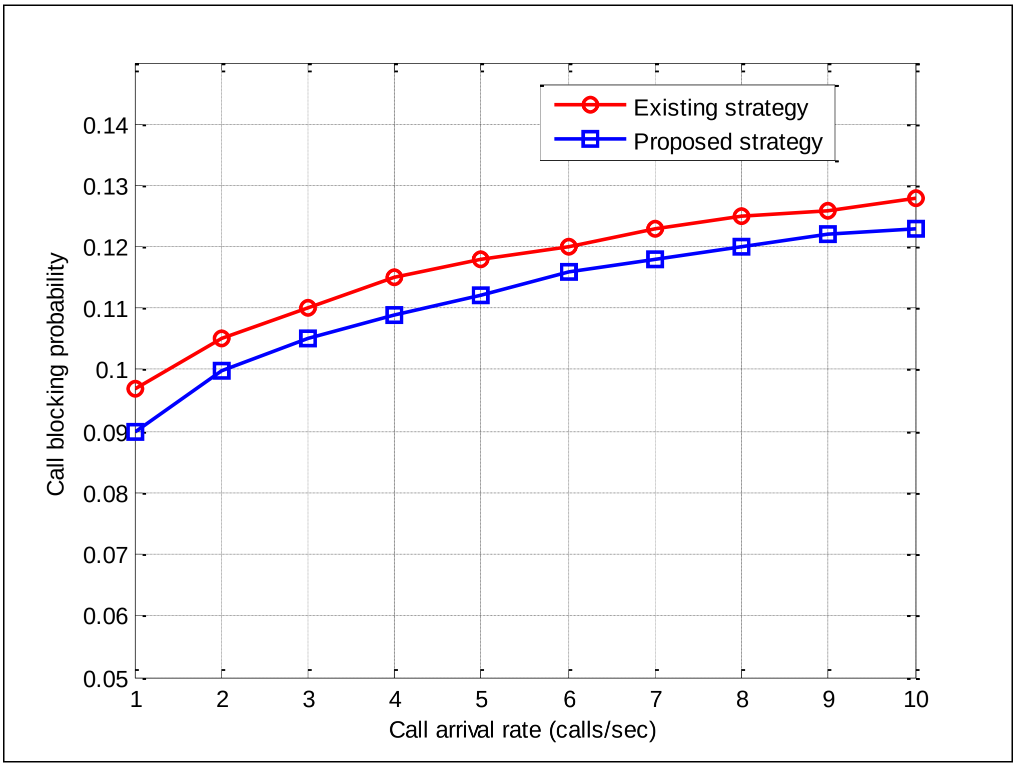

Figure 3.8 Total Call blocking probability

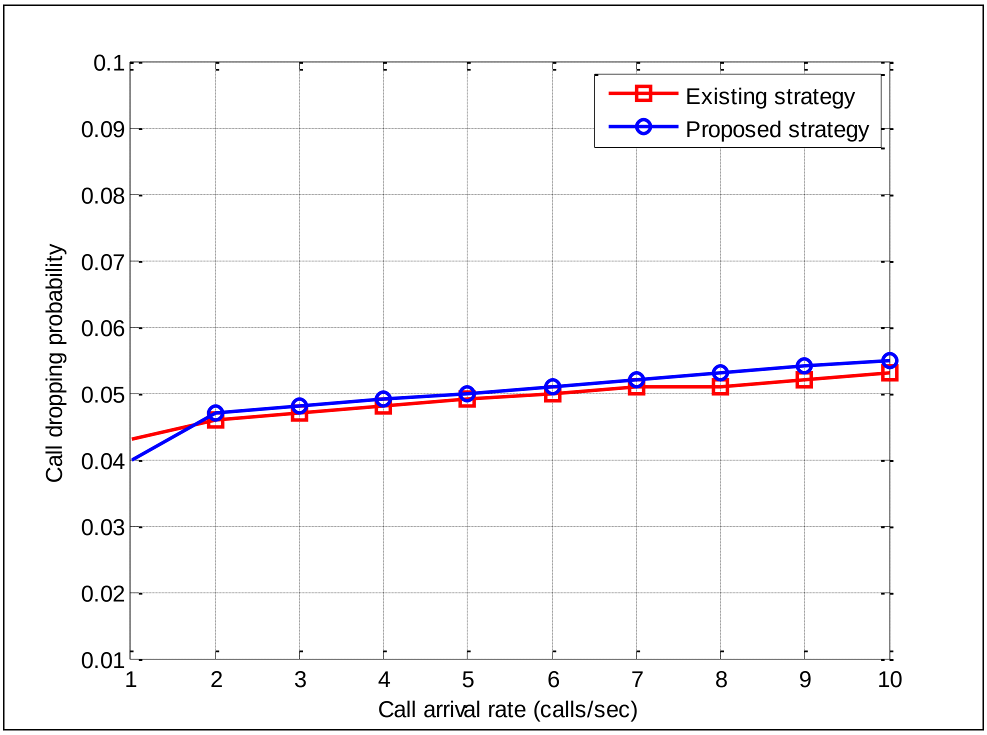

Figure 3.9 Total Call dropping probability

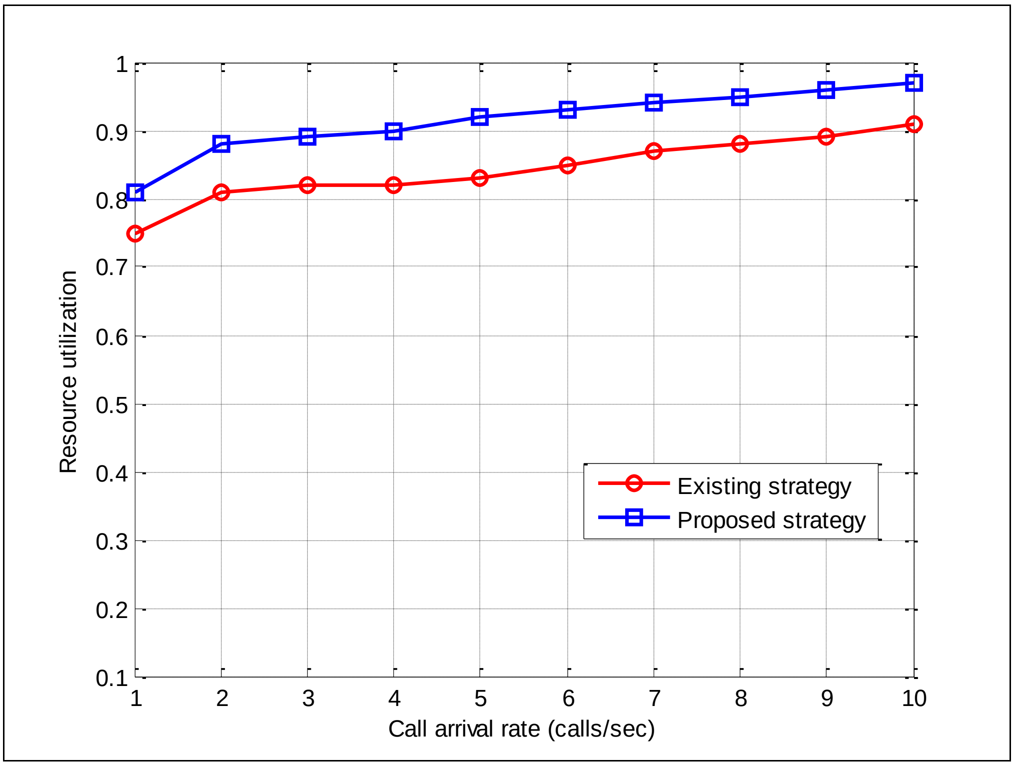

Figure 3.10 Resource utilization

The simulation result of the resource utilization for both the existing the strategy and proposed strategy is as shown in Figure 3.10. An improved performance in the resource utilization can be noticed with the proposed strategy. In the existing strategy, the resource utilization is worse than the one of the proposed strategy because of the fixed channel reserved for the handover calls and when there is no handover call, the reserved channel is not used, thus resulting in the entire channel resources being under used. With the proposed strategy, channels are used effectively by ensuring that whenever there are no handover calls, the reserved channels are used by the NRT new originating calls. This increases the resource utilization by about 10%. In summary, the proposed strategy outperforms the existing strategy in terms of system resource utilization.

3.5.1 Comparison of Analytical and Simulation Results

The values of CBP and CDP obtained mathematically by solving global equations 3.5 and 3.6 can be validated by comparing them with the values obtained through the simulation of the actual mixed loss-queueing model as follows.

Since we have established that, System Estimation 2 yielded linear equation and performed better than System Estimation 1 in terms of CBP and CDP. Therefore, we show the accuracy of the analytic results of Estimation 2 by comparing the CBP and CDP obtained from the simulation of the actual mixed loss-queueing model of the proposed channel-borrowing scheme with those obtained through mathematical derivation of the Estimation 2. By using the same parameter as in Table 3.1 and the same channel capacity (that is, $C_T = 16$ and $C_R = 8$), the results of the analytic evaluation of System Estimation 2 show closeness in terms of CBP and CDP with the simulation results as shown in Figure 3.11 and Figure 3.12 respectively. Since close results are obtained from the simulation and the analytic models, we, therefore, conclude that the System Estimation 2 is very useful in determining CBP and CDP values for the mixed loss-queueing model in the proposed channel-borrowing scheme.

3.5.2 Traffic Analysis of the New NRT calls and the Handover Calls

In this section, we further the analysis of the new NRT calls blocking probability and the handover call dropping probability as a function of the traffic loads. Recall that under the two dimensional Markov chain in system estimation 2, λ_{NRT} and λ_H represent the arrival rates for the new NRT calls and the handover calls respectively. Where $1/\mu_{NRT}$ is average channel holding time for the new NRT calls, $1/\mu_H$ is average channel holding time for the handover calls.

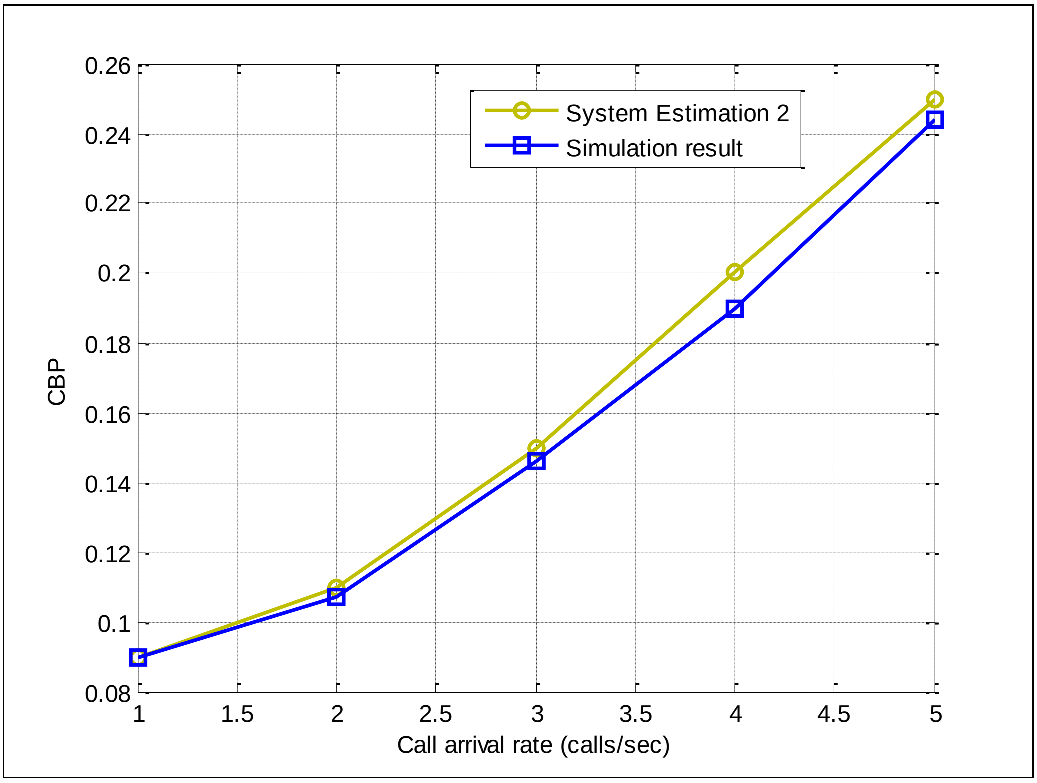

Figure 3.11 CBP System Estimation 2 vs Simulation Result

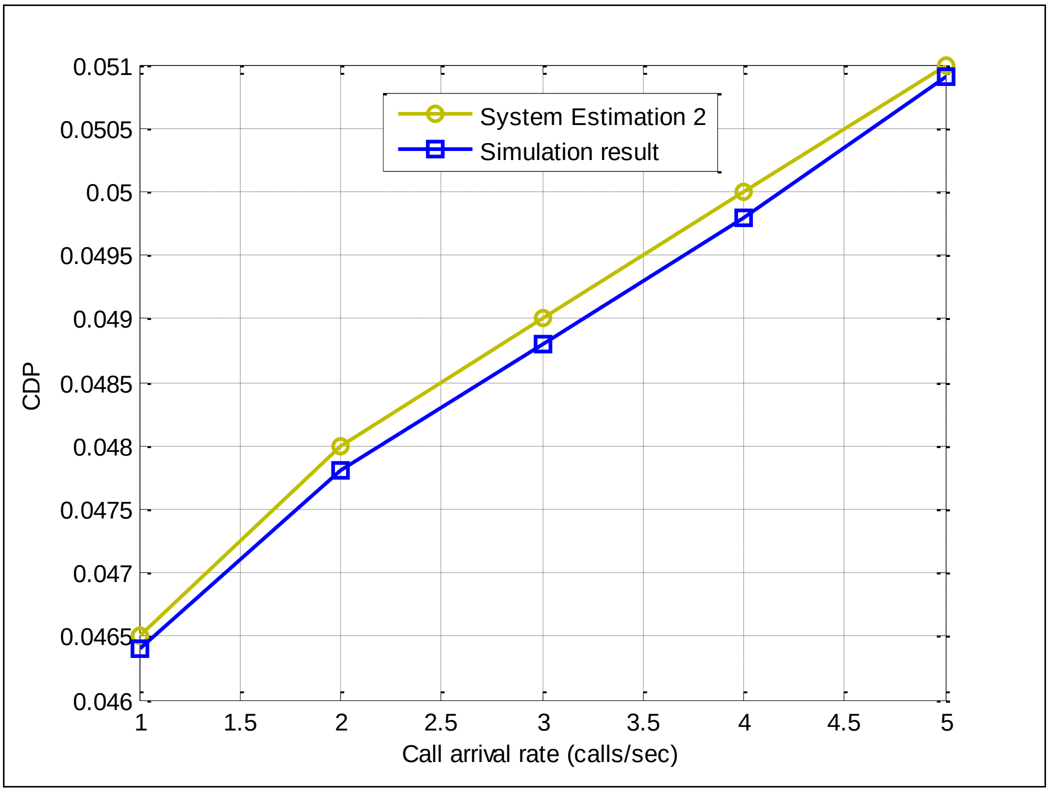

Figure 3.12 CDP System Estimation 2 vs Simulation Result

Let $\rho_{N=}\frac{\lambda_{NRT}}{\mu_{NRT}}$ = NRT new call traffic intensity and $\rho_{H=}\frac{\lambda_{H}}{\mu_{H}}$ = handover call traffic intensity P_K^n = represent the probability of k busy channels in steady state (k = 0, 1, ……..C_T), and C_T is as defined previously.

If k < q, the new NRT call is accepted, where q = threshold upon a new call arrival. Therefore,

$$p_k^q = \frac{\left(\rho_N + \rho_H\right)^q PO}{k} \quad \text{for } k \leq q$$

and

$$p_k^q = \frac{\left(\rho_N + \rho_H\right)^q P_H^{k-q}}{k} \quad \text{for } q+1 \leq k \leq C_T$$

Then

$$PO^q = \left[\sum_{k=0}^{q} \frac{\left(\rho_N + \rho_H\right)^K}{k!} + \sum_{k=q+1}^{C_T} \frac{\left(\rho_N + \rho_H\right)^q \rho_H^{k-q}}{k!}\right]^{-1} \tag{3.7}$$

From the above, the new NRT calls and the handover call blocking probabilities can be obtained as follows:

$$PB_N^q = \frac{\sum_{k=q}^{C_T} \frac{\left(\rho_N + \rho_H\right)^k \rho_h^{k-q}}{k}}{\sum_{k=0}^{q} \frac{\left(\rho_N + \rho_H\right)^k}{k!} + \sum_{k=q+1}^{C_T} \frac{\left(\rho_N + \rho_H\right)^q \rho_H^{k-q}}{k!}} \tag{3.8}$$

$$PB_H^q = \frac{\frac{\left(\rho_N + \rho_H\right)^q \rho_H^{C_T-q}}{C_T}}{\sum_{k=0}^{q} \frac{\left(\rho_N + \rho_H\right)^k}{k!} + \sum_{k=q+1}^{C_T} \frac{\left(\rho_N + \rho_H\right)^q \rho_H^{k-q}}{k!}} \tag{3.9}$$

where PB_N^q is the NRT new call blocking probability and PB_H^q is the handover blocking probability.

The results of the proposed strategy are presented and compared with the existing strategy by determining the NRT new call blocking probability and the handover call blocking probability. By using table 3.1, Figure 3.13 shows the graph of new call blocking probability versus the call traffic load. It is shown from the graph that when the traffic load is high, the blocking probability increases for both the proposed strategy and the existing strategy. However, this occurs at a much higher rate in the existing strategy than the proposed one. This is as envisaged because the proposed strategy allows the channel to be used more effectively thereby reducing the number of blocked new NRT calls.

The graph of the handover call dropping probability versus the call traffic load is as shown in Figure 3.14. In both the existing and the proposed strategies, there are no call drops when the traffic is very low because the channel has not been fully utilized. As the traffic becomes larger, the call dropping probability increases but at a higher rate in the existing strategy than in the proposed strategy. This is because the proposed strategy allows the channel to be reclaimed by the handover calls and thereby reduce the number of drop calls. As shown in the graph, the value of the call dropping probability when the traffic load is 15 is about 0.04 for the existing strategy and around 0.06 for the proposed strategy. This shows that the proposed strategy performs better than the existing strategy in terms of reducing the handover dropping probability.

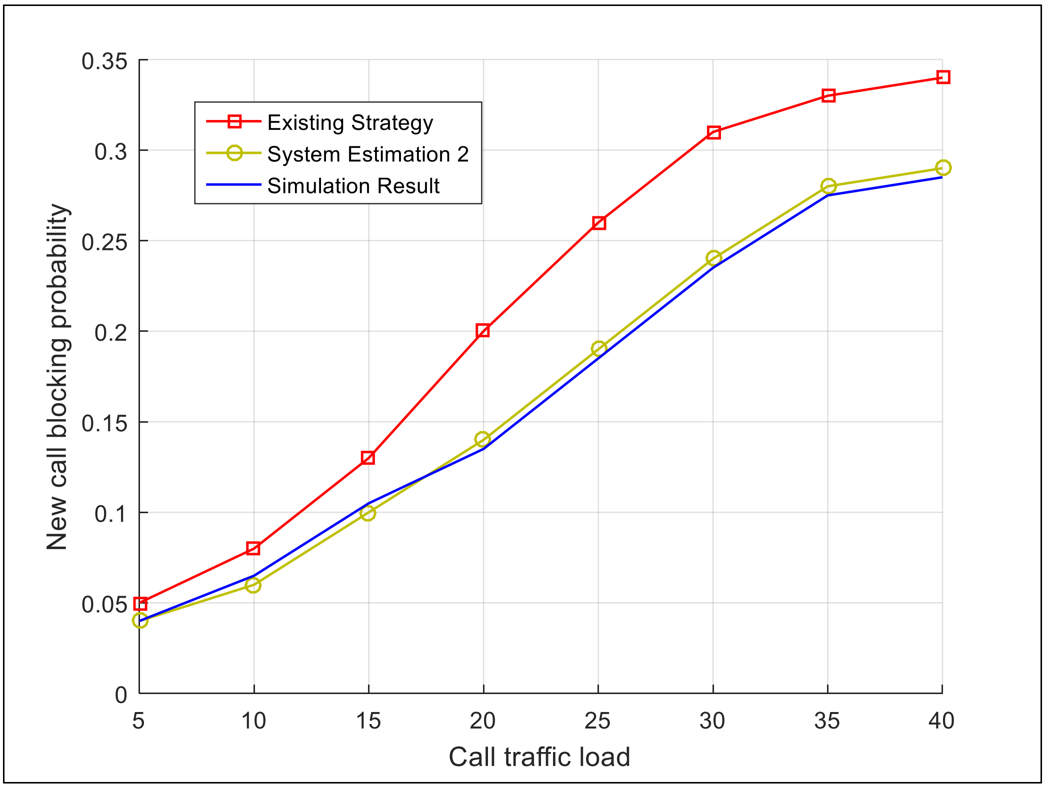

Figure 3.13 New Call Blocking Probability vs Call Traffic Load

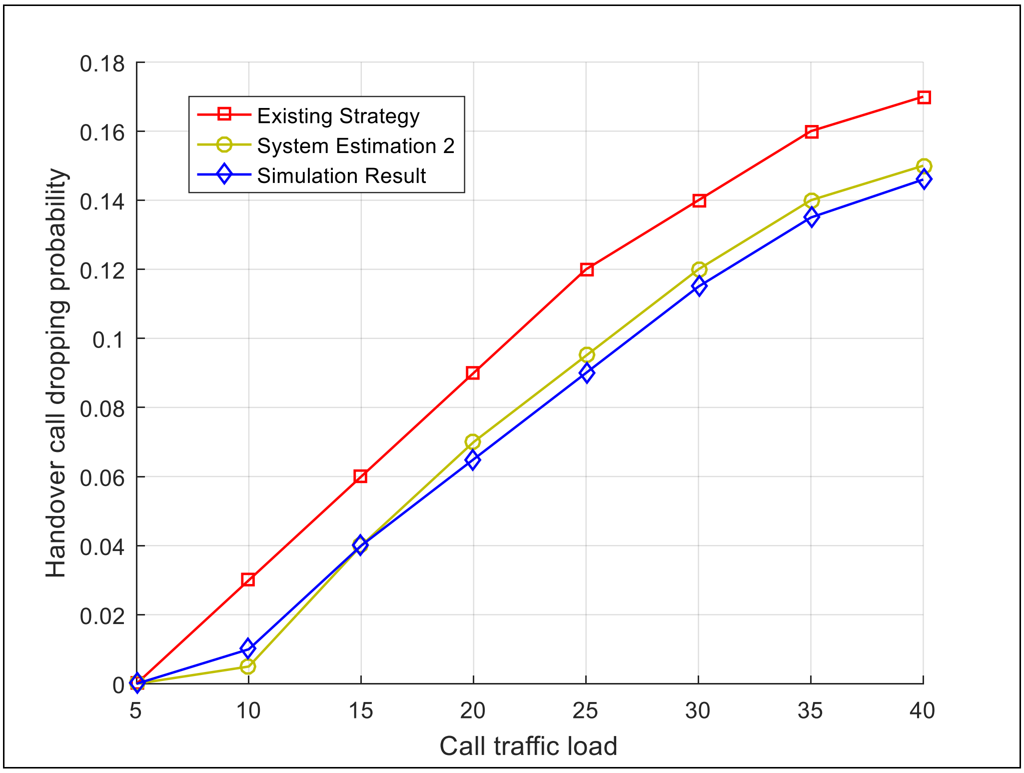

Figure 3.14 Handover Call Dropping Probability vs Call Traffic Load

3.6 Chapter Summary

In this section, a channel borrowing call admission control strategy has been proposed for the femtocell-macrocell LTE-A networks to manage the UE calls efficiently and to ensure that the channels are used effectively. We started by looking at the parameters for designing call admission control schemes and then proposed our strategy. In our strategy, the channel resources reserved for the handover calls in the macrocell can be borrowed by the NRT new originating calls. On the arrival of handover calls, the ongoing NRT call is pre-empted and stored in a queue to use the channel later when it is available. The channel-borrowing strategy is modeled using a mixed-loss system with two system estimations proposed. In terms of the call blocking probability and the call dropping probability, the system estimation 2 performed better than the system estimation 1. From the simulation results, we showed that when comparing the proposed strategy with the existing strategy, the proposed strategy performed better with respect to call blocking probability and system utilization while there is a very little drop in the call dropping probability. Also, we validated our analytical evaluation by comparing the analytic results with the simulation results.

CHAPTER FOUR

HANDOVER MANAGEMENT IN FEMTOCELL-MACROCELL LTE-A NETWORK

4.1 Introduction

In the LTE-A integrated network, femtocells form a two-tier network with macrocell to offload traffic from the macrocell. This results in improved performance and enhanced quality of service of both macrocell and femtocell users. In LTE-A, a femtocell is positioned in a way that enables it to operate independently of the type of backhaul and connect to an operator's network through internet connection thus eliminating the cost associated with deployment of huge macrocells [40, 42, 123]. A Femtocell provides cost-efficient ways of enhancing the capacity of the cellular system as well as improving the performance especially at the cell edge. As low-cost, low power and energy-efficient base stations, they can be easily installed and managed [124]. In 3GPP, the femtocell base station is known as the Home E-node B (HeNB) and provides the Radio Access Network (RAN) functions [38, 125].

This chapter focuses on the deployment of femtocell base stations within a macro base station with the aim of providing a solution to handover problems resulting from the integration of these two base stations. Thus, the main contribution of this chapter is to propose an efficient handover management algorithm in two-tier femtocell-macrocell in the LTE-A network. The proposed management scheme reduces the unnecessary increase in the number of handovers and the target femtocells in the network. A handover is considered unnecessary whenever the UE moves back and forth from one macrocell or femtocell to another within a very short time. We also investigate the effect of varying the number of deployed femtocells in the network. In addition, we look at the challenges facing the deployment of femtocells in the LTE-Advanced in this chapter.

4.2 Femtocell challenges

A major challenging issue in femtocells is its small coverage area which often leads to a typical increase in handover in high dense deployment. This can further lead to a very frequent handover and ping-pong effect. Other challenges include interference between femtocells and macrocells, power management, mobility management, mode of operation, timing and synchronization, power management and security.

4.2.1 Access mode challenge

The different modes of femtocells have been discussed in chapter two. A femtocell access point (FAP) owing to its short coverage can provide services for a limited number of UEs. A Femtocell deployed openly provides services for public UEs although, few UEs can only be accommodated. This scenario results in service degradation due to the number of UEs striving to use the resources. When a femtocell is in a closed access mode which is a preferred mode installed by private individuals, the unregistered UEs nearby experiences high signal interference albeit, not having access to the femtocell resources leading to a reduction in the QoS. In [126], the hybrid access mode provides a solution to the interference management problem by allowing unregistered UEs to access the resources of the femtocell while providing services to the registered UEs. However, with this, more registered UEs can be denied access to the femtocell resources as the number of unregistered UEs increases. Therefore, as a way of eliminating this challenge, a FAP should be made intelligent to allow and give priority to the specified number of registered UEs to use the resources [127].

4.2.2 Mobility challenge

Mobility management is one of the important challenges to be addressed in the LTE-A with the femtocell access points which provide low coverage to the users. Due to the low coverage and limited radio resource of the FAP, a large number of neighbour list FAPs is recorded when UEs become mobile. Because of these large numbers of neighbours, it is very difficult to make handover decision. The handover problem can be aggravated by the different types of access mode of the femtocells (as discussed earlier in this work). Therefore, efficient handover algorithms are required to overcome mobility issues in the LTE-A femtocell network and to also ensure that the QoS of the overall network is not depreciated [128].

4.2.3 Interference management

Interference occurs when femtocells and macrocells are deployed within the same frequency band due to non-availability of unused spectrum. This is usually done to increase the spectral efficiency and the network capacity [128]. This deployment type leads to two-tier interference: conventional macro-cellular and user deployed femtocell network [129]. The two-tiered interference can be divided into co-tier and cross-tier interferences as illustrated in Figure 4.1 and Figure 4.2.

A. **Co-tier interference**: This interference arises when two FAPs located close to each other operate in the same frequency band. The resulting interference can have a colossal impact on the closed access mode than the open access mode [128]. In the co-tier interference, femto-UEs functions as the source of interference to the neighbour femtocell AP in the uplink while femtocell AP functions as the source of interference to the femto-UEs in the downlink.
B. **Cross-tier interference**: This interference arises when the macro-UEs located close to the femtocell AP transmits at high power or when femto-UEs situated close to the macro BS transmits at a low power [130]. The femto-UE acts as a source of interference to the macro BS in the uplink while the femtocell AP acts as a source of interference to the macro-UE in the downlink [131].

These interferences can be reduced by using various interference cancellation and avoidance schemes discussed in [128]. In addition, power control schemes can be used to control the noise levels among the neighbouring FAPs and or femto and macro-UEs.

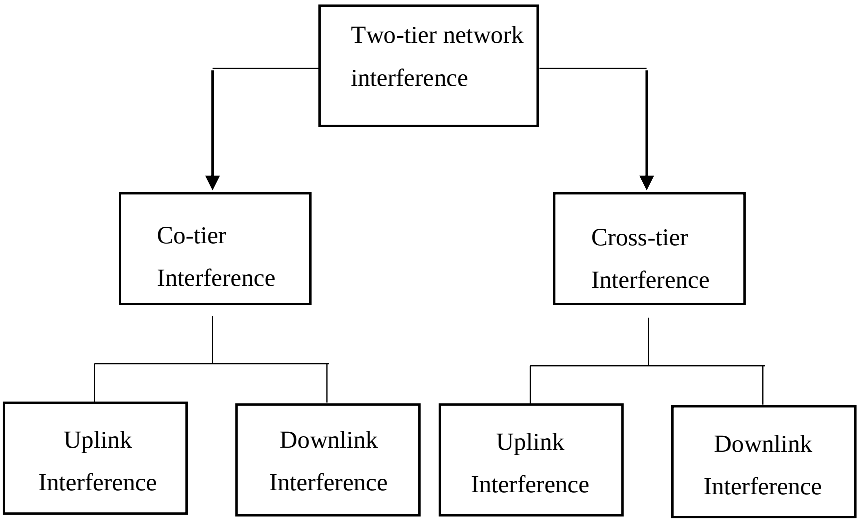

Figure 4.1 Interference in two-tier femtocell network [128]

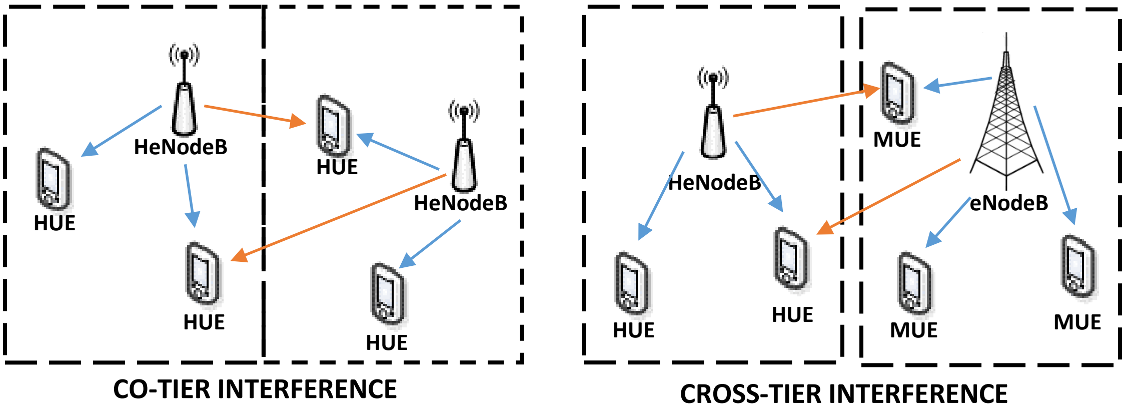

Figure 4.2 Co-tier versus cross-tier interference

4.2.4 Timing and synchronization

Timing and synchronization in the femtocell network involves network monitoring usage, tracking security breaches, event mapping, session establishment and termination [128]. In the femtocell networks, attaining time synchronization is very difficult for two main reasons: (i) as the number of femtocell increases, the network becomes denser thereby each femtocell location is unpredictable, (ii) the network provider has little or no control on the location and placement of each femtocell. Solutions to the timing and synchronization problem include incorporating a GPS receiver to the femtocell to provide subscribers with local information [128]. This help to locate and manage interference in the femtocell deployment. In addition, the femtocell can be synchronised with the core network with the help of neighbouring femtocells.

4.2.5 Security

This arises mostly when the privately owned femtocell operates in the hybrid mode. Since data traffic will be routed via the owner's internet backhaul, its confidentiality and privacy can be breached. Hackers can use the Denial of Service (DoS) attack to prevent the UEs from accessing the network by overloading the connection between the FAP and the Core Network (CN) [128]. A closed access mode also needs to be protected from unwanted users to prevent them from gaining access to the femtocell resources. The IPSec proposed in [132] can be used with the HeNB Gateway (HeNB GW) to provide a secured link between the HeNB and the core network [133]. The higher the number of deployed femtocells, the more challenging is the security of the network.

4.3 Related Studies

Handover management algorithms in two-tier femtocell-macrocell have been researched in previous studies recently. For instance, the author in [134] highlights key areas and challenges facing femtocells in the LTE-Advanced networks. Existing handover decision techniques for the femtocell-macrocell in the LTE-A were categorised. A comparative difference of the decision parameters for the handover decision algorithms was also provided. The handover decision policy studied in [38] is based on the user's mobility prediction. The movement prediction uses the Markov chain probability to determine the position and the direction of the UEs which help to reduce the handover. Horizontal and vertical handovers were studied in [39]. To remove the frequent and unnecessary handovers, the authors predicted user movements and the target FAP using Markov chain discussed in [38]. The authors in [135] propose that the femtocell should be accessed openly by all cellular users in order to achieve high data rate, improved overall network coverage and handover.

A handover mechanism based on the HeNB Policy function is proposed in [67]. The scheme which serves as a good basis for this study, considers user type, loads and femtocell access modes as metrics for determining the target femtocell for handover. Although this policy-based scheme takes the user type, access mode of HeNB and current load into consideration, there is however, no mechanism or scheme to handle different UEs' speed. In addition, the algorithm is applicable to macrocell to femtocell handover only. These are considered as the shortcomings of this scheme which we will compare with the proposed algorithm in this chapter.

In this research work, we propose an enhanced handover algorithm based on the speed of the UEs. The main idea of our work is to first reduce the number of target femtocells in the list, which automatically implies a reduction in the number of time UE calls will be transferred from one femtocell to another and subsequently a reduction in the handover number. To achieve this, the present research work considers the speed of the UEs and additionally the mode access of the femtocells, capacity of the target femto/macro station and signal after handover.

4.4 LTE-Advanced Architecture with support for Femtocell

The LTE-A system architecture in Figure 4.3 consists of the femtocell base stations and the macrocell base stations. A macrocell base station is called an eNB and the femtocell base station HeNB. The HeNBs are supported by the EPC which consists of the Serving Gateway (S-GW) and the Mobility Management Entity (MME) [38, 136]. The S-GW functions include routing and forwarding of the packets between the UEs, charging and accounting. It also acts as different anchor points for different handovers. The MME functions include managing the UE access and mobility, the UE bearer path creation as well as performing security and authentication [4]. The LTE-A EURAN architecture also consists of the HeNB-GW which acts as concentrator for the control plane to support large numbers of the HeNBs [111]. The HeNBs and the eNBs on the other hand, perform related functions of terminating the user and control plane protocols. They provide radio control functions, admission control, paging transmission or message broadcasting, routing and scheduling data towards the S-GW [134].

In Figure 4.4, the S1 interface is set in the macrocell-femtocell interfaces together with the gateways and units. Communication takes place between the HeNB nodes and the EPC via interface S1-U and S1-MME. The HeNB GW and management system entities perform the function of relaying packets to and from the femtocell stations.

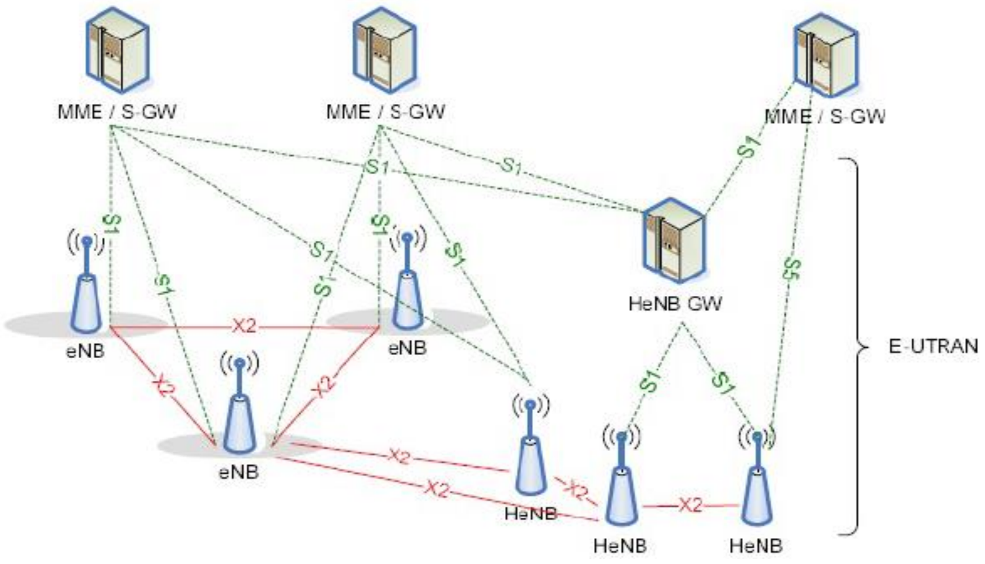

Figure 4.3 E-UTRAN architecture with Femtocells [134]

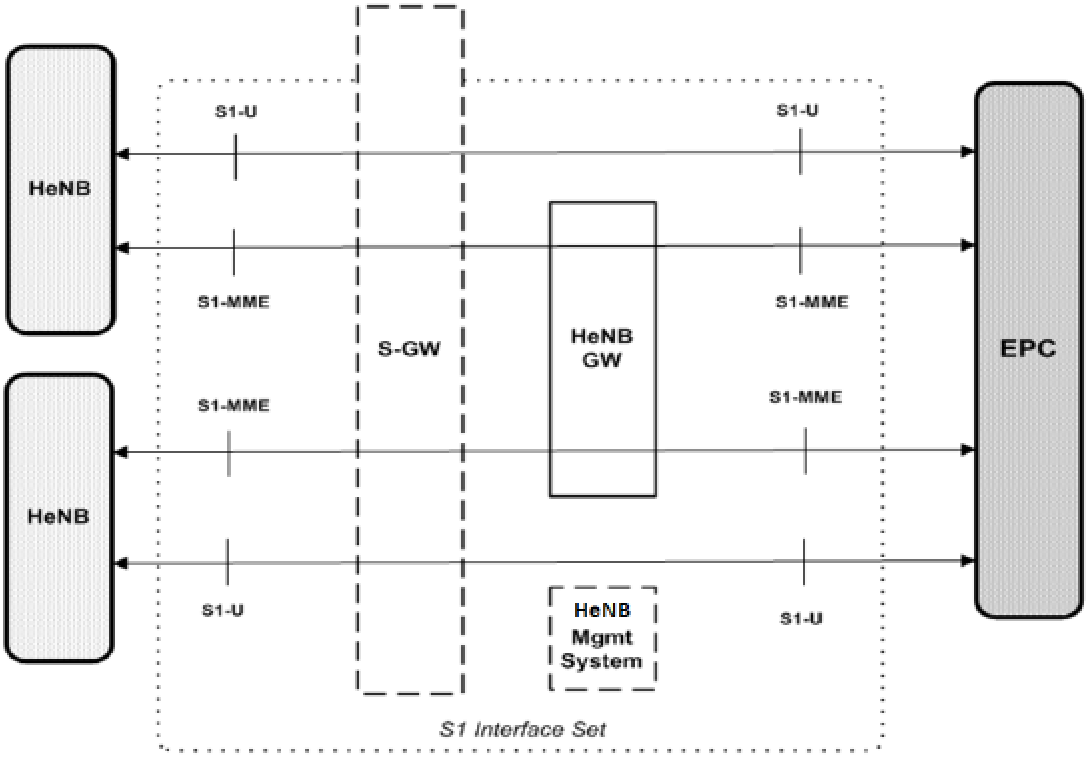

Figure 4.4 Macrocell-Femtocell Internal Interfaces for handover process [91]

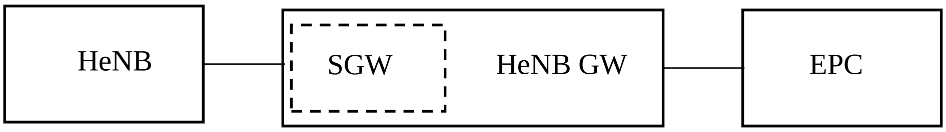

Figure 4.5 Logical architecture of femtocell

The LTE femtocell logical architecture includes an entity called the HeNB GW which functions as the concentrator to support many HeNBs. The HeNB GW connects many HeNBs to the EPC as shown in Figure 4.5. Between the HeNB and the CN, the HeNB GW occurs to the MME as eNB and to the HeNB as MME [67].

4.4.1 Handover Scenario in femtocell-Macrocell Networks

The following are the possible handover scenarios in the macrocell-femtocell integration [137]:

(a) Hand-in: In this scenario, the UE moves from the coverage of the macrocell to the femtocell coverage. This is the most challenging because of the difference in the backhaul routes of both the macrocell and the femtocell. Another challenging issue here is choosing the right HeNBs among the many HeNBs available. This often causes too long neighbour list and enormous demands on the system resources. However, the proposed algorithm in this research work ensures that the list of target HeNBs is reduced by considering other factors such as mode access of the femtocell, capacity and speed of the UE in addition to the signal level of the HeNBs in the UE’s direction

(b) Hand-out: This is the scenario whereby the UE originally connected to the femtocell handovers to the macrocell. This is similar to the macrocell to macrocell handover. However, there is usually no direct X2 interface between the two base stations. Hence, the control signalling takes place between the backhaul link and the core network. Hand-out is usually simple because the UE can only choose the only macrocell available. Only one macrocell is usually available. Hence, there is no option of selecting any other macrocell unlike in the hand-in scenario with many target femtocells. When the signal received from the macrocell is better than the signal received from the serving HeNB, and the speed of the UE has been determined, the UE can attach to the macrocell eNB and start transmitting its packet without consideration for other factors as in the hand-in scenario.

(c) Inter-HeNB: This is when the UE moves from the source femtocell to the target femtocell. The procedure for the femtocell to femtocell handover is similar to the one in the hand-in scenario [67] because the UEs’ need to select from hundreds of the target HeNBs available in the neighbourhood during handover. Signalling takes place between the HeNB GW through the S1 and the X2 interfaces and the control traffic is received at the EPC [138]. Both the source and the target femtocells are usually connected to the same network and, therefore, they need to be in close proximity [139].

4.4.2 Handover Procedure in femtocell-macrocell LTE-A networks

The Serving-eNB (SeNB) at a regular interval sends measurement request to the UE as shown in Figure 4.6. This request is replied by the UE to the SeNB. Based on the measurement information, the list of potentials in the HeNBs is forwarded to the HeNB-GW by the MME [2, 5, 140]. This list is updated at the HeNB-GW which selects the HeNB with maximum signal level in the UE’s direction. Once this is achieved, the algorithm proposed in

Figure 4.7 is used by the T-HeNB to accept the handover request. The handover response will then be sent to the HeNB-GW. On receiving the handover response, the HeNB-GW delivers it to the MME which then passes the received handover response to the SeNB. The SeNB informs the UE that the connection is complete. In order to access the target cell, the UE executes the handover by synchronising with the T-HeNB. At the completion of the handover, the downlink data path is changed to the T-HeNB by the MME. Once the resource release is completed, the T-HeNB begins transmitting the downlink packet data.

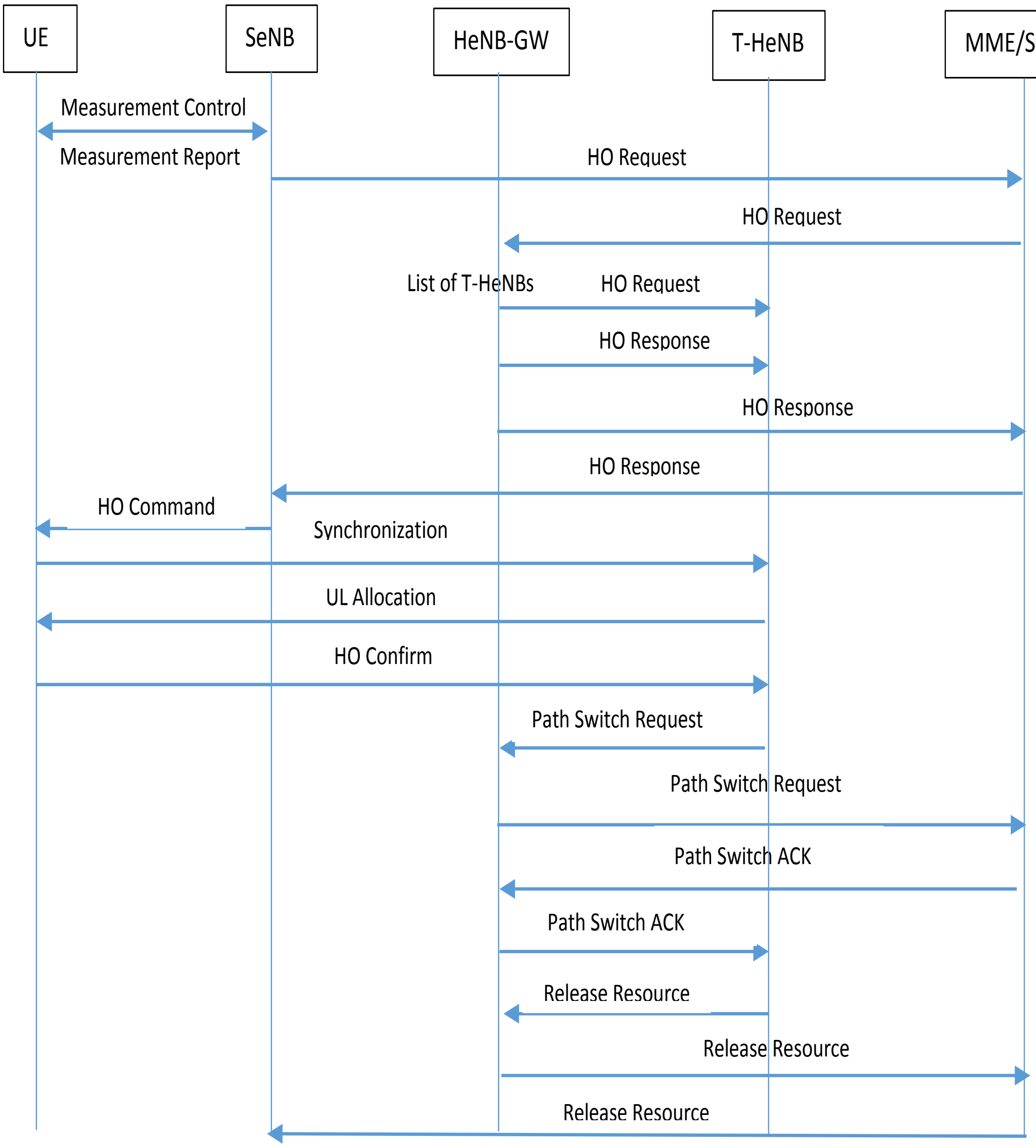

Figure 4.6 Handover procedure in LTE-A [124]

4.4.3 Proposed handover algorithm in two-tier macrocell-femtocell LTE-A

In this section, we propose an enhanced handover algorithm to reduce handover in two-tier macrocell-femtocell in the LTE-A. The proposed algorithm is detailed graphically by the flow chart in Figure 4.7 and pseudo algorithm in Figure 4.8. The procedure for admitting calls and the required steps in setting up the connection with the T-HeNB in the proposed algorithm are described as follows:

- **A.** The signal level of the UE to the SeNB is first checked and compared with a threshold signal (*k1*).
- **B.** The UE’s speed is determined according to Table 4.1 to know whether the UE will hand over to the T-HeNB or will remain in the eNB.
- **C.** For the UE to establish connection with the T-HeNB, the signal levels of the other connected UEs to the T-HeNB is checked to ensure that they are not affected below the threshold2 (*k2*).
- **D.** An UE is allowed to connect to the T-HeNB provided that the T-HeNB can be accessed openly and has not reached maximum capacity.

Table 4.1 Different speed range of UE

Speed type	**UE Speed in km/hr**
Low Speed	0 – 15
Medium Speed	15 – 30
High Speed	30 above

4.4.4 Algorithm Complexity

The complexity of an algorithm is closely associated with the number of iterations and variables. To evaluate the complexity of the proposed algorithm, the required lines from the algorithm in determining the time complexity can be described as follows:

O(1) – Initialization *//Line 1 to 7*

O(s) – for loop *//Line 8*

O(y) – number of HeNBs *//Line 17, already initialized as y in 6*

O(z) - total number of ListOf HeNB *//Line 19*

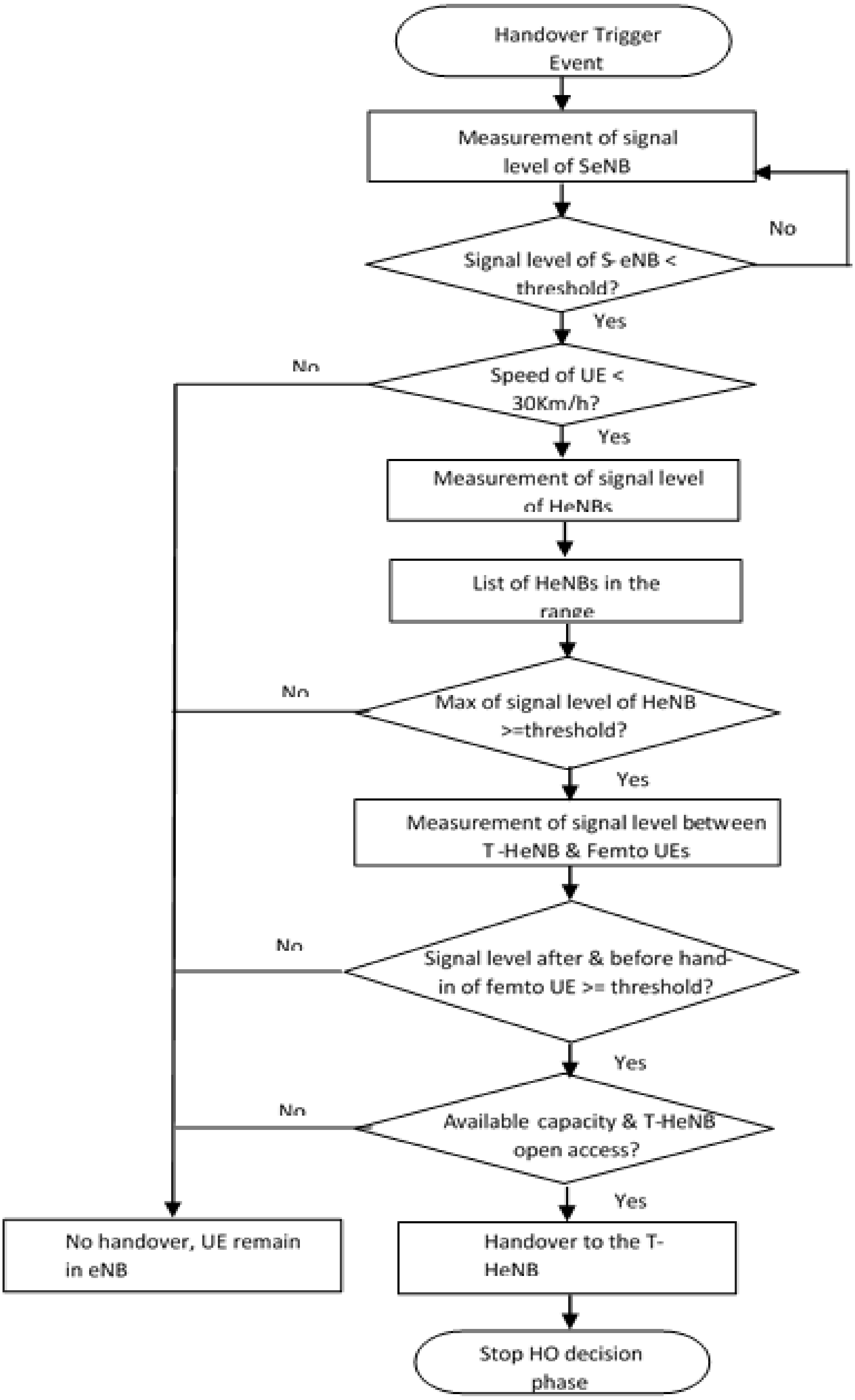

Figure 4.7 Flowchart for the proposed handover scheme

Algorithm: Procedure for reducing the handover

```
Initialize simulation time s
Initialize a container n holding user calls
Threshold = k1        // k1 is set threshold signal before handover
Threshold 2 = k2    // k2 is set threshold signal after handover
ListOf HeNBs = 0   // list of femtocells or HeNB
y = HeNBs  // number of femtocellsor HeNB in considered area
T-HeNB      // femtocell with highest signal
For (i = 0; i < s; i++)          // run for loop until i it reaches s
For each user x in n
Handover Trigger Event
Measurement x signal level of SeNB to the UE
If signal level of SeNB < k1
    Compute the speed of the UE
    If the speed of the UE < 30
        Compute HeNBs signal level measurement, $C_{uNB}$
            y = HeNBs.count()            // get total HeNBs
  for (i= 0; i<=y; i++)                  // generate list of HeNBs in the range of the UE
      ListOf HeNB.add(HeNB)  // add each HeNB that meets the HeNBs range to ListOf HeNB
      z= ListOf HeNB.count()        // get total number of HeNB in the list
    foreach (HeNB in ListOf HeNB) //identify the HeNB with max signal as T-HeNB.
             If (HeNB signal > k1)
           T-HeNB = HeNB
  If max signal level of T-HeNB > k2 and Bandwidth capacity available in T-HeNB and can be
      openly accessed
   Handover to T-HeNB
Remain in eNB //assuming speed of the UE > 30
Simulation time s has not reached
  Create new users and add to n
```

Figure 4.8   Pseudo Algorithm

We considered two cases to properly evaluate the computational efforts related to the time complexity: one with speed (proposed) and the other without speed (as in existing) and then determine their time complexity. Note that line 15 to 23 in the proposed algorithm is not required in the existing algorithm as the speed of the UE is not considered in the existing algorithm.

Case 1: time complexity of the proposed algorithm,

$$t = O(I) + O(s)$$

While equation (1) represents the time complexity for the best case scenario of the proposed algorithm, equation (2) indicates the time complexity for the worst case scenario of the proposed algorithm where the different speed of the UEs is put into consideration to achieve robustness.

$$t = O(I) + O(s)O((y)*O(z))$$

Case 2: time complexity for the existing algorithm

$$t = O(I) + O(s)$$

Equation (3) on the other hand, represents the time complexity of the existing algorithm where the speed of the UE is not put into consideration which explains the low complexity obtained in this equation. However, this is not usually the case as the UEs speed are different. Some users/UEs move at a speed less than 30 km/hr while some at more than 30 km/hr. Eventhough, this matches with the time complexity obtained in equation (1), that is, the best case scenario of the proposed algorithm, the existing algorithm is not robust to handle the different UE speeds.

Since the worst case scenario of the proposed algorithm wholistically handles these different UE speeds, as expected, a higher time complexity is recorded for this scenario. Therefore, in contrast to the existing algorithm, the proposed algorithm achieved an encompassing robustness by considering the different speeds of the UEs. Thus, the overall performance of the proposed algorithm in terms of reducing handover is better than the existing algorithm as we will see in the result later.

4.5 System Model and Traffic Analysis

We considered a scenario whereby the femtocells are placed within the coverage of a macrocell. Each femtocell initially serves four UEs and a maximum of eight UEs. Calls can be generated by Poisson Distribution with arrival rate γ. The macrocell' UEs and the femtocell' UEs are placed anywhere in the network and they can move from one location to another within the network. The user's speed is calculated for every 1 second interval using the Euclidean Distance method [111]. The distance travelled for every 1 second interval is also calculated. The speed of the UE is obtained by dividing the distance covered by the time spent to travel it, that is, speed $v = d/t$.

It is assumed that λ_o and λ_h are the originating call arrival rates and the handover call arrival rates respectively. $\lambda_{h,ff}$, $\lambda_{h,fm}$ $\lambda_{h,mf}$ and $\lambda_{h,mm}$ represents the femtocell-to-femtocell, femtocell-to-macrocell, macrocell-to-femtocell and macrocell-macrocell handover call arrival rates in the system. If $P_{b,f}$, $P_{b,m}$ are the new originating call blocking probabilities for both the femtocell and the macrocell then $P_{d,f}$, $P_{d,m}$ are the handovers call blocking probabilities for the femtocell and the macrocell respectively. The average macrocell layer channel release rate can be increased by increasing the number of femtocells. This is done to offload more traffic from the macrocell. If μ_f and μ_m are the average release rates of the femtocell and the macrocell respectively, then the average release rate can be determined from the following equations [141]. The average release rate for a femtocell layer

$$\mu_f = \eta_f + \mu \tag{4.1}$$

The average release rate for a macrocell layer

$$\mu_m = \eta_m \left(\sqrt{n} + 1\right) + \mu \tag{4.2}$$

where $1/\mu$ represents the average call duration. $1/\eta_f$ and $1/\eta_m$ are the cell dwell time for the femtocell and the macrocell respectively.

From Figure 4.8, newly arrived calls to the system can either compete within the primary cell or handover to other cell(s) before completion [116]. The total calls rate (originating and handover) entering a cell is equal to the calls leaving the cell. The handover calls arrival rates for the femtocell-femtocell, femtocell-macrocell, macrocell-femtocell and macrocell-macrocell handovers can be determined by combining [2, 111] as follows:

For the femtocell-femtocell handover

$$\lambda_{h,ff} = P_{h,ff} \frac{\lambda_{f,o}\left(1-P_{b,f}\right)+\lambda_{h,mf}\left(1-P_{d,f}\right)}{1-P_{h,ff}\left(1-P_{d,f}\right)\left[\alpha+\left(1-\alpha\right)P_{d,m}\right]} \tag{4.3}$$

For the femtocell-macrocell handover

$$\lambda_{h,fm} = P_{h,fm} \frac{\lambda_{f,o}\left(1-P_{b,f}\right)+\lambda_{h,mf}\left(1-P_{d,f}\right)}{1-P_{h,ff}\left(1-P_{d,f}\right)\left[\alpha+\left(1-\alpha\right)P_{d,m}\right]} \tag{4.4}$$

For the macrocell-femtocell handover

$$\lambda_{h,mf} = P_{h,mf} \frac{\left(1-P_{b,m}\right)\left(\lambda_{m,o}+\lambda_{f,o}P_{b,f}\right)+\left(1-P_{d,m}\right)\left[\lambda_{h,fm}+\lambda_{h,ff}\left(1-\alpha+\alpha P_{d,f}\right)\right]}{1-P_{h,mf}\left(1-P_{d,m}\right)} \tag{4.5}$$

For the macrocell-macrocell handover

$$\lambda_{h,mf} = P_{h,mf} \frac{\left(1-P_{b,m}\right)\left(\lambda_{m,o}+\lambda_{f,o}P_{b,f}\right)+\left(1-P_{d,m}\right)\left[\lambda_{h,fm}+\lambda_{h,ff}\left(1-\alpha+\alpha P_{d,f}\right)\right]}{1-P_{h,mf}\left(1-P_{d,m}\right)} \tag{4.6}$$

where $P_{h,ff}$, $P_{h,fm}$, $P_{h,mf}$ and $P_{h,mm}$ are the handover probabilities of the femtocell-femtocell, femtocell-macrocell, macrocell-femtocell and macrocell-macrocell cells, respectively and $\lambda_n(1-P_b)$ represent traffic intensity for any of the handover type described above.

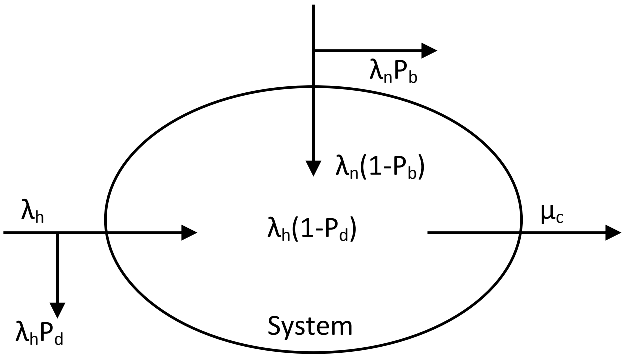

Figure 4.9 Call rate traffic model

From Figure 4.8, the rate of the handover traffic entering a cell is given as $\lambda_h(1-P_d)$. The average rate of calls leaving the cell would be equal to the average rate of calls requiring handover.

Traffic Analysis of the femtocell network: The UE's traffic behavior in the femtocell network for the proposed algorithm is analyzed as follows. By using the Discrete Time Markov Model (DTMM), the behavior of the UE in the network can be captured. The handover probabilities of the UE in each femtocell can be used to obtain closed-form expressions for the handover performance parameters. Since the UEs can be placed anywhere in the network, they can also change the state at the end of a discrete time slot (Δt). State variables can be used to indicate an active UE call within the femtocell.

Let N represent the number of the target femtocell in the network and the state variable $S(N)$ represent that the UE is associated with N. Let the additional state variable Sno represent the UE with no active call. As earlier stated, the calls are generated with arrival rate γ with the call arrival probability $P\gamma = \gamma\Delta t$. The call duration is exponentially distributed with the average call duration $1/\mu$. Therefore, the probability of the call termination is given as $P\mu = \mu\Delta t$.

Recall, the cell dwell time is the time the UE spent in its current cell. It is given as $1/\eta$ and it is modeled using exponential distribution. The average cell residence time is given as 1/r and the probability of an UE leaving the current cell is $Pr = r\Delta t$.

In the DTMM shown in Figure 4.9, the EU remains in an inactive state Sno with a probability of $1-P\gamma$. After the call arrival, the EU goes into any of the states Si based on the density of the cell in that state. The EU, thereafter, returns to the Sno from Si with a probability $P\mu$. The EU remains in the current cell during active call with a probability $(1-P\mu)(1-Pr)$ while the EU transition probability from Si to state Sj is given as $Pr(1-P\mu)Psisj$. The EU returns to state Sno at the end of a call.

The Ps_is_j can be calculated as follows:

$$Ps_is_j = \{1/4 \text{ if } N > 3 \text{ or } 1 \text{ if } N = 3\} \tag{4.7}$$

In Fig. 4.10, K is the total number of the femtocells in the network.

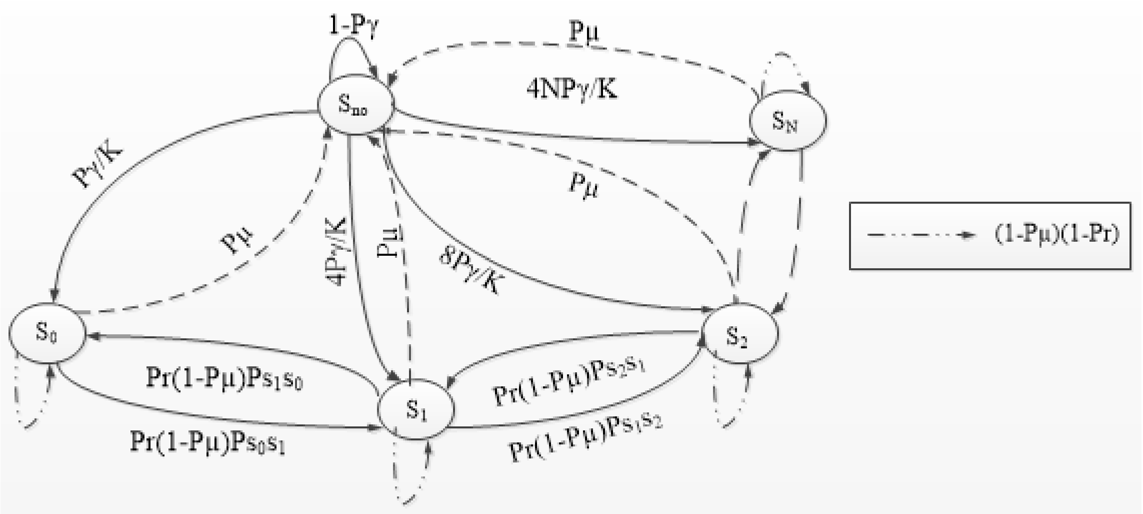

Figure 4.10 DTMM for all states

The balance equations can be determined using the transition probability matrix of the DTMM as follows:

$$\delta_{id} = (1 - P\gamma) + P\mu \sum_{i=0}^{k} \sum_{j=1}^{[\frac{i+1}{2}]} \tag{4.8}$$

where δ_{id} is a stationary distribution used to obtain the handover performance parameters. The number of handover: this can be obtained by calculating the average handover number in the network. To calculate this, we consider the handover in each of the different call types and determine the average handover using the close-form expression as follows:

$$H_{avg} = \frac{1}{\ell}\left[\frac{\ell}{n}\right]\left\{h\phi + h\theta + \sum_{i=1}^{K} \sum_{j=1}^{\left[\frac{K+1}{2}\right]} h\phi\right\} + \frac{1}{\ell}\left(\ell - \left[\frac{\ell}{n}\right]\right)\left\{h\phi + h\theta + \sum_{i=1}^{K} \sum_{j=1}^{\left[\frac{K+1}{2}\right]} h\phi\right\} \tag{4.9}$$

where ℓ is the average number of handovers per UE. n is the number of handovers during an active call. h is the handover number to a femtocell/macrocell in state S. ϕ is the probability that a UE handover to a state which is not its current state. θ is the probability of the EU handover from one femtocell/macrocell to another whose is state S. K is as stated earlier.

4.6 Results and Discussion

To determine the performance of the proposed algorithm, the proposed algorithm is compared with an existing algorithm in terms of the number of handovers and the ratio of the T-HeNB. By using the simulation parameters in Table 4.2, the simulation results generated are explained as follows.

The result of the proposed algorithm is presented with respect to the number of handovers as shown in Figure 4.10. We called the algorithm with no mechanism to handle different UEs speed an existing algorithm, (that is, reference [67]). By comparing the results of the proposed algorithm with the existing algorithm, which allows the UE to handover to the femtocells without considering the speed of the UE, it can be noticed that there are more handovers in the existing algorithm. This can be attributed to the fact that when the UEs become highly mobile, they experience more handovers due to the low coverage area of the femtocells. This can lead to more packet loss, and a large load signalling in the core network. To prevent these frequent handovers, the speed of the UE has been considered in the proposed algorithm. Having determined the speed of the UE beforehand, the proposed scheme ensured that highly mobile UEs remained attached to the macrocell with the larger coverage area by initiating inter-frequency handover to the macrocell while stationary or low speed UEs can handover to the femtocell. Although the proposed algorithm exhibits a higher computational time (as determined in the algorithm complexity for the worst case scenario) due to encompassing the UE’s speed consideration, however, as shown in Figure 4.10, the proposed algorithm has been able to reduce the total number of handovers in the network by almost 40% of the existing algorithm.

To further show that the proposed algorithm performs better than the existing algorithm in terms of the number of handovers, we varied the number of the femtocells as shown in Figure 4.11. It can be seen that when few numbers of the femtocells were deployed, that is, less than 10, the number of handovers in both existing and the proposed scheme are almost the same. However, as the number of the femtocell increases and with the UEs becoming highly mobile, the UE experiences more frequent handovers with the existing algorithm compared to the proposed algorithm. Hence, the proposed algorithm outperforms the existing handover algorithm again in this regard.

Table 4.2 Simulation Parameters

Parameter	**Value**
Radius of the eNB	500 m
Radius of HeNB	10 m
Power of eNB	46 mW
Power of HeNB	20 mW
Bandwidth capacity of macrocell	10 Mbps
Number of users	Varies
Initial number of users in a femtocell	4
Mode access of femtocell	Open
UEs Mobility model	Random WayPoint
UE speed	(3, 25, 60, 150, 300) kmph
Average call duration	150 seconds

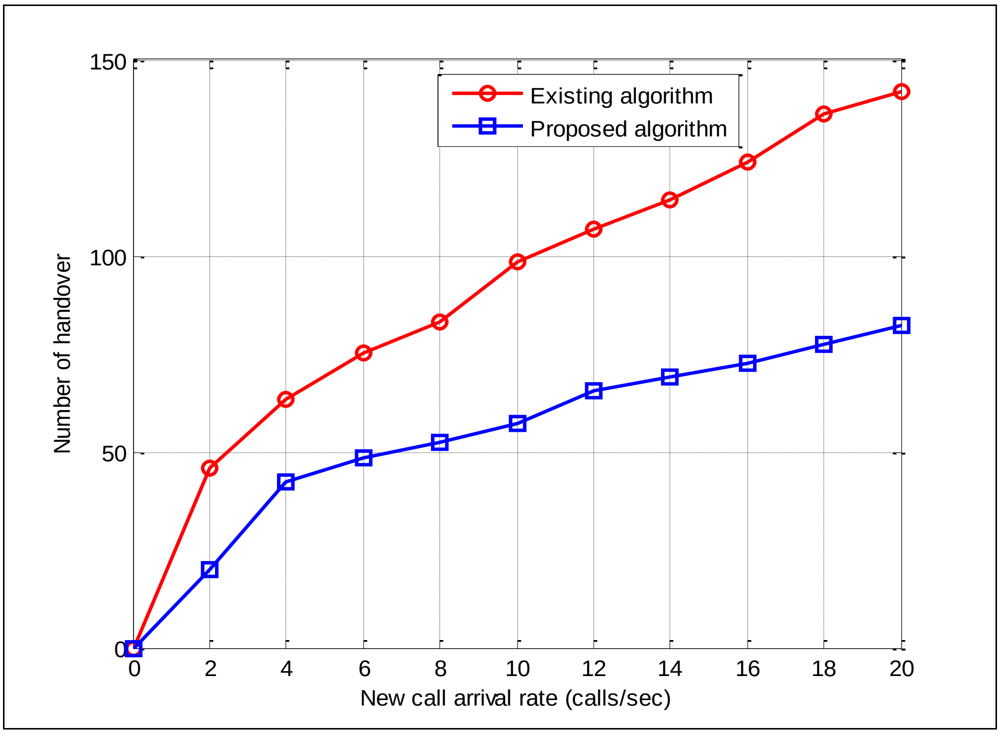

Figure 4.11 Number of handover against new call arrival rate

To evaluate the performance of the proposed algorithm in terms of the ratio of the T-HeNB, the ratio of the T-HeNB is defined as the number of the target HeNBs in the list to the total number of the femtocells in the system.

$$T-HeNB(Ratio)=\frac{T-HeNBs}{Totalfemtocells} \tag{4.7}$$

The graph of the ratio of the T-HeNB against the number of the femtocell is as shown in Figure 4.12. In comparing the proposed algorithm with the existing algorithm, it can be noticed that the ratio of the T-HeNB in the existing algorithm doubled the ratio of the T-HeNB in the proposed algorithm for every increase in the number of the femtocell. This is because the mobile UE performed frequent handovers from one femtocell to another and because of the number of the femtocells, the rate of the ping-pong increases in the existing algorithm. However, with the proposed algorithm, only the stationary or low speed UEs can perform handover to the femtocell and the high speed UEs remain connected to the macrocell or handover to another macrocell thereby reducing the ping-pong effect.

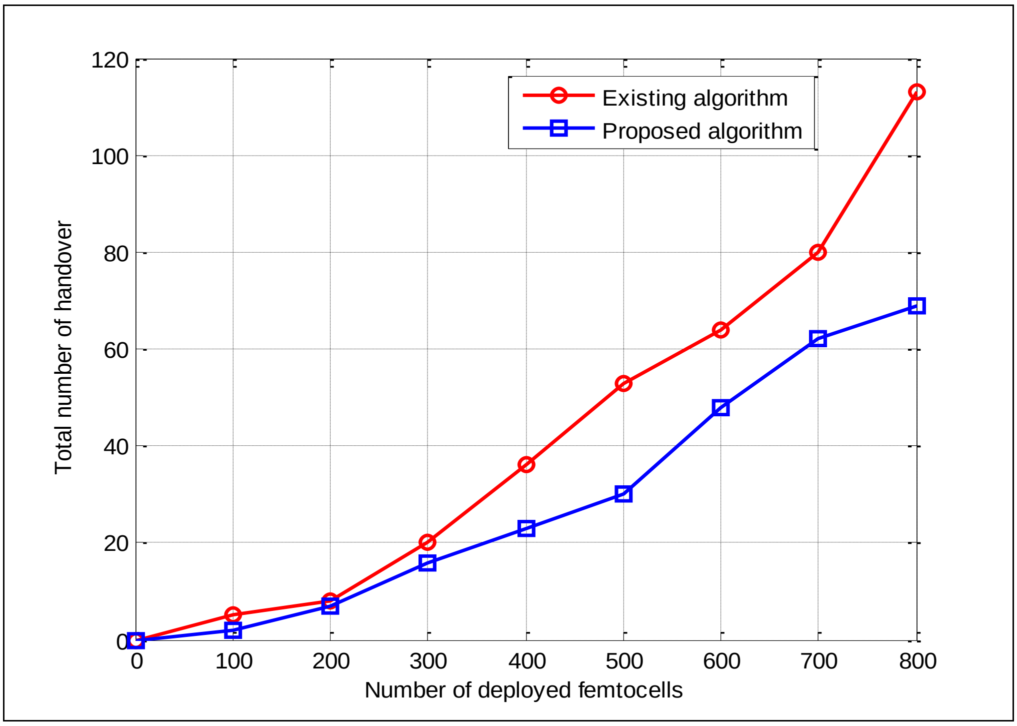

Figure 4.12 Effect of varying the number of femtocells on handover

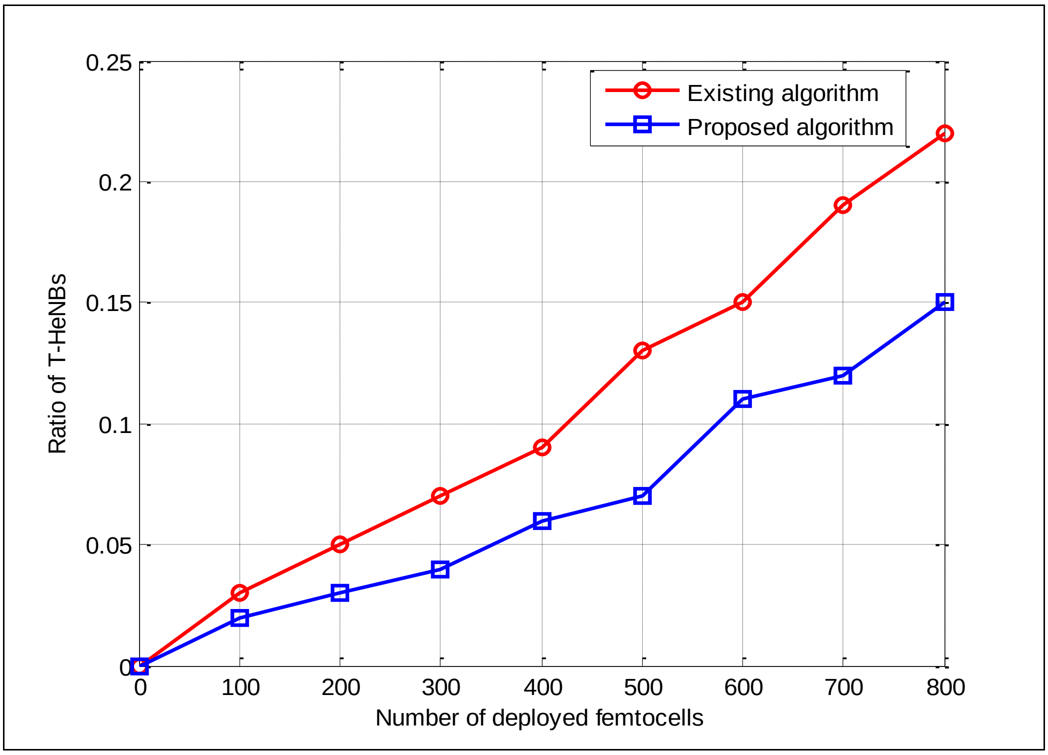

Figure 4.13 Ratio of T-HeNBs

The result obtained from the close-form expressions in equation 4.9 for the number of handovers and by solving equation 4.10, is compared with the simulation (model) result as shown in Figures 4.13 and 4.14. In Figure 4.13, the total number of handovers in the system is small when few numbers of deployed femtocells are considered for both the analytical and the simulation model. However, as the number of deployed femtocell increases, there is an increase in the curve of the two models indicating that more handovers occurred when more femtocells are deployed even though they both tried to reduce the number of handovers with the two results which do not vary significantly. When the deployed femtocell is around 500, we noticed that the two curves meet and then closely follow each other for the rest of the curve. The idea here is not to compare the proposed models with the existing model as we have already compared the simulation model with the existing model. Our aim here is to see whether the results obtained analytically corroborate with the simulation results. Hence, we can say that the results for both the analytical and the simulation models are closely related. The same close behavior can be noticed in Figure 4.14 when both models are compared with respect to the ratio of the T-HeNBs. The ratio of the T-HeNBs increases for both models with no significant difference in the two. Thus, based on the closeness of the two models in both cases we have considered, the accuracy of the proposed algorithm is validated.

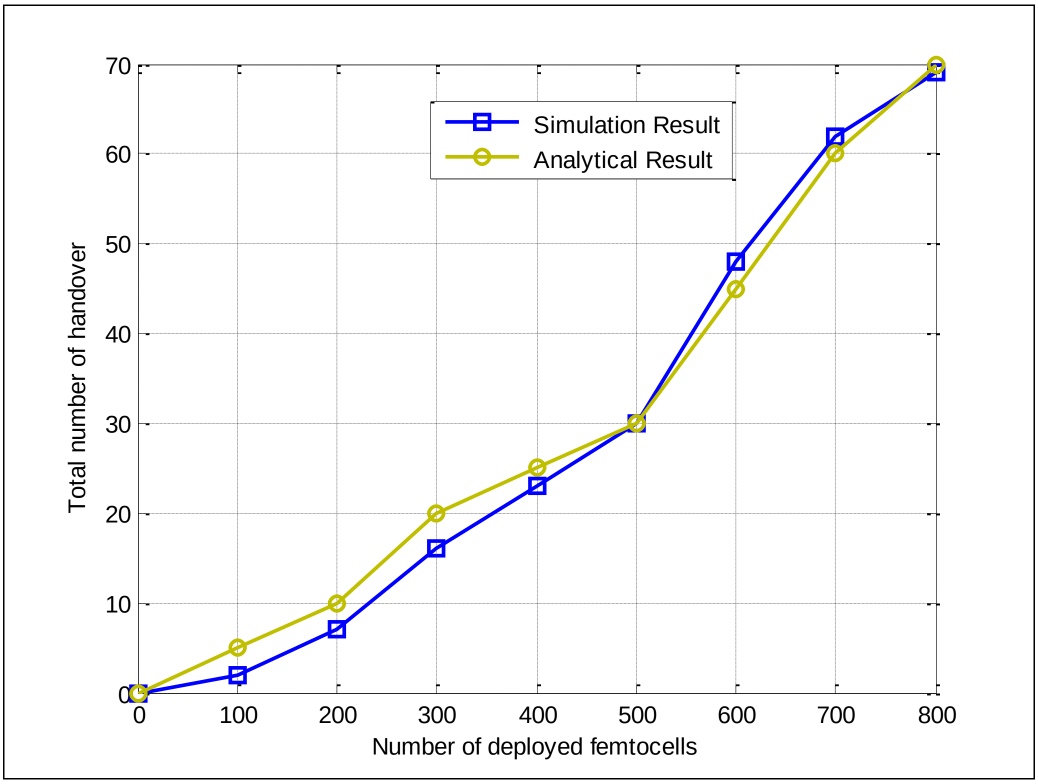

Figure 4.14 Handover simulation result vs Analytical result

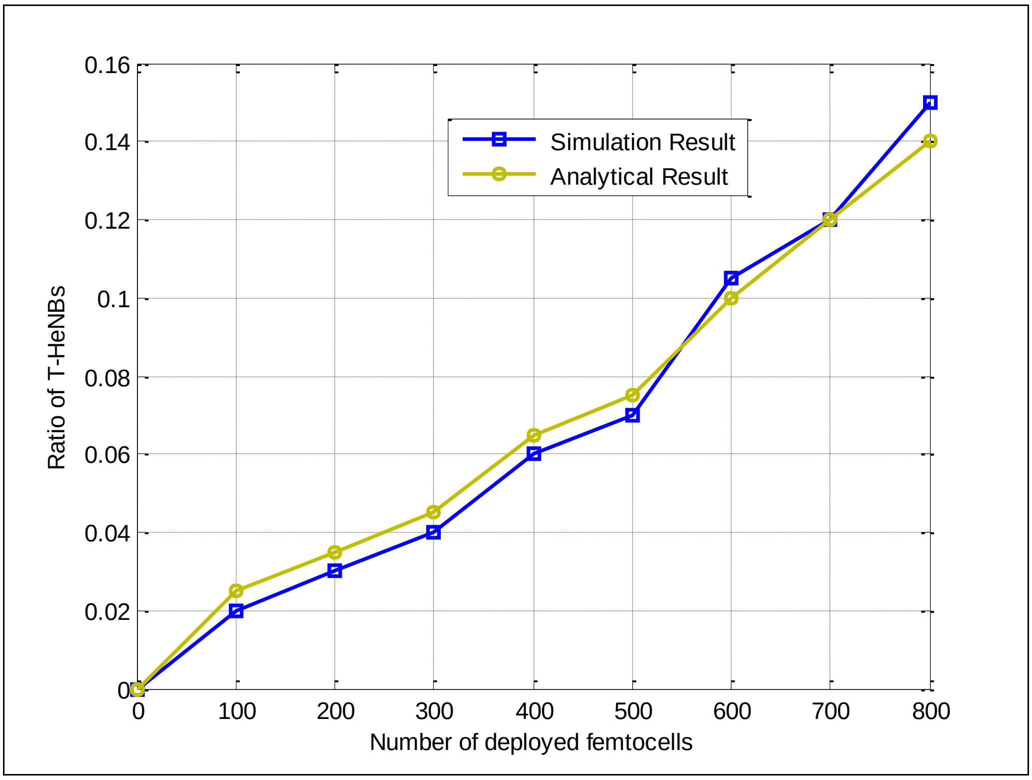

Figure 4.15 T-HeNBs simulation result vs analitical result

4.7 Chapter Summary

In this chapter, an enhanced handover algorithm has been proposed to reduce the handover in the two-tier macrocell-femtocell LTE-A networks. The algorithm is based on the speed of the UE in addition to the signal level of the UE and capacity of the femtocell before making handover decision. The highly mobile UEs can be connected to the macrocell while the stationary or low speed UEs can be connected to the femtocell.

Moreover, the potential target femtocells were listed and the algorithm further checks the femtocell with the highest signal level to the UE as well as its capacity to accommodate the UE’s services. From the simulation results obtained, we established that the proposed algorithm outperforms the traditional algorithm with respect to the number of handovers and ratio of T-HeNB.

CHAPTER FIVE

HANDOVER MANAGEMENT IN DENSE FEMTOCELL DEPLOYMENT IN LTE-ADVANCED

5.1 Introduction

Femtocells have been introduced in the previous chapters as low-power and low cost devices used to enhance the capacity and performance of mobile cellular networks. Apart from forming a two-tier network with the macrocell to offload traffic from the macrocell, femtocells can be deployed in a densely populated urban area to achieve more data rate with better QoS. However, this increases the frequency of the handover of the UEs. The large and frequent handover arises due to many neighbouring femtocells, thus making the handover management extremely difficult. Selecting a particular femtocell for handover is a serious challenge in a dense femtocell deployment environment. Due to this, a robust CAC-based handover strategy for dense deployment of the femtocell in LTE-A network is proposed in this chapter. We start by probing into the challenges attendant to high dense femtocell deployment.

5.2 Challenges in high dense femtocell deployment

Various challenges arise as a result of densifying cellular networks with femtocells. Thus in this section, we discuss these challenges which include handover failure, the ping-pong effect and cell association issues.

5.2.1 Handover Failure

In LTE-A, there is a huge instability of signal as many femtocells are deployed under the coverage of the macro base station (macrocell) where handover decision is determined basically by using the signal quality of the UE to these base stations [142]. Due to this signal instability caused by factors such as UE mobility and overloading of the base stations, the signal quality deteriorates resulting in the handover failure. Also, since both macrocell and femtocell can operate in the same frequency, a strong interference occurs in the overlaid which further deteriorates the quality of the signal.

5.2.2 Ping Pong Effect

Ping Pong is an effect caused by the frequent movement of UEs between the source and the target base stations. This effect arises as a result of deploying numerous femtocells at the hotspot areas such as shopping malls, airports, sport centres and railway stations to provide an increased capacity to users. Due to the smaller coverage of femtocells, the mobile UE continuously change its association from one cell to another. This causes interruption in the connection and unnecessary frequent handovers. Ping pong can also increase the dropping of calls and poor network performance [143].

5.2.3 Cell Association Issue

In dense femtocell networks, many femtocells with low power are placed within the coverage of the macrocell. Because of the high transmitting power of the macrocell, the UE tends to be associated with the macro base station irrespective of its distance to the femtocell. This unavoidable high transmitting power of the macro cell prevents the necessary handover from taking place. To solve this problem, various load balancing algorithms were developed in [144].

5.3 Related Work

Vasudeva *et al.* [145] investigated handover failures in heterogeneous networks. New models for analysing handover performance in heterogeneous networks such as cell size, vehicular UE velocity and mobility management parameters were presented. ***Chowdhury and Jang*** [146] proposed a handover algorithm for managing issues related to mobility in dense femtocell to macrocell network. To handle large numbers of FAPs within the macrocell coverage, the authors introduced SON-based network architecture. They also proposed an algorithm which exposed hidden FAPs that cause handover failure using SON features. The SON-features ensure that FAPs keep location information of one another thereby overcoming hidden FAP problems. This, however, can lead to increased neighbour cell list. For performance analysis, traffic model different from the macrocellular only network was used for the femtocell-macrocell integrated network. An adaptive user movement prediction technique has been proposed in [147] to further minimize the list of neighbour femtocells in dense femtocellular networks. Their movement prediction technique aimed at enhancing the work in [146] by identifying parameters such as the movement direction of the Mobile Station (MS) and the neighbour FAPs' location in relation to the serving FAP. By using positioning technology, the authors were able to divide the femtocell area into sub-areas consisting of femtocell APs, user mobility analysis server and mobile terminals. To predict the next MS movement, server mobility rules were used and the predicted movement delivered to the femtocell BS.

In this chapter, we propose a robust CAC-based handover management strategy for LTE-Advanced network. We consider femtocell-to-macrocell, femtocell-to-femtocell and macrocell-to-femtocell handovers for effective handover analysis and management. We also consider a large-scale deployment of femtocell to upload huge traffic from the macrocell to the femtocell in the femtocell-macrocell integration. However, this leads to more challenges caused by large numbers of neighbouring femtocells. Thus, the proposed CAC strategy will be used with the handover algorithm proposed in chapter four to reduce handover probability, call blocking probability and call dropping probability. Also in this work, we differentiate call into various types and apply the proposed strategies to handle these various types.

5.4 System Model

The system model for femtocellular network is shown in Figure 5.1. Various femtocell access points (FAPs) are connected to the Femtocell Gateway (FGW) via Internet Service Provider (ISP) cable or Digital Subscriber Line (DSL) modem. The FGW can be used as both concentrator and security gateway for the FAPs. It should be noted that there is no direct link between FGW and RNC [2]; Hence, FGW communicates with RNC via the Core Network (CN). The FGW controls traffic flows in and out of the femtocell. The FGW also forwards traffic received from the access networks to the destination network. Femtocell UEs are connected to the macrocell UEs through the ISP network. An agreement is required between a femtocell operator/owner and an ISP to provide the required bandwidth to the femtocell UEs. FGW provides FAP's position and authorised UEs via CN to the macrocell database server (DBS) [2]. The FGW and RNC are connected to the user plane and control plane respectively.

A dense deployment of the femtocell base station within a macrocell is shown in Figure 5.2. Finding an appropriate Target femtocell (T-HeNB) among the many neighbouring femtocells by the UE is a huge challenge. When a UE previously connected to a macrocell or a femtocell needs to handover to another femtocell for reasons such as low signal from the serving cell, signals are detected from the neighbouring femtocell stations. In the process, much power and overhead is required by the UEs to scan the potential numerous T-HeNBs. The large overhead is due to large amount of information broadcast by the UEs. This unnecessary scanning often leads to serious handover problems in the densely deployed femtocell network.

Therefore, a robust handover management scheme is required in a dense femtocell deployment to reduce the overhead incurred in scanning a large number of femtocells which ultimately leads to a reduction in the rate of handovers in the network.

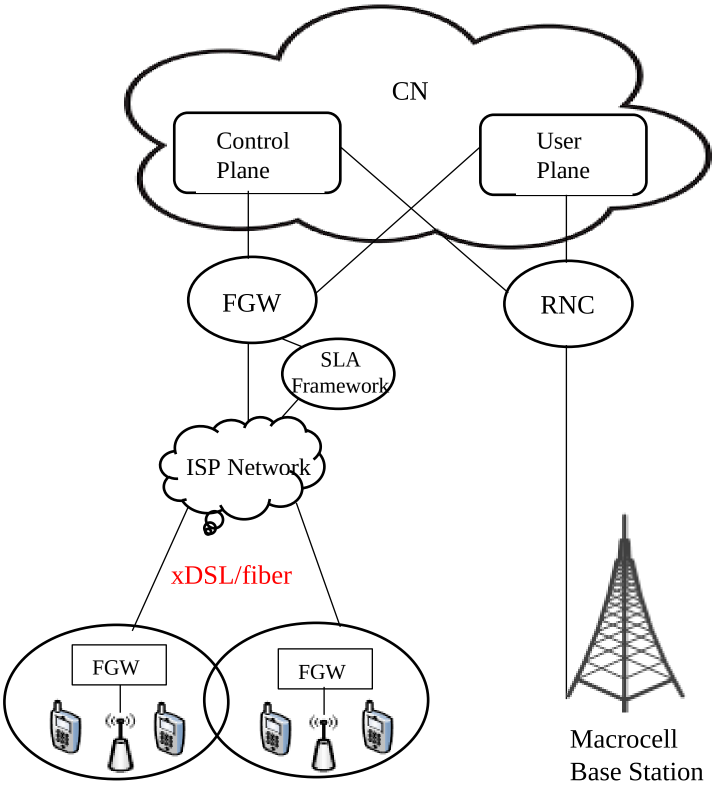

Figure 5.1 Femtocellular network connection to the CN

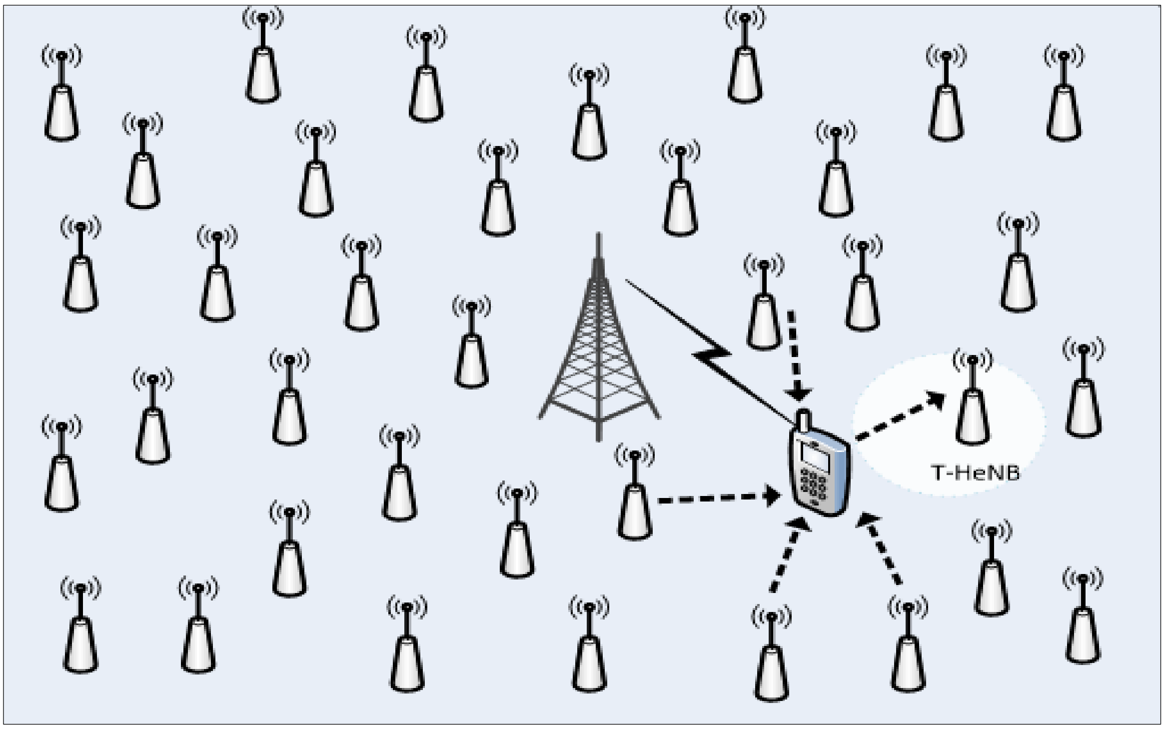

Figure 5.2 Dense femtocell deployment scenario

5.5 Proposed CAC-based Handover Management Strategy

The proposed CAC-based handover management strategy combined the CAC scheme with the handover algorithm proposed in chapter four to reduce handover in the dense femtocell deployment LTE-A network. While the algorithm proposed in chapter four ensures that the speed of UE is put into consideration**,** the CAC scheme controls the admission of different UE's call types into the network. In addition, CAC manages a large number of calls between the macrocells and the femtocells. The proposed strategy can be grouped into three parts as follows: the first part is used to accept new calls, the second part is used to accept calls already connected to the macrocell and the third is used to accept calls already connected to the femtocells. Two threshold levels K_1 and K_2 of signal-to-noise plus interference ratio (SNIR) are used to accept a call into the system. K_1 is the minimum signal level required to connect a UE's call to the HeNB. K_2 is used to reduce undesired macrocell-femtocell handovers. The QoS adaptive traffic in [146, 148] is used to accept more handover calls to the macrocell. The bandwidth required to accept a call and the minimum bandwidth allocated to call of nth traffic class are $\beta_{r,m}$ and $\beta_{min,m}$ respectively. Each nth class calls releases bandwidth $\beta_{r,m} - \beta_{min,m}$ to accept a new call into the macrocell. Also, C and C_{used} represent the total bandwidth of the macrocell and bandwidth used by the existing calls. The unused bandwidth C_{unused} in the macrocell is equal to C-C_{used}.

5.5.1 New calls

The CAC scheme applicable to the newly arriving call is as shown in Figure 5.3. Whenever a new call arrives the femtocell-macrocell coverage area, a femtocell availability is checked. If resources available are in the femtocell and the femtocell can be accessed openly, the new call is admitted to the HeNB provided the received signal level K_2 condition is also met. The received signal level of the target HeNB is $\mathrm{SNIR}_{\mathrm{T,\,F.}}$ If these conditions are not met, the resources of the macrocell are checked. If there are sufficient bandwidth resources available in the macrocell, the call is connected to the macrocell otherwise it is rejected.

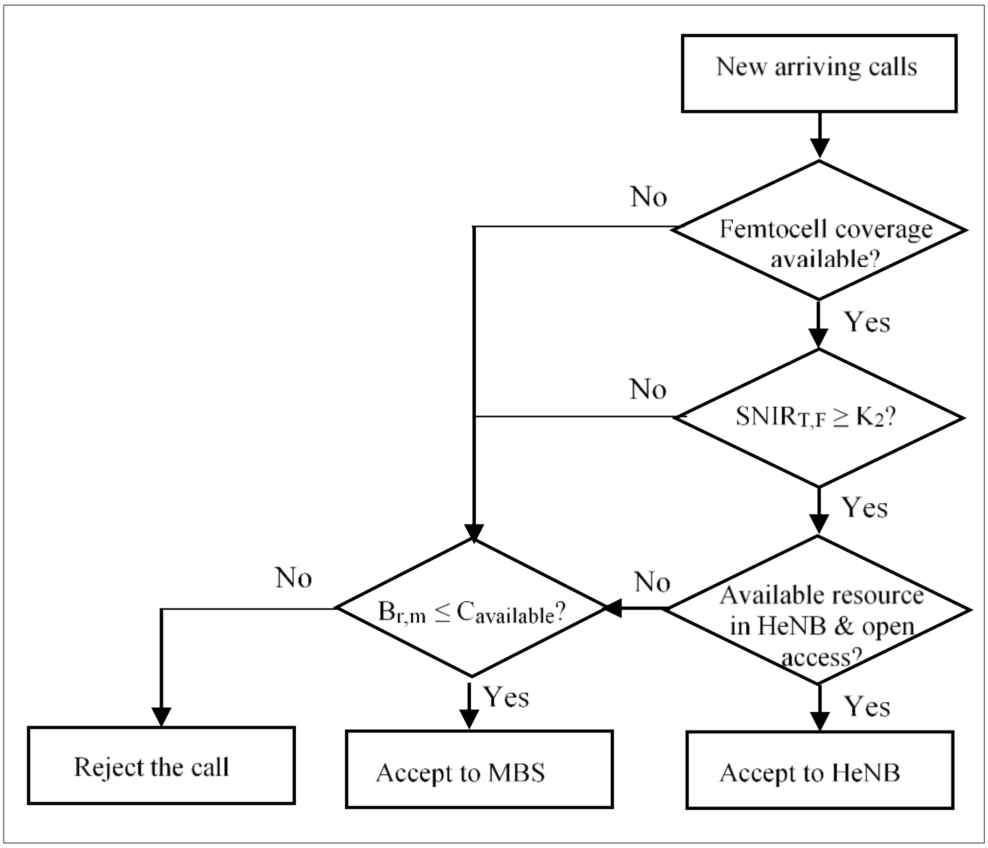

Figure 5.3 CAC strategy to accept new calls

Algorithm for accepting new calls into the system

```
1.  Start
2.  //checking femtocell availability
3.  If UE receive signal from a femtocell/within the femtocell coverage then
4.  //check if femtocell signal is greater or equal to threshold $K_2$
5.  If $\mathrm{SNIR}_{T,F} \geq K_2$ then
6.  //check if the femtocell is open access and resource availability
7.  If femtocell open access and resource available then
8.  Accept calls into HeNB
9.  End
10. Else go to 14
11. Else go to 14
12. Else
13. //check if bandwidth required to accept call ≤ available bandwidth in the macrocell
14. If $\beta_{r,m} \leq C_{available}$ then
15. Accept UE call to the MBS
16. Else
17. Reject the call
```

5.5.2 Existing calls with the Macrocell

The CAC scheme applicable to the calls already connected to the eNB is as shown in Figure 5.4. Whenever a moving Macrocell UE (MUE) detects a stronger signal from HeNB, the scheme checks the signal received from that target HeNB. If the signal is equal to the threshold of K_2 or if the current received signal level of macrocell is less than or equal to signal of the target HeNB, then the MUE call is handed over to the femtocell provided other conditions are satisfied.

Algorithm for accepting handover call to the T-HeNB from eNB

```
1.  Start
2.  //compare target femtocell signal detected with the threshold $K_2$
3.  If $\mathrm{SNIR}_{T,F} \geq K_2$ then
4.      //check if target femtocell is open access and resource availability
5.      If T-HeNB open access and resource available then
6.          Handover to the HeNB
7.          End
8.      Else go to 14
9.   Else
10.  //check if target femtocell signal ≥ macrocell signal
11.  If $\mathrm{SNIR}_{T,F} \geq \mathrm{SNIR}_{T,M}$ then
12.  Go to 5
13.  Else
14. UE call remain with the MBS
```

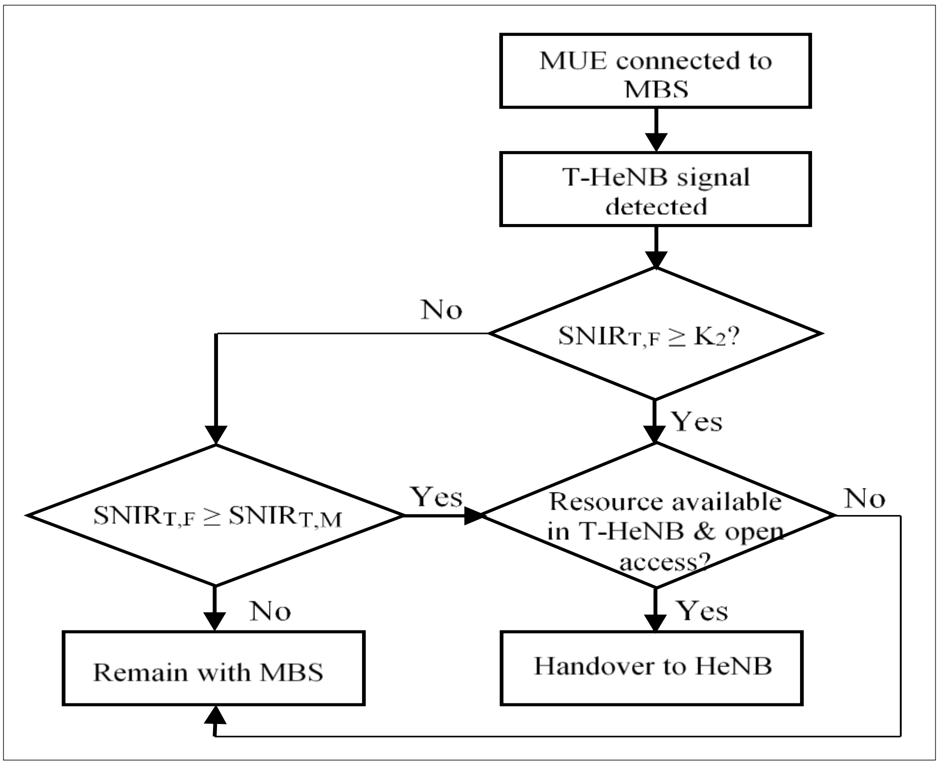

Figure 5.4 CAC strategy for existing call with eNB

5.5.3 Existing calls with the Femtocell

The CAC scheme for calls initially connected with the HeNBs is shown in Figure 5.5. The scheme is applicable to handovers from femtocell to femtocell or femtocell to macrocell. When the signal received from the HeNB by a moving UE becomes low, the UE based on its speed, begins a handover process either to the neighbour femtocell or to the macrocell. If the target femtocell signal is greater than or equal to K_2, and can be openly accessed, the UE call will hand over to the T-HeNB. However, if the target femtocell signal is within the K_1 and K_2 range, the UE tries to connect to the macrocell.

If the bandwidth resources available in the macrocell are not enough to admit the call, the CAC scheme reduces the QoS of the existing calls to release some bandwidth. The maximum amount of bandwidth to be released for a requested handover call on existing calls has been given as: $\beta_{r,m} - \beta_{min,m}$. Therefore, the total admitted calls in the system is increased. This reduces the handover dropping probability. However, the call is dropped if after some bandwidth have been released from the existing calls, the $\beta_{min,m}$ is still not available in the macrocell.

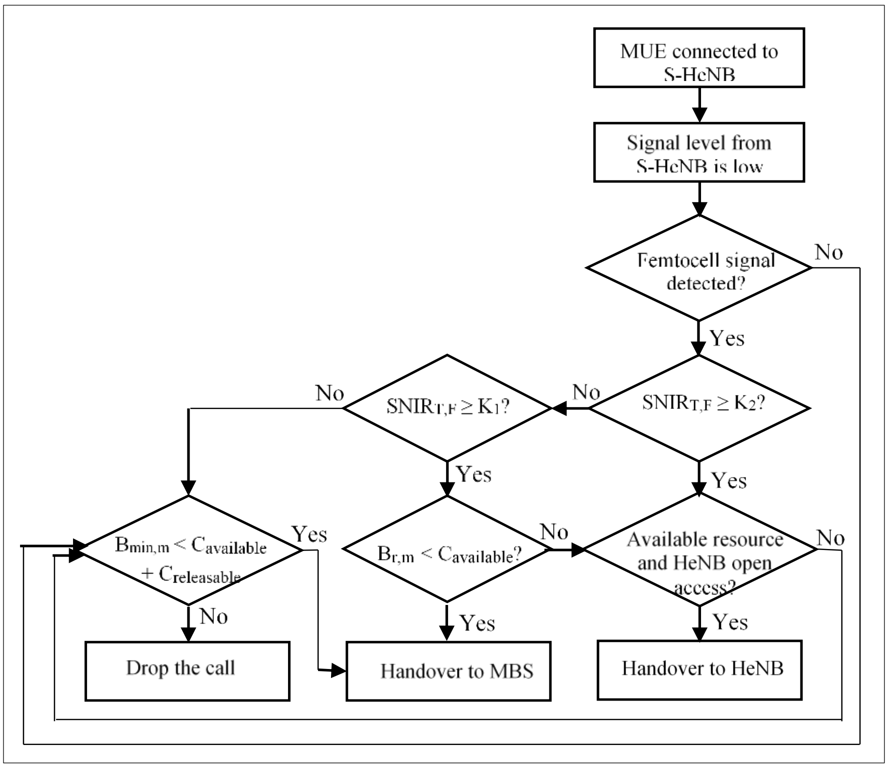

Figure 5.5 CAC strategy for existing calls with the HeNB

Algorithm for accepting handover call to the HeNB from S-HeNB

```
1.  Start
2.  //checking if signal received from Serving femtocell becomes low
3.  //checking signal from other neighbor femtocell
4.  If a femtocell signal detected then
5.      If $SNIR_{T, F} \geq K_2$ then
6.          If HeNB open access and resource available then
7.              Handover to HeNB
8.              End
9.          Else go to 19
10.     Else
11.     If $SNIR_{T, F} \geq K_1$ then
12.         If Br,m < $C_{available}$ then
13.             Handover to MBS
14.             End
15.         Else
16.         Go to 6
17.     Else
18.     //check if bandwidth remain < available bandwidth + releasable bandwidth in the macrocell
19.     If Br,m < $C_{available} + C_{releasable}$ then
20.         Drop the UE call
21.         End
22.     Else go to 13
23. Else go to 19
24. End
```

5.6 Queuing Analysis and Traffic Model

The Markov chain model in [146] has been modified for modelling the proposed strategy as shown in Figures 5.6 and 5.7 respectively. For the femtocell and macrocell layers, the number of calls represents the system's state. Let N be the maximum number of calls that the femtocell can accommodate in the system, where the number of calls in the system represents the state of system. We assumed that the arriving process for all calls follow Poisson distribution and then defined the femtocell and macrocell channel release rates as μ_f and μ_m respectively. Femtocells are deployed randomly within the coverage of the macrocell.

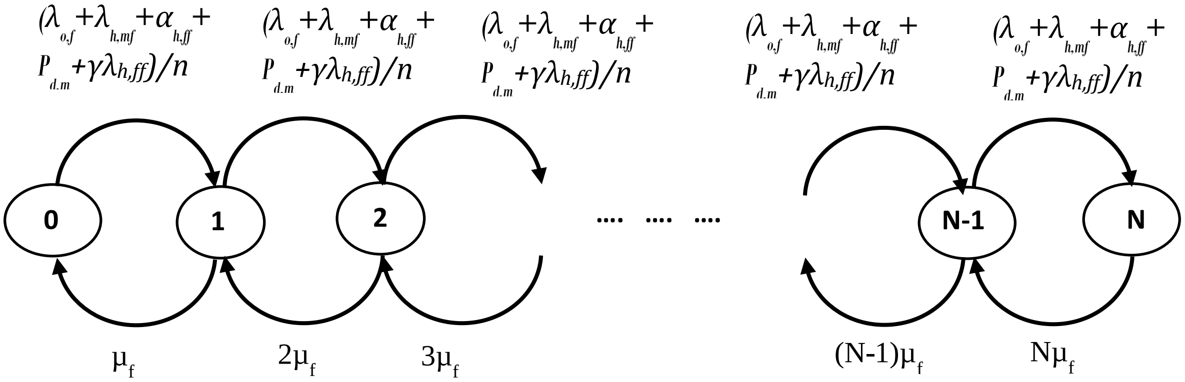

Figure 5.6 Markov chain for the femtocell layer [146]

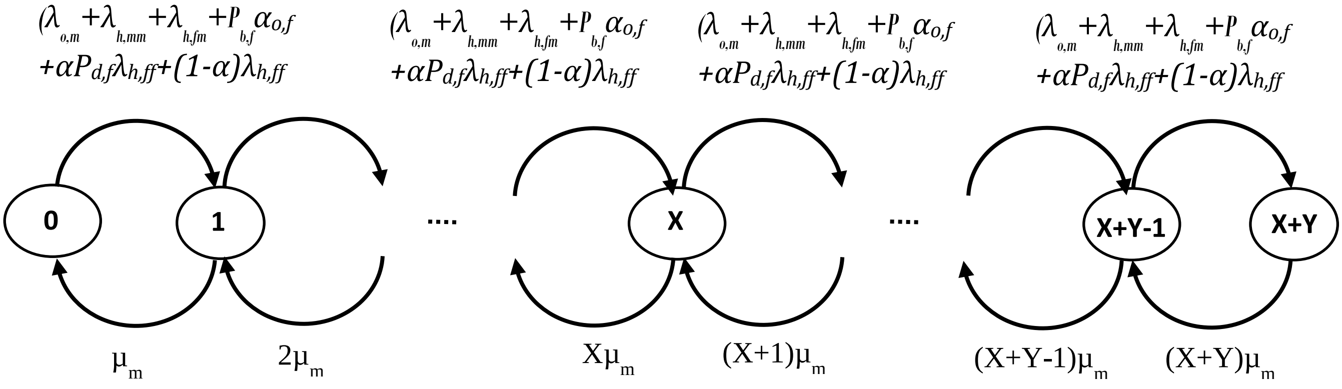

Figure 5.7 Markov chain for the macrocell layer [146]

where $\lambda_{o,f}$ represents the total originated-call arrival rate in the femtocell area and $\lambda_{o,m}$ is the total originated-call (*RT and NRT*) arrival rate in the macrocell area. n is the number of the femtocells within the macrocell area. $\lambda_{h,ff}$, $\lambda_{h,fm}$ represents the call rates for femtocell-to-femtocell, femtocell-to-macrocell respectively and $\lambda_{h,mf}$, $\lambda_{h,mm}$ represents macrocell-to-femtocell, macrocell-to-macrocell handover respectively. $P_{b,f}$, $P_{b,m}$ is the blocking probability of originated-call in the femtocell and macrocell respectively. $P_{d,f}$, $P_{d,m}$ is the dropping probability of handover call in the femtocell and macrocell respectively. α is the probability of received SNIR of T-HeNB which is greater than k_2 in a femtocell-femtocell handover. β is the probability of received SNIR of T-HeNB which is between k_1 and k_2 in a femtocell-to-femtocell handover.

State *X* is the maximum calls that the macrocell can accommodate without QoS' scheme and *Y* is the additional state used to support the handover calls in the proposed QoS scheme that is, the proposed scheme provided additional state used only in the macrocell to accept more calls.

The average channel release rate in the macrocell increases with respect to the increase in the deployed femtocell. This is because more traffic from the macrocell is handed over to the femtocells as the femtocell number increases. The average channel release rate for both femtocell and macrocell is as calculated in chapter four while the handover probabilities can be determined using the following equations:

$$P_{h,mm} = \frac{\eta_m}{\eta_m + \mu} \tag{5.1}$$

$$P_{h,fm} = \left[1 - n\left(\frac{r_f}{r_m}\right)^2\right]\frac{\eta_f}{\eta_f + \mu} \tag{5.2}$$

$$P_{h,ff} = (n-1)\left(\frac{r_f}{r_m}\right)^2 \frac{\eta_f}{\eta_f + \mu} \tag{5.3}$$

$$P_{h,mf} = n\left(\frac{r_f}{r_m}\right)^2 \frac{\eta_{m\sqrt{n}}}{\eta_m\sqrt{n} + \mu} \tag{5.4}$$

The femtocell average CBP $P_{b,f}$ together with average CDP $P_{d,f}$ can be determined as in [149] as:

$$P_{b,f} = P_{d,f} = P_f\left(N\right) = \frac{\left(\frac{\lambda_{T,f}}{n}\right)^{N} \frac{1}{N!\,\mu_f^{N}}}{\sum_{i=0}^{N} \left(\frac{\lambda_{T,f}}{n}\right)^{i} \frac{1}{i!\,\mu_f^{i}}} \tag{5.5}$$

where $\lambda_{T,f} = \lambda_{f,0} + \lambda_{h,mf} + \alpha\lambda_{h,f,f} + P_{d,m}\gamma\lambda_{h,f,}$, α and β are as defined previously.

The QoS policy having been applied to the macrocell only, the average CBP $P_{b,m}$ and the average CDP of the macrocell can be determined as follows [149].

$$P_{b,m} = \sum_{i=X}^{X+Y} P(i) = \sum_{i=X}^{X+Y} \frac{\left(\lambda_{m,o} + \lambda_{h,m}\right)^{X} \left(\lambda_{h,m}\right)^{i-N}}{i!\,\mu_m^{i}} P(0) \tag{5.6}$$

$$P(0) = \left[\sum_{i=0}^{X} \frac{\left(\lambda_{m,o} + \lambda_{m,h}\right)^{i}}{i!\,\mu_m^{i}} + \sum_{i=X+1}^{X+Y} \frac{\left(\lambda_{m,o} + \lambda_{m,h}\right)^{X} \left(\lambda_{m,h}\right)^{i-N}}{i!\,\mu_m^{i}} \right]^{-1} \tag{5.7}$$

where $\lambda_{h,m} = \lambda_{h,fm} + \alpha P_{d,f}\lambda_{h,ff} + \left(1-\alpha\right)\lambda_{h,ff}$

5.7 Results and Discussion

The simulation results of the proposed CAC-based handover management strategy for dense femtocell deployment together with a non CAC-based handover management strategy [147] are as shown in Figure 5.8, 5.9 and 5.10. The Simulation parameters and their values as used in this work are shown in Table 5.1. The two schemes are compared on the basis of the Handover Probability (HP), CBP and CDP.

In the non CAC-based handover strategy, a HeNB/eNB is selected as the target HeNB/eNB only if the signal level received from the target HeNB/eNB is greater than or equal to the signal the UE receives from the serving HeNB/eNB. Figure 5.8 shows the comparison between the proposed CAC-based handover strategy and the non CAC-based handover strategy in terms of handover probability. It is noticed from the graph that the handover probability of calls connected to the femtocell increases initially up to the call arrival rate of 2 for both strategies.

Table 5.1 Simulation Parameters

Parameter	Value
Radius of the eNB	500 m
Radius of HeNB	15 m
Power of eNB	46 mW
Power of HeNB	20 mW
Number of users in a macrocell	1000
Initial number of users in a femtocell	4
Mode access of femtocell	Open
k1: threshold value	-80 dBm
k2: threshold value	-60 dBm
Bandwidth capacity of a macrocell	10 Mbps
Number of femtocell deployed within the macrocell area	100 – 1000
Average call duration time for all calls	150 seconds
UEs Mobility	Random
Users traffic model	Real and Non real time
UE Speed	Varies
Simulation duration	100 seconds

However, the handover probability in the non CAC-based strategy doubles that of the proposed scheme from 2 up to the call arrival rate of 20. This is because in the proposed strategy, the handover algorithm ensures that mobile UEs are served by the macrocell while the QoS scheme ensures that some resources are released for the handover calls to be served. These together reduce the probability of handover calls in the proposed strategy. The handover probability of the non CAC-based handover strategy, on the other hand, is very high owing to the fact that the UEs are served by the femtocells irrespective of their mobility and there is no mechanism in place to allow more handover calls to be served in the macrocell. This causes frequent handovers from one femtocell to another. In addition, with CAC strategy, calls are adequately managed in the macrocell than without the CAC strategy.

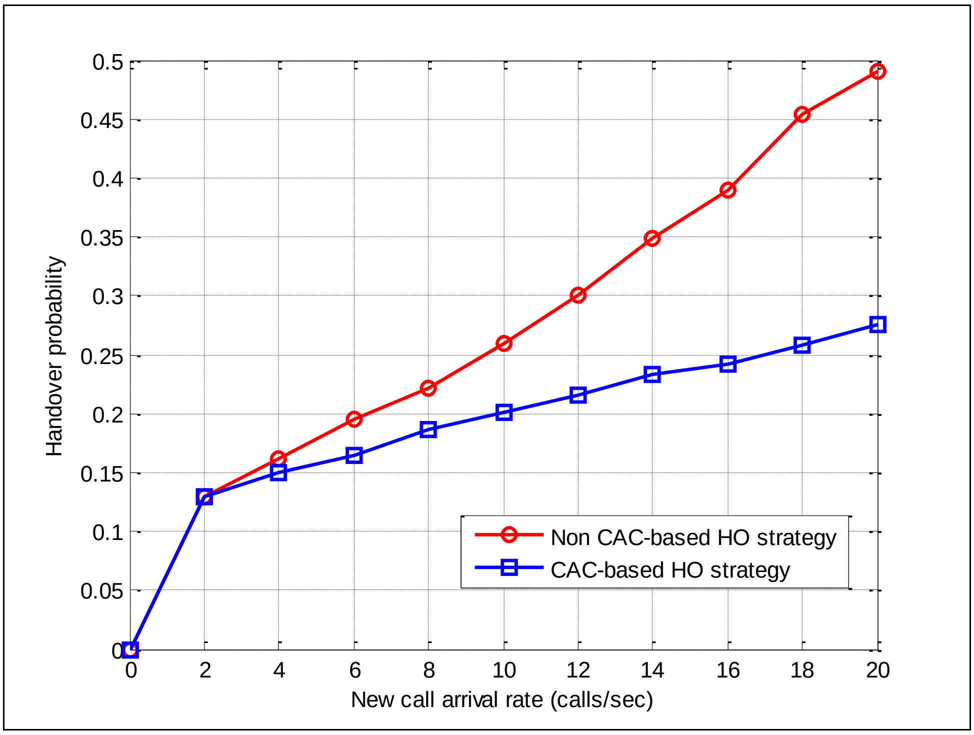

Figure 5.8 Handover probability

The blocking probability of the proposed CAC-based handover strategy and the non CAC based handover strategy with respect to the call arrival rate is as shown in Figure 5.9. It can be noticed that the call blocking probability at the call arrival rate of 2 calls/sec, is about 0.06 and 0.12 in the proposed CAC-based strategy and the non CAC-based strategy respectively. In the proposed CAC strategy, the calls originated from the mobile UEs stay connected to the macrocell or handed over to the macrocell while the stationary UEs are connected to the femtocells. The QoS' scheme also allows more handover calls to be served by the macrocell without overloading it. Thus, fewer calls are blocked in the system as indicated in the graph. On the other hand, the large value of the CBP in the non CAC-based strategy is due to the fact that the calls from the mobile UEs are handed over to the femtocells which make them to be quickly used up thereby leading to more calls being dropped. This happened because the femtocells are of low coverage and with more UEs coming to the femtocell, its capacity is used up quickly and call dropping is inevitable. By looking at the arrival rates between 2 calls/sec to 20 calls/sec, it can be concluded that the proposed CAC-based handover strategy performs much better and reduces the probability of calls being blocked by almost 50 % of the non CAC-based handover strategy. This shows that the proposed CAC-based handover strategy works efficiently and is suitable for dense femtocells network deployment than the non CAC-based handover strategy.

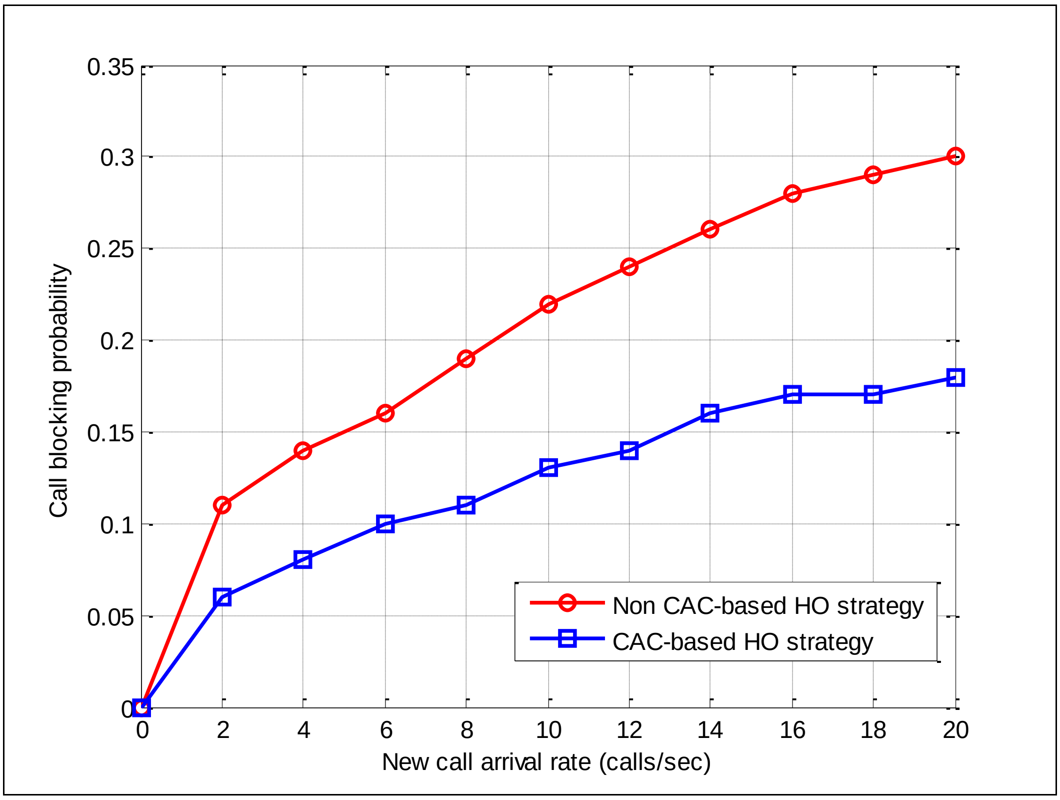

Figure 5.9 Call blocking probability

The graph in Figure 5.10 shows the result in terms of the call dropping probability of the proposed CAC-based handover strategy and the non CAC-based handover strategy against new call arrival rates. The CDP is very high in the non CAC-based strategy compared to the proposed strategy throughout the new call arrival rates. For example, at the arrival rate of 2 calls/sec, the CDP in the non CAC-based strategy is about 0.035 while it is around 0.005 in the proposed CAC strategy. This means that there is a significant improvement in the CDP of the proposed strategy. This is because in the non CAC-based strategy, the UEs handover to the nearby femtocells. This makes the femtocells to be quickly filled with UE calls while the macrocell is underused, hence, the existence of large CDP in the system.

In the proposed strategy, on the other hand, apart from the fact that mobile UEs are handed over to the macrocell, the CAC scheme ensures that the macrocells are not overused or underused while also maintaining the QoS of the handover calls. In order words, the proposed strategy ensure that the resources of the macrocells are effectively utilized leading to a reduction in the CDP.

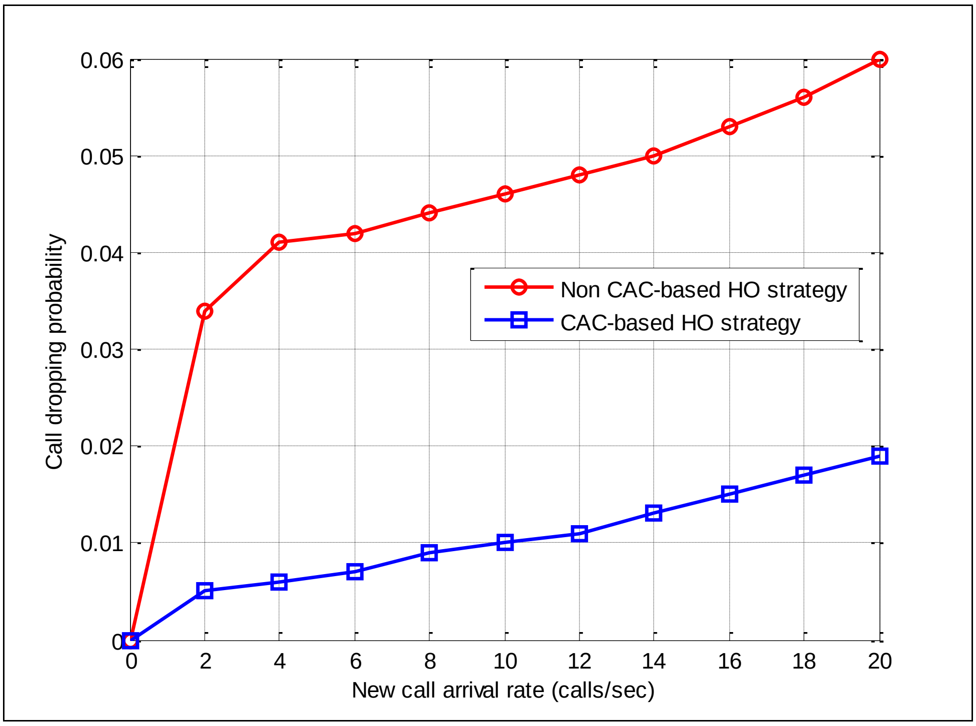

Figure 5.10 Call Dropping Probability

Comparison of the Analytical and the Simulation Results: We compare the results obtained during simulation with those of the analytical framework. A numerical evaluation of the proposed CAC-based strategy is performed using the derived equations 5.5 and 5.6 for the call blocking probability and call dropping probability respectively.

The results obtained for the call dropping probability from both the simulation and the analytical models are illustrated in Figure 5.11. Notably, between the call arrival rate of 0 and 2 (calls/sec), the same CBP values were recorded in the two models with little difference noticed beyond arrival rate of 2 calls/sec. However, the increase in the CBP behavior can be noticed in both the simulation and the analytical results. Since the CBPs in both models follow each other closely, this validates our analytical framework with the simulation model. In Figure 5.12, the call dropping probability results of the analytical framework and the simulation model are compared. Notably, the CDP values obtained in both are closely related for all the new call arrival rates. However, just like the CBP, both the analytical framework and the simulation model exhibit an increase in the CDP. Thus, since we have similar behavior in both models, this shows that the analytical framework can also be used to capture the behavior of the proposed strategy in terms of the CBP and the CDP in the LTE-Advanced network.

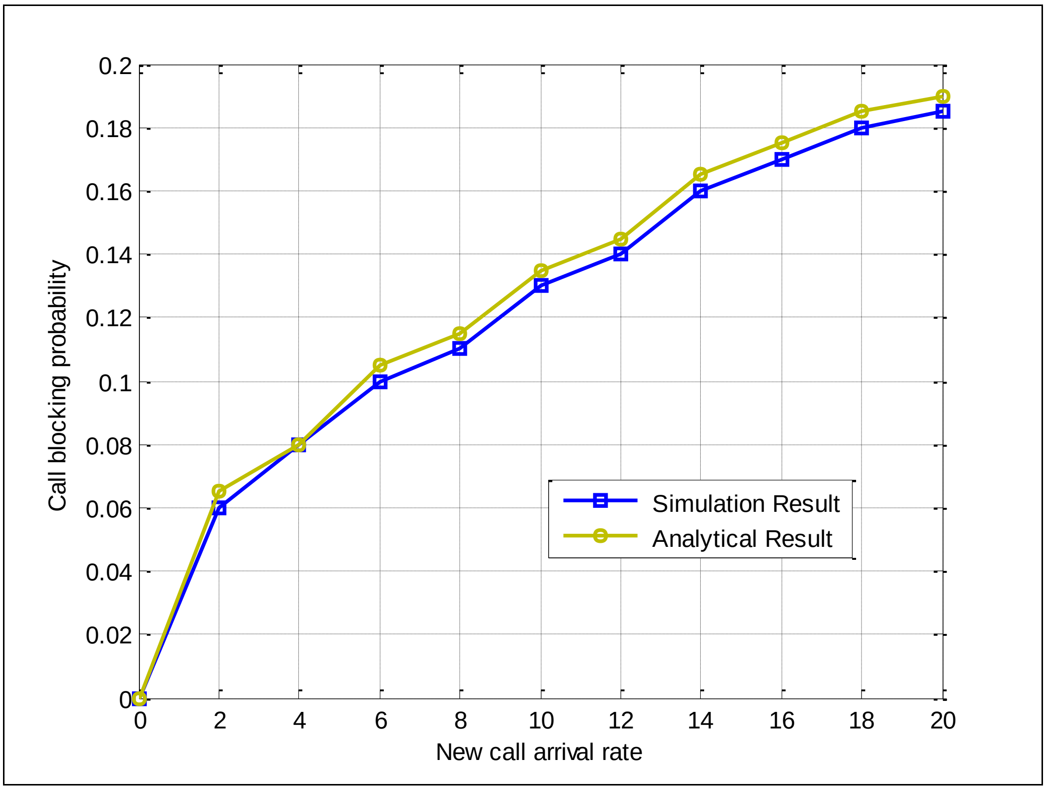

Figure 5.11 CBP Simulation result vs Analytical result

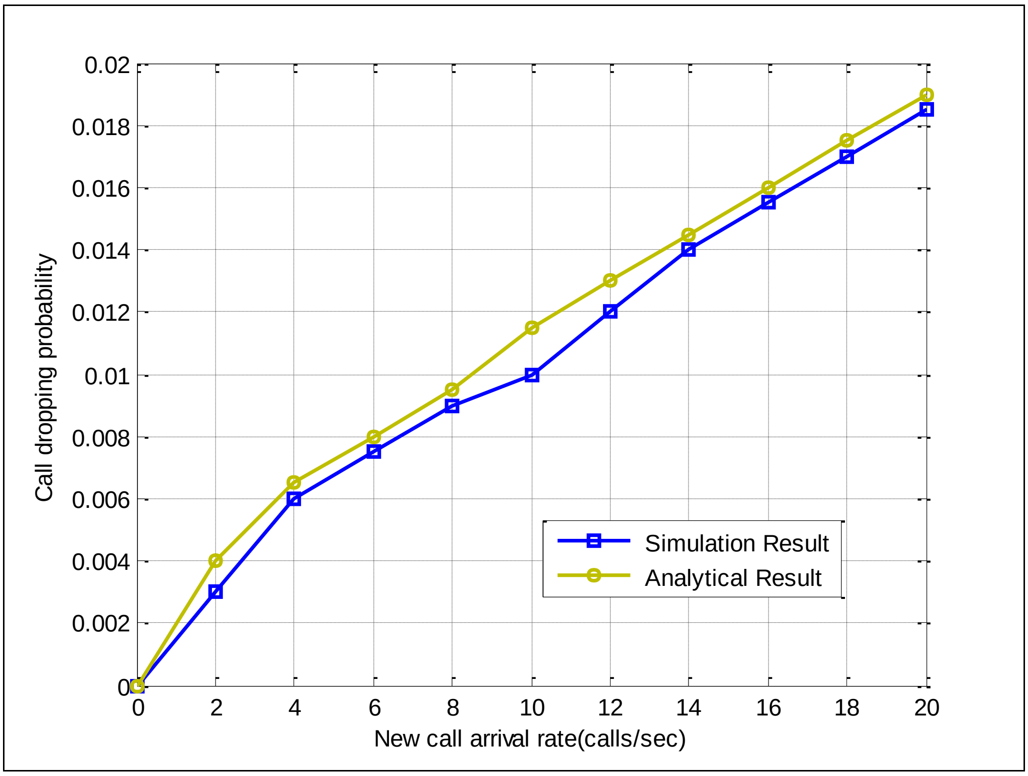

Figure 5.12 CDP Simulation result vs Analytical result

5.8 Chapter Summary

Dense deployment of the femtocell is said to be one of the cost effective ways of achieving increased coverage and capacity in the present LTE-A heterogeneous networks and future networks. Through the overlaying of hundreds of femtocells within the coverage of the macrocell, critical traffic can be offloaded to the femtocells. However, this often leads to frequent handover of the mobile UEs from one femtocell to another. Therefore, to harness the great benefit provided by the femtocells and to utilize the femtocell and the macrocell resources effectively, a robust handover management algorithm is a necessity for successful deployment of the dense femtocell networks. In this chapter, a robust CAC-based handover management strategy has been proposed to address this handover problem.

In the proposed strategy, many handovers were reduced by ensuring that the mobile UEs use the resources of the macrocell and the non-mobile UEs use the resources of the femtocells, and the QoS scheme enables the macrocell to accept more handover calls. There is high improvement in terms of the blocking and dropping probabilities with the proposed CAC-based handover strategy compared to the non CAC-based handover strategy. In addition, we have evaluated the call blocking probability and the call dropping probability through the analytical framework and achieved results closely related to those obtained through the simulation model.

CHAPTER SIX

GROUP HANDOVER STRATEGY FOR MOBILE RELAYS IN LTE-ADVANCED NETWORK

6.1 Introduction

Data and voice services demands in public transport vehicles are currently on the increase and to provide these services to every UE inside the vehicles, the present architecture of the LTE-A system has been redesigned to allow the mobile cells handle mobile traffics. Hundreds of UEs on-board of high moving trains are served by small cells such as relays which have been integrated to the LTE-Advanced system [150]. The relay nodes can carry all the mobile traffic (UE traffic) and hand them over to the eNB as a group [53]. To effectively perform the handover and enhance the quality of experience of the moving UEs, an efficient handover strategy is required.

This chapter proposes the group handover strategy for mobile relays in the LTE-A network. The objective is to provide solution to the frequent handover and call drop associated with UEs inside fast moving vehicles. The proposed strategy considers the mobile relay node deployed on fast moving trains and is evaluated by comparing it to the fixed relay node and direct UE deployments.

6.2 Relay Node (RN)

In this chapter, relay and RN are used interchangeably. Relays are small cells with a wireless backhaul connection to the eNBs. Communication takes place between a mobile UE and Donor eNBs (DeNBs) wirelessly and intelligently through the Relay Node (RN). Point-to-Point connectivity between DeNB and RNs is similar to the one between eNB and UEs. Like femtocell’s Internet Protocol (IP) backhaul connection to the core network [2], communication between the RNs and the DeNB occurs through a wireless backhaul connectivity [151]. The RN establishes Point to Multipoint (PMP) with the UEs to deliver the uplink and downlink to the UEs. The links DeNB to RN and RS to DeNB, are regarded as relay links while that of DeNB to UE and RS to UE are termed access links. In cellular networks, the relay provides increased capacity with the support of frequency reuse. This means that an increased capacity can be achieved if RN and DeNB communicate with different UEs using the same frequency [152]. The relays provide an improved coverage and enhanced throughput [153, 154] through a low deployment cost since they use wireless backhaul to connect to the network. Where the DeNB is unable to deliver adequate coverage, a relay can be deployed in an ad-hoc manner to provide sufficient coverage. Also, where backhaul connection between the DeNB and the RNs exists, better propagations, that is, reduced shadowing and path loss plus good Line-of-Sight (LOS) are experienced. Vehicle penetration loss at varying frequencies, path loss and the impact of LOS have been determined in [155, 156].

6.2.1 The Relay Node Deployment Scenarios

Generally, the RN nodes can be used either to provide an additional traffic capacity or to extend the coverage of a cell. When it is used to provide the former, it results in higher SNIRs and with the latter, a large geographical area is covered by the cell. The practical deployment scenarios of RN include the following.

A. **Cell Coverage Extension**: The RN is used to extend the cell coverage of an eNB in a cost effective manner [157]. For instance, in rural areas where it is expensive to install many macro base stations, only few macro base stations are installed and relaying can be a cheaper means of extending the coverage. In this kind of scenario, the RN is installed on a mast that transmits at 46 dBm, that is, same power as eNB. This is useful to maintain the same level of coverage without installing additional base stations.

B. **Outdoor Capacity Boost**: RNs can be used to boost capacity in the hotspot areas or at the edges of the cell to make the throughput experienced in all parts of the cell equal. For example, lampposts can be used as RN sites to provide more capacity outdoor. Due to their smaller sizes and inter-cell interference, the RNs can be deployed easily on top of the lamppost. RNs transmit power at around 30 dBm in urban environment and 37 dBm in suburban.

C. **Indoor Coverage Boost**: RNs can be used to provide increased coverage inside a building. In this kind of scenario, the RN is said to be functioning as femto eNodeB (or HeNB) with a wireless backhaul to the core network. This is mostly used in the absence of the ADSL link or wired network infrastructure for backhaul access. To prevent interference, the RN installed indoors must have low transmission power [57].

D. **Temporary Deployments**: the RN can be deployed temporarily to provide coverage during special events such as trade fairs, sports, convention, or during emergency or after a natural disaster such as the earthquake, flood, hurricane etcetera, which damages the existing wired network infrastructure. Low power RN is suitable for the provision of temporary coverage in such situations.

E. **Dead Spot Mitigation**: The RN can be used to fill coverage holes caused by large obstacles. For instance, high buildings can block signal propagation in a particular direction in the macro network and with the RN installed in that area, coverage can be provided. The RN is deployed in line-of-sight with the DeNB and it radiates in the direction of the dead spot. In this case, RNs provide a cost effective alternative to the conventional eNBs in dead spot zones [158].

F. **Group Mobility**: RNs can provide coverage to users on a fast moving train, or bus. In this scenario, the RN is deployed on top of the moving vehicle and communicates with the suitable DeNB. However, it is required that the RNs deployed in this situation be able to support group handover. Generally, the RN deployed on vehicles has higher transmission power and more efficient antennas than the UEs [158], thus leading to a reduction in call drops and handovers. They also offer better coverage and better battery usage of the UE as UEs' uplink transmission power is lowered than the usual eNBs.

6.2.2 Relay Node Selection Algorithm

The relay node selection algorithms can be divided into four different categories as explained below.

Classification based on the relay node numbers and attributes: the selection of the algorithm of a relay node can be divided into single-node and multi-node algorithms with respect to the number of nodes. The single node algorithm requires less power and it is fast and convenient. However, this algorithm is unsuitable when there is critical decline in signal or total signal loss from the node. Multi-node algorithm, on the one hand, can select the best cooperative node. On the relay node attributes, the selection algorithm can be divided into fixed node algorithm and mobile node algorithm. The design of a fixed node algorithm is less complex and requires less energy between the base stations. On the other hand, the mobile node algorithm considered relative distance between the base station and the mobile station.

Classification based on the cooperative approach: This approach includes decoding forward, amplifying forward and encoding cooperative. This approach combines cooperative diversity with channel coding. Different relay node algorithms require different cooperative approaches. For example, in amplifying forward cooperative on the one hand, cooperative nodes do not require any processing, albeit the nodes can transmit information on the source node. However, in decoding forward cooperative on the other hand, information needs to be decoded correctly by the nodes for proper transmission.

Classification based on energy consideration: in mobile and wireless communication, energy consideration is important because the mobile station changes location frequently. Thus, the Relay node selection algorithm executes in two modes namely: central and distributed modes. For the central algorithms, central nodes are responsible for accepting and transmitting information in the network. They are usually designed with energy support and multiple antennas for strong information processing capability. There is no central node in the distributed mode. Each node chooses whether to be involved in the cooperation or not. The distributed algorithm relies on its own energy and thus has weak information processing capability.

Classification based on the channel state information: algorithms are also classified on the basis of the state of the channel. The function of this algorithm is to transmit or send a request and or command between the source and the destination nodes. Channel measurement can be achieved in the process of sending this command or request. The node monitors, collects, and calculates the channel parameters and sends this information to the other nodes. The system then determines the best channel based on the information available and then end relay selection.

6.3 Related Studies

Relays have been classified into (i) fixed and (ii) mobile relays. A fixed relay node (FRN) supports many use cases and has been standardized in the 3GPP LTE release 10 standards [50]. Conversely, a mobile relay node (MRN) supports more use cases. The operators in a more deterministic fashion mostly deploy FRNs in coverage holes whereas MRNs are deployed in a flexible way particularly where FRN does not exist or is not economically justified [159]. Key network requirements such as low latency, high spectral efficiency and reduced handover interruption time are addressed in the MRN.

When an MRN is deployed at the top of a moving vehicle, it forms its own cell inside the vehicle thereby serving vehicular UEs efficiently [48] as shown in Figure 6.1. Signal strength enhancement to the UE can be achieved through an MRN which also decreases signaling overhead by handling multiple service connections simultaneously to the DeNB situated along the train routes [160]. Improved communication can be realized with MRNs through their smaller antenna size and power which exploit smart antenna and advanced signal processing techniques [48]. For the MRN to work effectively to improve communication in moving vehicles, the network connectivity to the DeNBs must be maintained to prevent frequent handovers associated with the direct UEs communication with the DeNBs. This can only be achieved with an efficient group handover management strategy in place. However, designing an appropriate handover management strategy for the group handover in the MRN is a huge challenge due to the difficulty in determining the actual point at which to trigger handover for group mobile users in moving vehicles. Also, the present architecture of the LTE-A supports the FRN, fixed relay architecture has been adapted to the mobile relay in [50].

The global tunneling concept was introduced in [50] to reduce the signaling of messages kept by the network nodes. The global tunnel is used to transmit vehicular UEs' data traffic served by a mobile relay. To identify the global tunnel, a Tunnel Endpoint Identifier is used. To reduce handover failure in mobile relay, a CoMP-based handover proposed by *Luo et al*. [51] allows a train to receive different signals from adjacent base stations whenever it passes the overlapping areas. The scheme utilizes CoMP joint processing and transmission technology to enable a high-speed train to obtain diversity gain. This, however, leads to improved quality of received signal, reliable communication between the train and the eNBs and significant improvement in handover. Group handover management for moving the cell based on the LTE-A was proposed by *Hwang and Shin* [52]. The authors argued that the fixed relay architecture of the LTE-A was not suitable for the mobile relay as all the UEs handovers need to combine into a single handover of one MRN. *Chen et al*. [53] proposed an architecture for the mobile relay node in the LTE-A. However, there was no strategy in place to handle group handover. The authors discussed only key techniques such as group mobility for supporting the mobile relay and there is no efficient strategy to handle handover resulting from the group mobility. Therefore, an enhanced group handover strategy for the mobile relay node in the LTE-A network is presented in this work. Reduction in the number of handover associated with the MRNs as well as maintaining the radio links between the MRN and DeNBs throughout the handover process is the main motivation for the proposed group handover strategy. The impact of the speed of the train on the call dropping probability is investigated.

Figure 6.1 shows an MRN deployed on a high-speed train communicating with the source DeNB (DeNB1) performing group handover to the target DeNB (DeNB2). The point of attachment of the MRN is changed from DeNB1 to DeNB2. For clarity, the deployment of the MRNs on the public train scenario was considered albeit any high-speed transport system can make use of the proposed work.

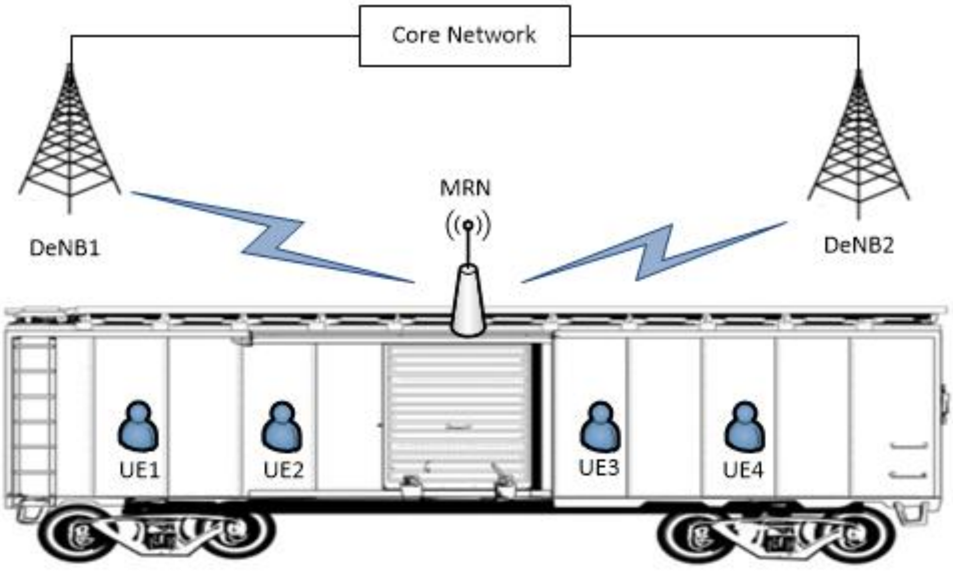

Figure 6.1 Group handover scenario in high-speed train

6.4 General Relay Architecture

In the LTE-A relay architecture, the RN supports full DeNB functionality as shown in Figure 6.2. It also supports other features such as the S1, X2 interfaces and the radio protocol termination. The backhaul interface which connects the RN to the DeNB via the S1 and the X2, is called the Un interface. The DeNB provides the S1 and the X2 proxy function between the RN and the other eNBs, MMEs and S-GWs [57]. This proxy-function includes passing the S1 and the X2 signaling messages specific to the UE, GPRS Tunneling Protocol (GTP) data packets between the RN' S1/S2 interfaces and other network nodes' S1/S2 interfaces [33]. DeNB occurs to the RN in many different ways because of the proxy functionality, that is, as the MME, eNB and as S-GW.

6.4.1 RN User Plane

The DeNB serves as the S-GW and the P-GW to the RN [158]. The functions of the S-GW and the P-GW include creating the RN session and the EPS bearer management in the RN. The DeNB and the RN perform signaling and data packets mapping to the evolved packet system (EPS) bearers. This mapping depends on the QoS mechanisms like the quality class identifier (QCI) in the UE and the P-GW. There are eight (8) data radio bearers (DRBs) per RN on the backhaul link. Data on the RN bearers is mapped according to the QCI values of the EPS bearers. The mapping configuration is achieved by the O&M with multiple to single mappings supported. The DeNB then completes the set up implementation and other implementation such as the timing and the Un bearers modification. The RN user plane protocol stack is depicted in Figure 6.3.

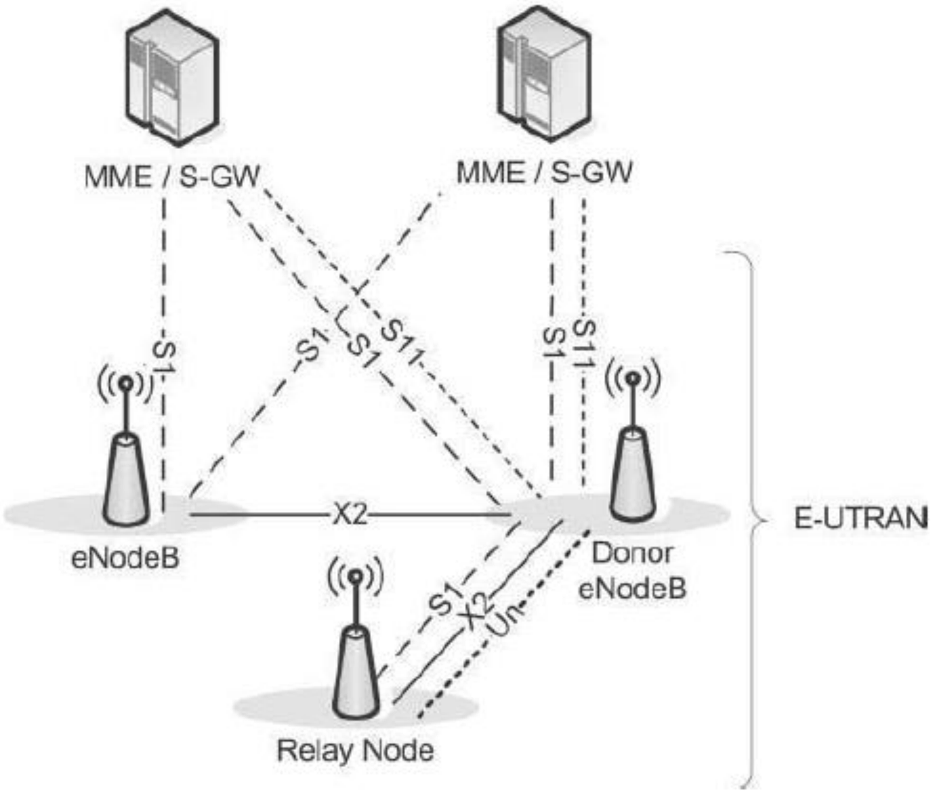

Figure 6.2 RN network architecture and interfaces [57]

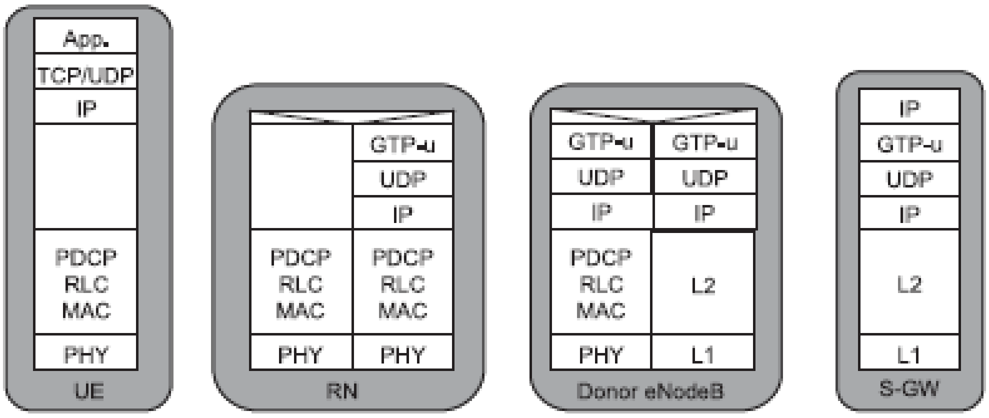

Figure 6.3 RN user plane protocol stack [57]

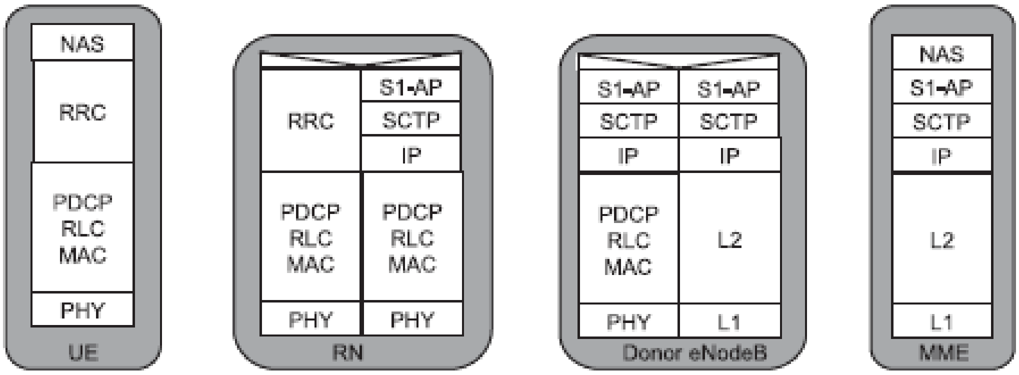

Figure 6.4 RN control plane protocol stack [57]

6.4.2 RN Control Plane

In the control plane of the RN, all the S1 messages between the MMEs and the RN are processed and forwarded to the DeNB for all the UEs dedicated procedures. In the UE dedicated procedures, the S1 Application Protocol messages can be processed by modifying the UE message identities and the GTP Tunnelling End IDs (TEIDs). However, other parts of the messages remain unchanged. Non-UE dedicated procedures between the RN and the DeNB and between the DeNB and the MMEs are handled locally. Similarly, for mobility, the X2 messages are processed like the S1 messages. More explanation on the RN user and control planes can be found in [57]. Figure 6.4 shows the control plane protocol stack.

6.4.3 Mobile Relay Architecture

Due to different DeNBs serving the MRN, [53] proposed two possible architectures known as the initial GW and the relocated GW architectures as displayed in Figure 6.5 and

Figure 6.6 respectively. In Figure 6.5, the MRN PGW/SGW is always at the S-DeNB (initial DeNB) for typical operation of the mobile relay in the initial GW architecture. The forwarding of packets of data between the S-DeNB and the T-DeNB is accomplished by the S-DeNB which also performs the function of keeping the MRN, and the UE's content. During the MRN mobility, no additional signaling is required for handover in the network.

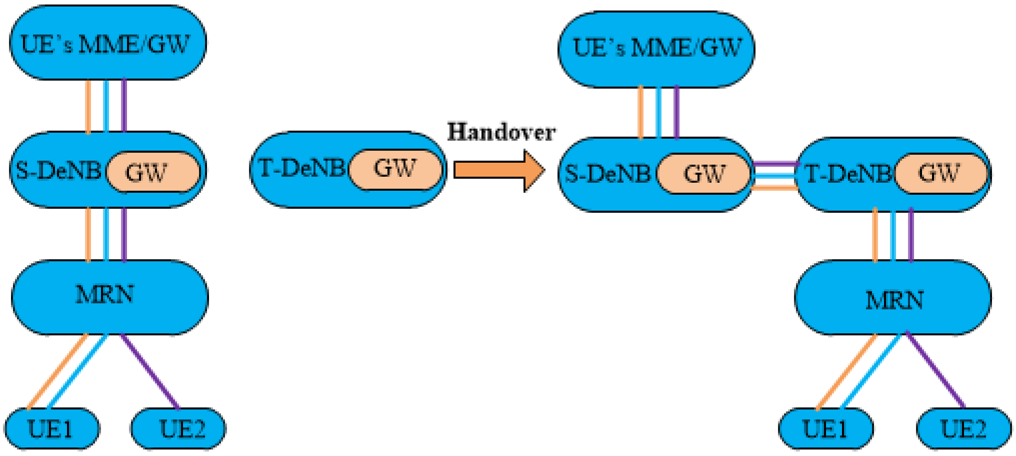

Figure 6.5 Initial GW architecture [53]

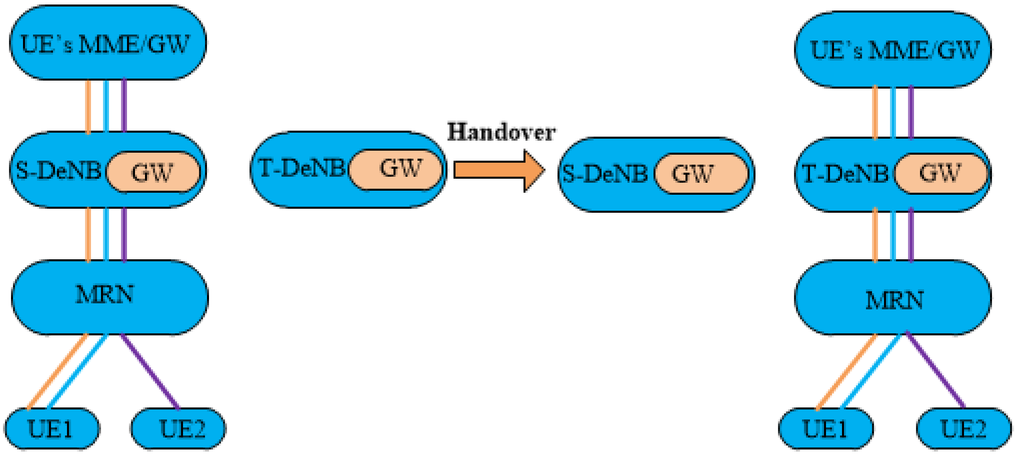

Figure 6.6 GW relocation architecture for MRN [53].

In the GW relocation architecture shown in Figure 6.6, SGW/PGW and Relay GW have been relocated to the T-DeNB. The MRN's SGW/PGW and Relay GW are relocated to the T-DeNB whenever a handover occurs from the S-DeNB to the T-DeNB. If the MRN travels a long distance from the S-DeNB, a long routing path is created in the initial GW architecture [53]. Moreover, additional signaling overhead is guaranteed in situations where the GW relocation occurs each time a handover is performed by the MRN in the GW relocation architecture. A combined solution has been provided in [53] where the GW relocation is only carried out when required.

6.4.4 Proposed Group Handover Strategy

The proposed group handover for the MRN is represented by the flowchart of Figure 6.7. To enable group handovers of in-train users, the relay node is mounted on the high-speed train with wireless backhauls to the DeNBs as shown in Figure 6.1. This way, a single group handover procedure displayed in Figure 6.7 ensures proper handover of the users served by the MRN between two DeNBs. The radio interface and the network overheads can be greatly lowered by the group handover aside the reduced number of handovers and call dropping probabilities achieved through the group handover. It should be noted that [53] proposed only the architecture for the MRN in the LTE-A, that is, no special scheme or strategy to handle the resulting group handover. In this work, however, we propose a special mobile device (*mdev*) to be integrated and deployed with the MRN, the function of which is to forecast the location and the direction of DeNBs and to prepare the MRN for timely handover to the target DeNBs. Multiple radio access technologies [48] can be supported by the MRNs since they act as regular eNBs. Steps for the proposed group handover strategy as depicted in the flowchart are highlighted below:

A. The signal level to the S-DeNB is measured by the MRN and it compares the output with a threshold signal.

B. In case the signal in (A) above is less, the MRN with the *mdev* measures its signal level to the T-DeNB and compares it with the threshold signal.

C. Resource availability at the T-DeNB is determined if the signal in (b) above is greater than the threshold.

D. In cases where resources are available, the MRN handovers the UEs group communication information to the T-DeNB otherwise there is no handover and the MRN remains with the S-DeNB. The steps are repeated until the new T-DeNB is found.

It should be noted that the MRN performs a single measurement to the S-DeNB and the T-HeNB for the group handover and not the individual UE performing measurement to the S-DeNB and the T-HeNB.

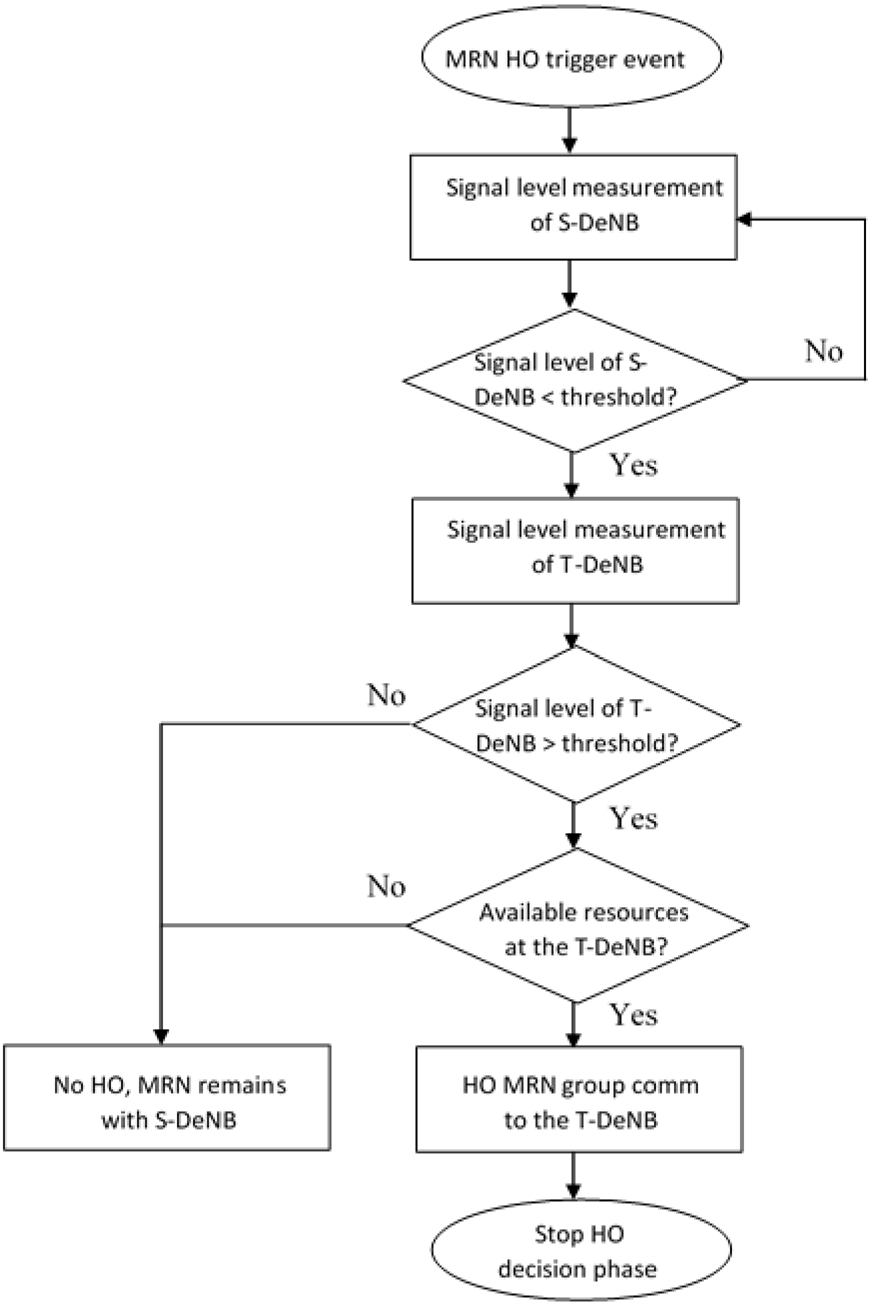

Figure 6.7 Proposed group handover flowchart

Equation (6.1) determines the available resources at the target DeNB:

$$C_{users} + C_{req} \subseteq C \tag{6.1}$$

where C signifies the total system capacity, C_{req} signifies the capacity requested by the group handover call, and C_{users} signifies the actual capacity required by the connected users.

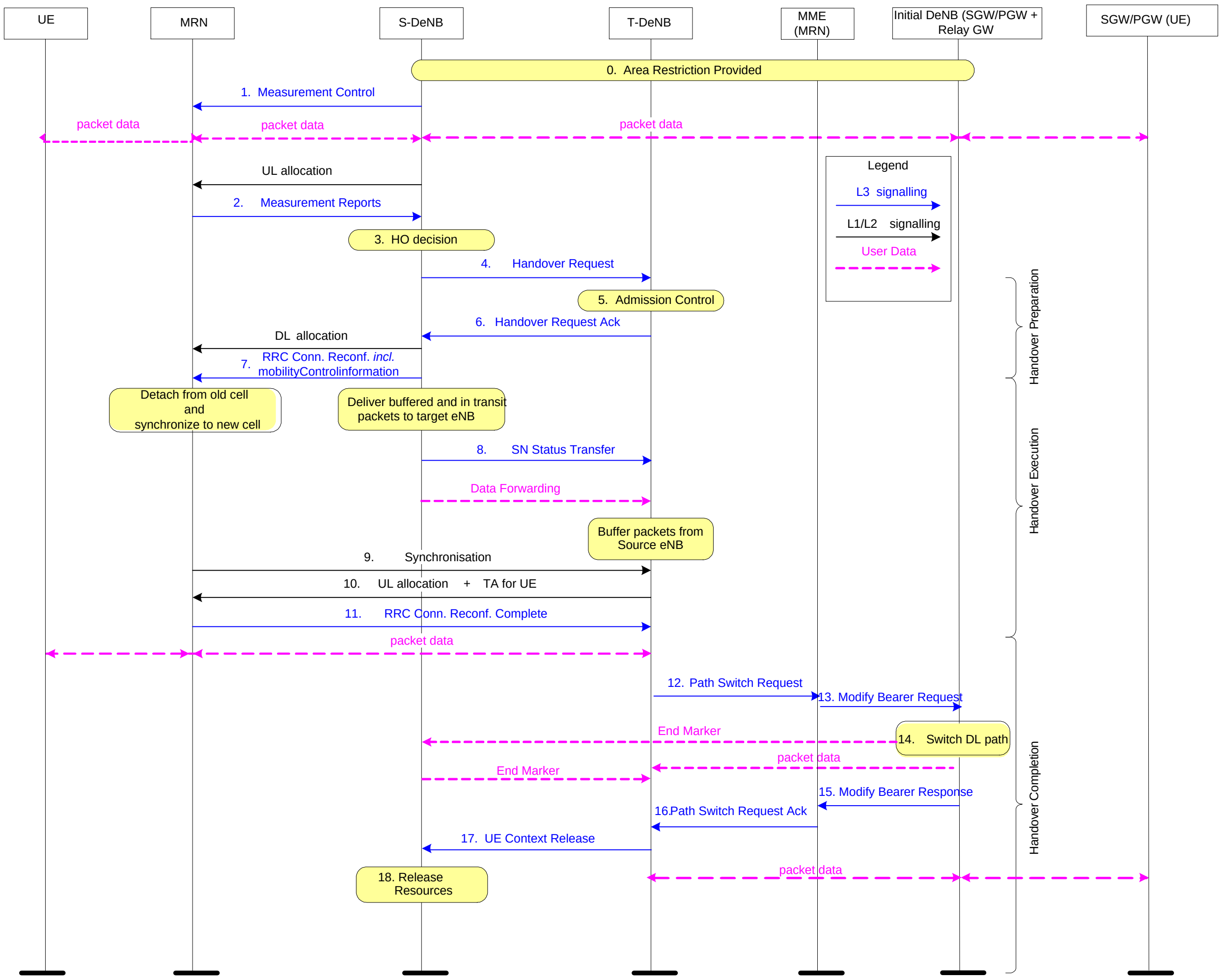

Figure 6.8 MRN Handover Procedure [161]

The procedure for establishing the group in the MRN is shown in Figure 6.7. The signal measurement to the S-DeNB is performed by the MRN and if the signal is low, the S-DeNB initiates group handover by sending handover request to the target DeNB. The S-DeNB makes the handover decision based on the proposed strategy depicted by the flowchart of Figure 6.6. The target DeNB performs the admission control of the backhaul link to decide whether to accept the MRN or not. If yes, the T-DeNB replies to the S-DeNB with the handover request acknowledgement.

The S-DeNB sends the RRC message containing the connection reconfiguration and the mobility control information to the MRN. The MRN is detached from the old cell (that is, S-DeNB) and tries to synchronize with the new cell (that is, T-DeNB). A status transfer command which informs the T-DeNB about allocating the uplink resources to the MRN, is sent by the S-DeNB to the T-DeNB. After successful synchronization, a tracking area update is sent by the MRN to the MME which updates the location of the MRN. The T-DeNB sends path switch request to the MME in order to switch the routing path to the MRN. The MME sends and receives modified bearer requests to and from the SGW/PGW/Relay GW. The T-DeNB receives the path switch request acknowledgement and the resource release is completed after the S-DeNB receives UE context release.

6.5 Results and Discussion

Analysis of the performance of the proposed group handover strategy on the UEs communication can be done against:

Scenario 1, where the UEs communicate directly to the T-DeNB (that is, no group handover). This can be represented by the FRN GRP-HO.

Scenario 2, where the FRN node (with group handover) is used. This can be represented by DIRECT-HO.

Through the event-based simulator developed in C#, the number of handover and call dropping probabilities were evaluated. We assumed that the train moves in a straight line with the DeNBs deployed alongside the railway line. In order to represent different scenarios, the FRN and the MRN were deployed on top of the train separately. In the proposed strategy, *mdev* in the MRN monitors and detects signals from the DeNBs every few second. It also activates the group measurement report and prepares the MRN for timely handover once the condition in the proposed strategy is fulfilled. The threshold and other parameters were set by referring to the [162] and the default parameters used are as presented in Table 6.1.

The two DeNBs: the S-DeNB and the T-DeNB discussed earlier in this study are represented by *Bs* and *Bt* respectively in Figure 6.9. The distance from *Bs* to *Bt* is designated as *D* and the train velocity as *V*. Let *d* be the distance from *mdev* in the MRN to the DeNB *v,* where *v* Є {*Bs* and *Bt*}. The signal strength from the DeNB to *mdev* can be given as:

$$R(v,d) = K - 10y\log(d) + \varpi \tag{6.2}$$

where K represents a constant and signifies the revised transmit power of v. ϖ is a zero-mean Gaussian-random variable with a shadowing fading represented by deviation σ .

We assumed that the MRN through *mdev* received messages on signal strength from the DeNBs and the DeNBs also receive messages from the MRN through the same means. If the quality of signal in T-DeNB is greater than a threshold *U* in *dB* and it is known by the *mdev*, the measurement report can be triggered immediately in the MRN. The *mdev* awaits the Radio Resource Connection (RRC) reconfiguration message from Bs which replies in a time *Td* after the measurement report is triggered. However, if the message is lost, it is resubmitted within a fixed interval *Tr* by the *Bs*. Finally, the RRC configuration is received by the *mdev*, otherwise the radio link failure occurs.

Assuming the measurement report is triggered at a location *X* of the *mdev*, if the RRC connection reconfiguration is sent by the *Bs*, the *mdev* with the MRN would have moved with the train to location X_1.

$$\text{Where } X_1 - X = V * T_d \tag{6.3}$$

If the RRC connection reconfiguration message is, however, not received correctly by the *mdev*, the *Bs* resends the message when *mdev* is in location X_2.where

$$X_2 - X_1 = V * T_r \tag{6.4}$$

Table 6.1 Simulation Parameters

Parameter	**Value**
Bandwidth	10 MHz
Frequency	2.6 GHz
Train speed	Up to 350 km/h
Transmit power (eNB/DeNB)	46 dBm
Transmit power (Relay)	10 dBm
Path Loss Model	32.4 + 20 log (f) + 20 log (d) dB

Since the handover can be triggered between *Bs* and *Bt*, the probability of successful handover performed by *mdev* during the handover procedure can be given as:

$$P = \frac{1}{D}\int_{o}^{D} P\{R(B_t, X_t) + R \supseteq U\} * \left(1 - \sum_{x,\in\{x_1, x_2 \dots\}} P\{R(B_s, X_s) \subset S\} d(X)\right) \tag{6.5}$$

From Equation (6.5), when *mdev is at Bs,* the handover procedure is triggered when the signal quality detected plus *R* is greater than or equal to *U.* Where *R* is known as a reward parameter used by *mdev* when moving towards a nearby DeNB to speed up the triggering process of a measurement report. Similarly, in case the signal quality in *Bs* is greater than *S* at any point in set *Xs,* the handover is successful. The distance *Xt* in Figure 6.9 becomes shorter for a fixed distance *D* and the probability of *mdev* triggering a handover is higher. However, the probability of *mdev* receiving the RRC connection reconfiguration becomes lower.

The performance of the proposed MRN GRP-HO can be determined by comparing it with the two scenarios described above. We also refer these two scenarios as conventional procedure. The handover number in Figure 6.10 shows the three cases that we considered in this work. In the FRN GRP-HO and the Direct-HO, the handover number increases when the train's distance progresses further. This is because the FRN and the UEs respectively can no longer keep connection with the S-DeNB due to signal loss and the inability to timely detect the T-DeNB to communicate with. Since the UEs remain connected to the MRN throughout the train sojourn and the MRN can detect the T-DeNB on time with the aid of mdev, the number of handovers is the same throughout and much less in the proposed MRN GRP-HO. Consequently, compared to the overhead in both the Direct-HO and the FRN GRP-HO, the control signalling overhead in the MRN GRP-HO is significantly reduced.

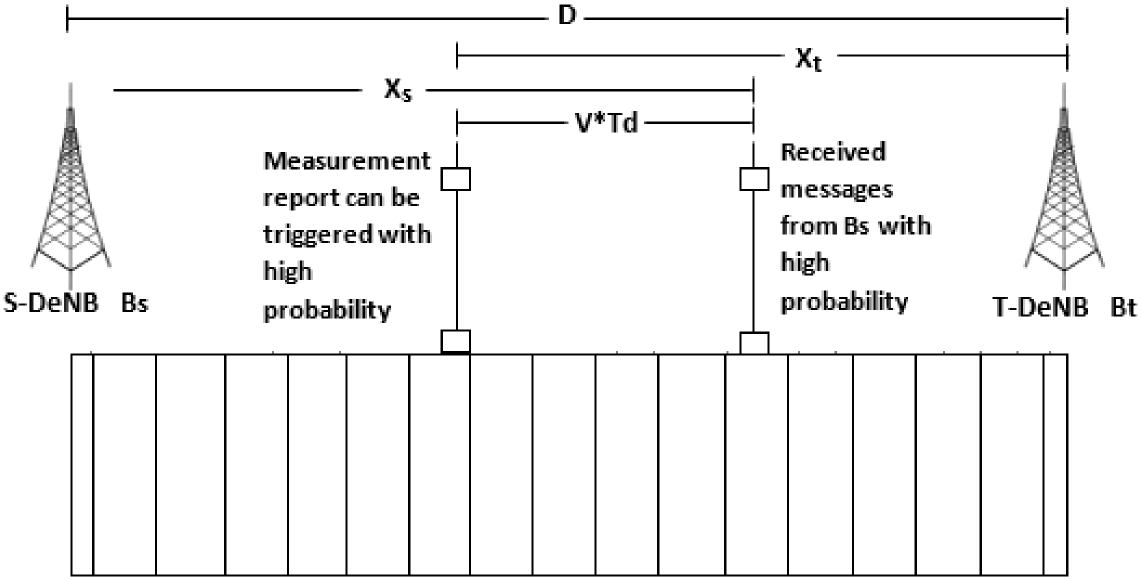

Figure 6.9 Distance between the DeNBs

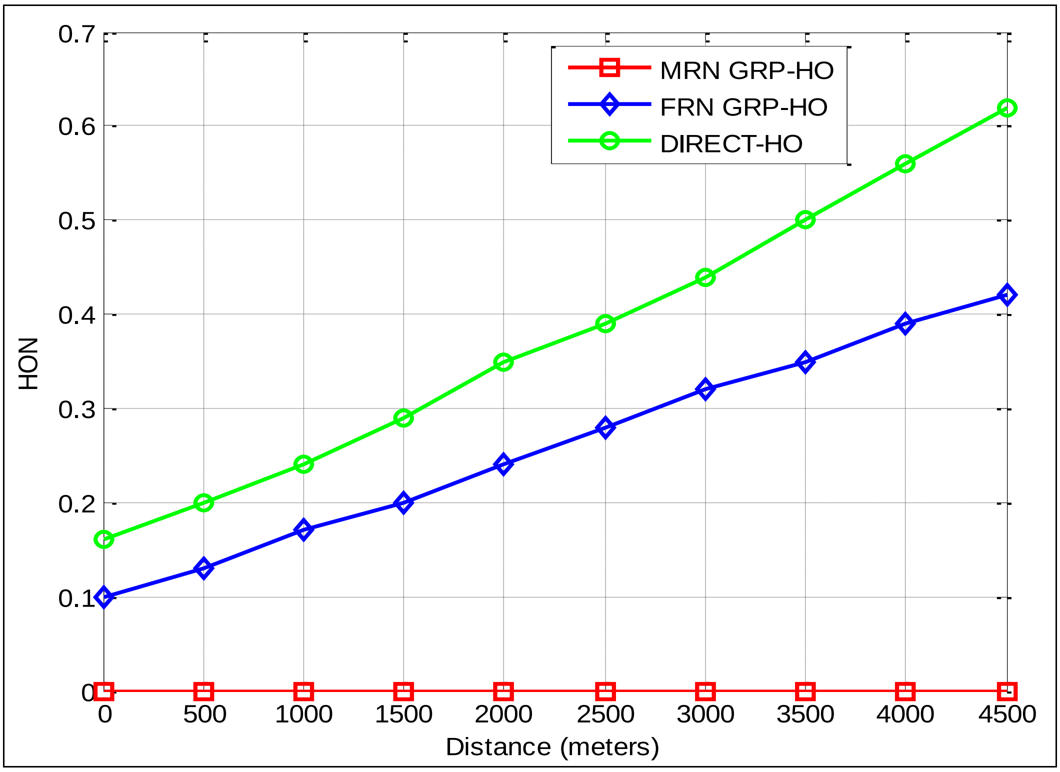

Figure 6.10 Handover number

However, with the FRN, better connection is available particularly at the edges of the cell compared to the direct UE connection to the DeNB. Hence, the number of handovers in the FRN GRP-HO is less than that of the Direct-HO.

Most of the UEs calls were dropped in the DIRECT-HO, that is direct communication between the UEs and the DeNBs, as all the UEs try to perform handover to the T-DeNB individually because the strategy to prepare each UE for handover beforehand and to determine the availability of resources at the T-DeNB does not exist. This also applies to the FRN GRP-HO. In all, there were little call drops as the train moved a certain distance when the UEs were initially connected to the S-DeNB as shown in Figure 6.11. However, as the train moves further around 1500 m, the highest call drops from this point were noticed and throughout the rest of the train stay in the DIRECT-HO as the UEs could not handover timely to the T-DeNB. This is coupled with the unavailability of a mechanism to prepare handover before time. Compared to the DIRECT-HO, calls dropped in the FRN GRP-HO are lower because of the group handover scheme but lack in strategy to assist in preparing the group to handover to the T-DeNB on time and accurately. However, the lowest call drop is recorded in the proposed MRN GRP-HO due to mdev which determines the closeness of the MRN to the T-DeNB and prepares the MRN for timely and accurately handover to the T-DeNB.

6.5.1 Effect of the speed of the train on the CDP

In the proposed MRN GRP-HO, the speed of the train has little effect on the CDP as shown in Figure 6.12. When the train is moving at a speed of 50 km/hr, the total CDP is about 0.02. By the time the speed of the train increases to 350 km/hr, there is a little increase in the CDP. The CDP is very small owing to the fact that the distance between the MRN and the UEs is very small and there is LOS link between the two. The signal loss is very little and therefore, there is no significant call drop as the train moves at a higher speed. If we compare this with the FRN curve where the UEs communicate with a dedicated DeNB, we can see that as the speed increases, a higher CDP is recorded. Due to the speed of the train, most of the ongoing UEs calls are dropped while trying to connect to another FRN. Also, since there is no LOS between the UE and the FRN, signal loss is increased and the CDP is higher than in the proposed MRN GRP-HO. Similarly, in the DIRECT-HO to the DeNB, there is no LOS between the UE and the DeNBs. Neither is there any dedicated FRN deployed along the train path. Therefore, a higher CDP than the proposed MRN GRP-HO and FRN GRP-HO is recorded in the DIRECT-HO. Since the CDP in the proposed MRN GRP-HO is the smallest, we can conclude that the proposed strategy performs better than the other two when the speed of the train is considered.

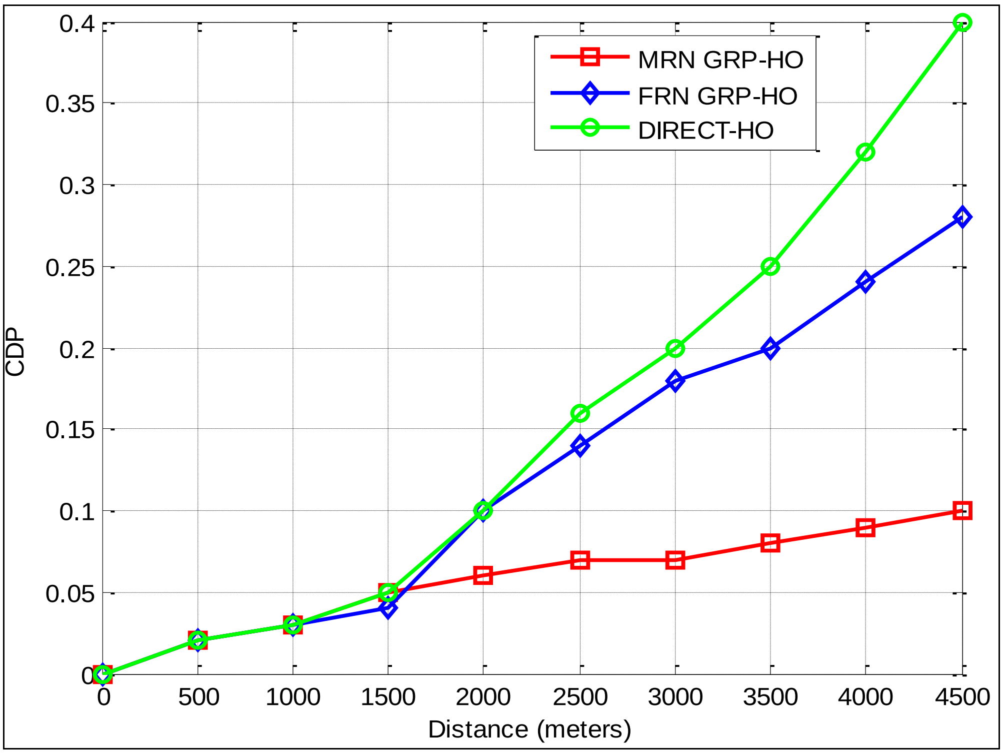

Figure 6.11 Call dropping probability

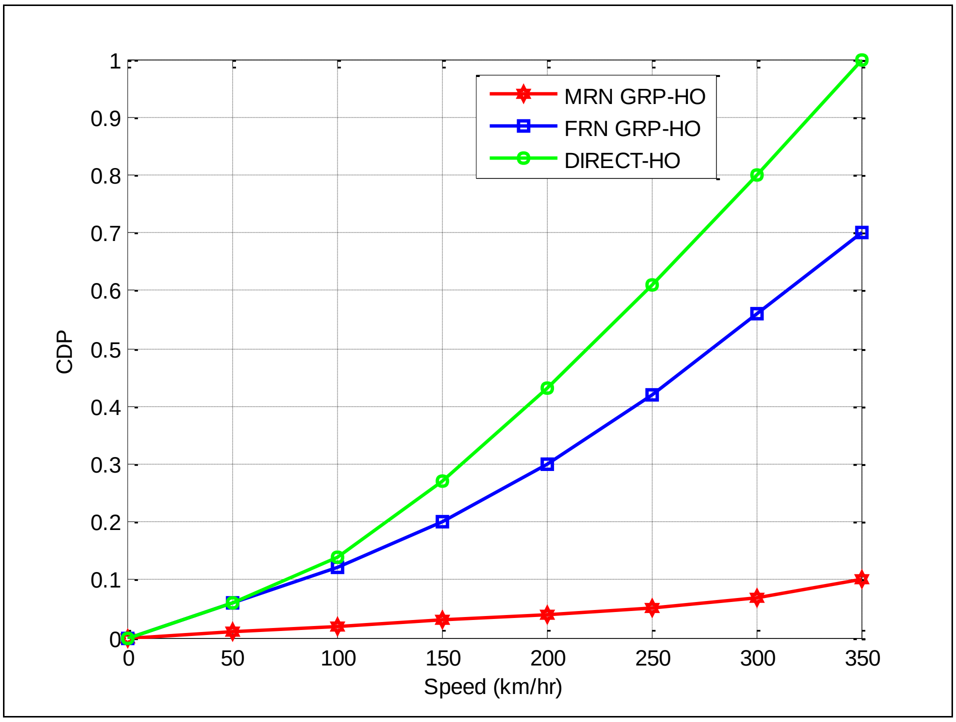

Figure 6.12 CDP vs Speed of the Train

6.5.2 Performance Analysis of the Distance between the S-DeNB and the T-DeNB

Consider the distance *D* between the *Bs* and *Bt* as given in Figure 6.9, and the train moving between the two DeNBs at a velocity v along a straight line. The UE measures the signal strength between the DeNBs at constant intervals T. Due to distance, Path loss and Lognormal (shadow) fading affect the total received signal power level. Rayleigh fading is, however, neglected due to its shorter distance correlation which gets average out with respect to shadow fading. Therefore, we calculate the signal levels which the UE receives from *Bs* to *Bt* at time *nT* as:

$$P_k(n) = \gamma_k - \chi_k \log\left[d_k(n)\right] + \eta_k\left[d_k(n)\right] \tag{6.6}$$

where k = 0, 1 and d_0, d_1 are the distances of UE from *Bs* and *Bt* respectively.

$d_0(n) = vTn$ and $d_1(n) = D - d_0(n)$ where n = 1, 2 …... R and $R = D/vT$.

And the path loss term $\gamma_k - \chi_k \log\left[d_k(n)\right]$, γ_k and χk are the mean signal strength parameters for the UE-DeNBs link. η_1 and η_2 refer to as self-dependent zero-mean stationary Gaussian modelling processes.

The handover and outage probabilities can be determined as follows. At every *T* seconds, the handover decision process can be defined as *x(qG)*:

$$x\left(qG\right)=l_0\left(qG\right)-l_1\left(qG\right) \tag{6.7}$$

where $q = 1, 2 \ldots N/G-1$

The following can be defined based on the equation (6.7)

$d(qG) = 0$ if $x(qG) \geq 0$ else $d(qG) = 1$ if $x(qG) \leq 0$.

where *d(qG)* is the DeNB the UE is connected to at *(qG + 1)* time.

As handover occurs at time *d(qG)* and *d(q+1)G*, therefore, the performance of the proposed algorithm can be evaluated by defining the outage probability as:

$$P_{out}\left(qG+g\right)=P\left[Pd_{qg}\left(qG+g\right)<\rho\right] \tag{6.8}$$

The handover probability P_{HO} can be defined as:

$$P_{HO}\left(qG\right)=P\left[d\left(qG\right)\neq d\left(qG-G\right)\right] \tag{6.9}$$

We evaluate the performance of the proposed strategy and existing strategy based on the handover probability of equation (6.9). We assumed that some of the UEs are initially connected to the *Bs*. When the UE is within or near the *Bs* as shown in Figure 6.13, the handover probability is almost around zero (0) for both strategies. This is because the UE remains connected to the *Bs* and no handover or handover attempt occurs between the *Bs* and *Bt*. As the train moves further in distance and towards the midway of the two DeNBs, the handover probability is at the highest level with the proposed MRN GRP-HO strategy performing better due to the *mdev* which helps to prevent unnecessary handover and also determine if resources available at the Bt. The FRN GRP-HO strategy, however, performs better than the DIRECT-HO due to the presence of the fixed relay which reduces the handover but unlike the MRN strategy, there is no mechanism in place to determine the available resources at the target-DeNB.

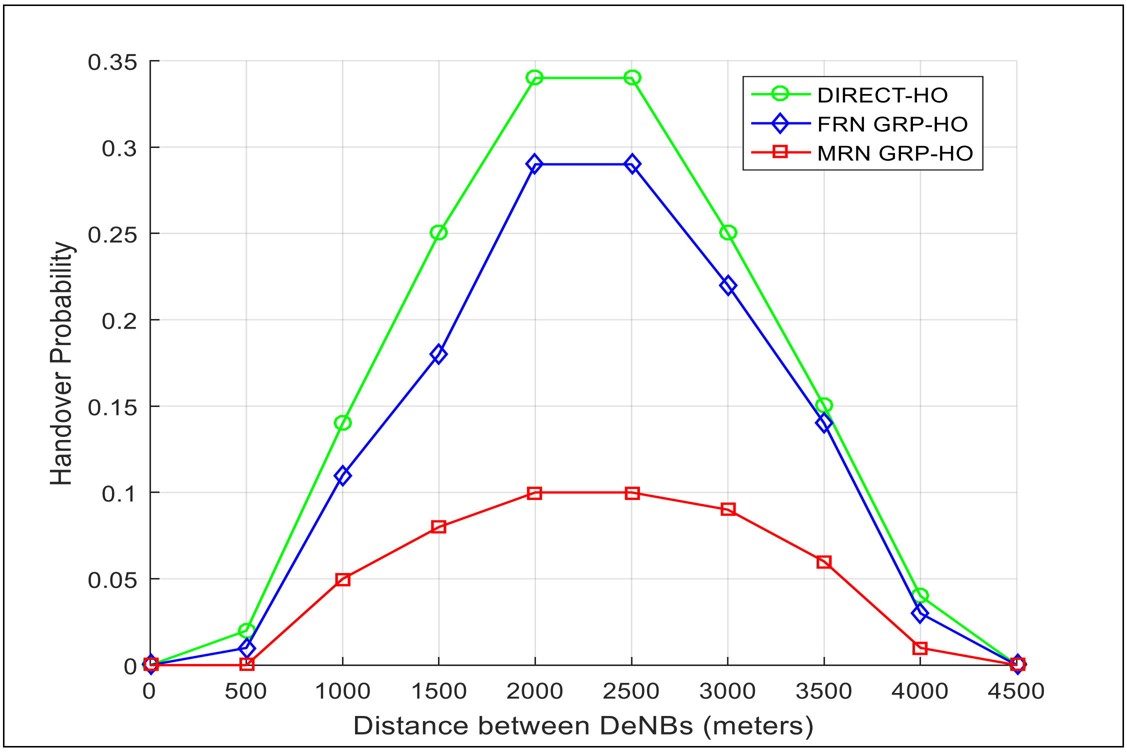

Figure 6.13 Handover Probability

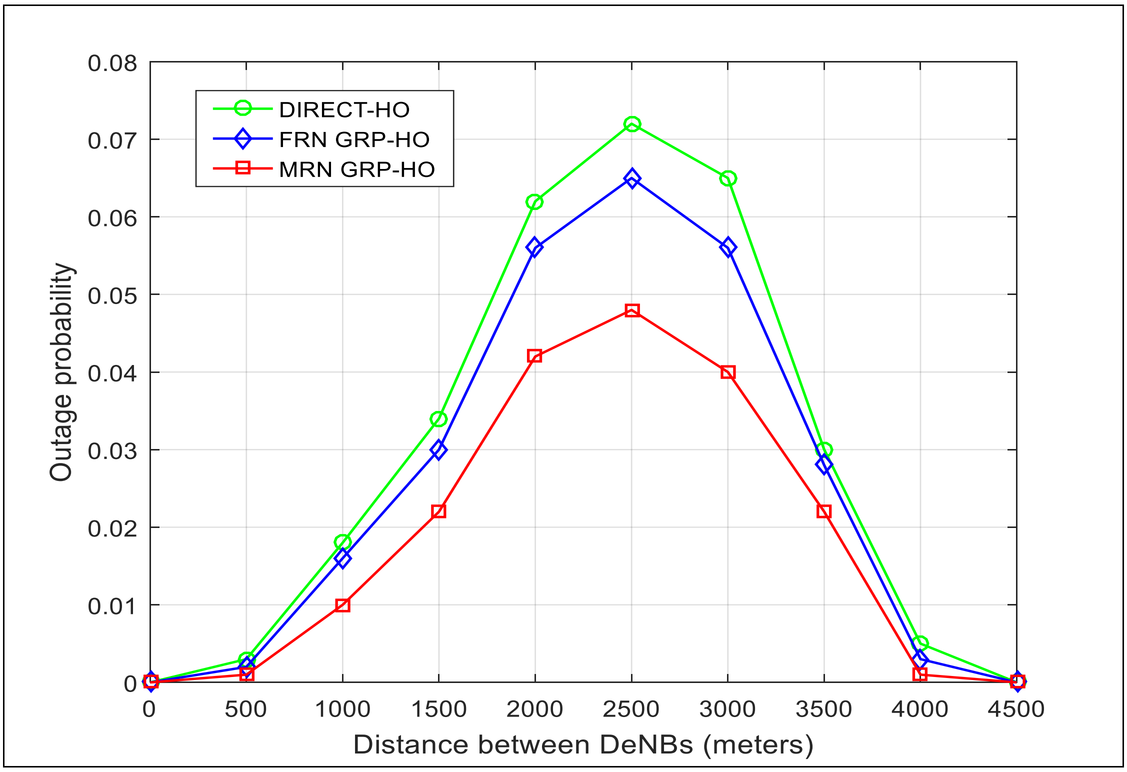

Figure 6.14 Outage Probability

The graph of the outage probability shown in Figure 6.14 is similar to the graph of the handover probability in Figure 6.13. The outage probability increases in all the strategies due to the distance of the UEs from the Bs and reaches the maximum midway Bs and Bt. This then becomes low as the UEs approaches Bt where it receives maximum coverage. However, the proposed strategy outperforms the others. This is because the mdev integrated into the MRN in the proposed strategy helps in the timely location of Bt and in determining the available bandwidth resources at the DeNBs. This means that the UE cannot only connect to the MRN but can also know through mdev the target DeNB as well as the available resources. This therefore, reduces the connection failure. The FRN strategy, on the other hand, performs better than the DIRECT connection as some of the UEs were able to connect to the fixed relay thereby reducing the connection failure to some extent.

6.6 Chapter Summary

An effective group handover strategy for the UEs in the LTE-A high-speed train systems have been proposed in this research work. It has been observed that the handover frequency is very high in the conventional handover procedure where the UEs communicate directly to the DeNBs. Also, due to the speed of the train, the recent LTE-A fixed relay node and the mobile relay node solutions which led to the group handover management is not effective without an additional strategy or mechanism to prepare the group information for timely handover though the two reduce the frequency of the handover and the probability of call drops to some extent.

Therefore, the group handover management procedure has been enhanced with our strategy as a result of the appreciable reduction in the number of handovers and call dropping probabilities in the system with our strategy. Also, the speed of the train has little effect on the CDP with the proposed strategy.

CHAPTER SEVEN

CONCLUSIONS AND FUTURE WORKS

7.1 Introduction

This chapter concludes the work done on handover performance in LTE Advanced heterogeneous networks and advances the proposed strategies towards handover management in relation to the different scenarios considered in this research work. Contributions and outcomes of each chapter have been summarised. In addition, suggestions are made regarding future studies for further investigation in the subject matter.

7.2 Conclusions

The demand for voice and multimedia services in cellular networks is growing at a very high rate. The existing macro cellular network cannot alone meet this demand due to its insufficient capacity. Also, the cost of installing several macro-base stations to boost capacity and extends coverage is very high. This is coupled with the urban space restriction issues. Due to these, several methods have been proposed in LTE-A to increase the coverage, capacity and data rate. Among the most cost effective methods is the heterogeneous network deployment. LTE-A HetNet provides huge capacity and performance increase in wireless cellular networks. HetNets allow the use of different cell sizes such as femtocells, macrocells, picocells, microcells and relays to provide increased capacity and improved coverage. HetNet provides the most efficient, cost-effective and scalable way of enhancing the capacity of the present and future wireless networks. It provides the UEs with good network connection and better quality of experience. However, deployment of HetNet often leads to more handover for UEs if not properly managed.

Handover is required for effective user mobility in a network. In LTE systems, handover occurs when a UE loses radio coverage or when the signal from a particular node or base station serving UE deteriorates which results in poor communication quality between the network and the UE. The UE connection to the old base station has to be undone so that new connection can be made to the new base station that offers better signal quality. Therefore, handover may be required to maintain the UE’s mobility, keeping traffic flowing across the network and to improve load balancing even when a good signal strength is maintained between the current serving node and the UE. Other reasons for handover which occur within a network include the need for better QoS, insufficient bandwidth, lower cost, etcetera. which causes the UEs to begin to search for base stations with better service conditions. In this research work, we propose different handover management strategies to reduce various handovers associated with LTE-Advanced heterogeneous networks. The major contributions made to the LTE-Advanced heterogeneous network in the areas of handover management delivered in this work are summarised as follows.

In chapter two, related works on handover management in femtocell-macrocell integrated and mobile relay LTE/LTE-Advanced networks were presented. The general architecture of LTE-Advanced including the protocol layers was studied and key functions discussed. Key features and enhancements that define LTE-Advanced were examined and their important contributions highlighted. HetNet, which is the use of smaller base stations and one of the most cost effective ways of boosting capacity and increasing network coverage being the major area of concern of this work, was examined. Important contributions of small cells and their mode of access were discussed in this chapter. In addition, other important areas such as LTE-A handover techniques were discussed.

In chapter three, we discussed handover initiation as one of the three stages required for successful handover. During handover initiation, handover decision is required to transfer UEs’ services from the source base station to the target base station. The handover decision is based on signal measurement report of UE to the serving base station and available radio resources in the target base station. To determine the available radio resources in the target base station, we have introduced a channel borrowing call admission control strategy into the LTE-A femtocell-macrocell system. With this CAC strategy, radio resources in the system can be utilized more efficiently by controlling the admission of various traffics inside the system. Two types of call traffic (i.e. services) were differentiated as new originating call and handover call. These two services were further divided into RT and NRT services. The proposed strategy ensures that channel is reserved for handover services but when channel is not being utilized fully by the handover services, the new originating NRT services makes use of the channel. However, on arrival of handover services, the on-going NRT services are pre-empted, and forced to the queue until the resources are available again.

While we proposed a new system model for this strategy, an existing traffic model has been adapted for the analysis. Based on the results obtained during the analysis, the proposed strategy was able to accept more calls to the system thereby reducing the call blocking probability than the existing strategy without borrowing. In addition, an improved performance in resource utilization is recorded in the proposed strategy than the existing strategy. However, call dropping probability is less affected by the proposed strategy.

Femtocells as an example of small cells form a two-tier network with macrocell to improve the capacity and UE quality of experience. Recently, femtocells have been deployed in urban areas such as modern cities characterized by big residential and office buildings to offload indoor and road traffic from the macrocell. However, as road traffic becomes clear and UE becomes mobile, the UEs unnecessarily handover to the other femtocells due to low coverage. This unnecessary handover leads to wasteful load and short failures in the network. In chapter four, an efficient handover management algorithm based on the speed of the UE was proposed to reduce the number of handovers in LTE-A networks. The algorithm ensures that mobile UEs are served by the macrocell while the stationary or low-speed UEs are served by the femtocell. In addition to the speed of the UE, the algorithm considered the capacity of the target cell as well as the signal after handover to further reduce handover problems. The results showed not only a reduction in the number of handover with the proposed algorithm but also a reduction in the ratio of the target femtocells. Notably, various femtocell challenges and possible solutions were discussed in this chapter.

In a dense deployment of the femtocell, a simple handover-decision strategy may not be sufficient to reduce frequent handovers and improve the system performance. Therefore, an optimized call admission control scheme is required with the handover strategy for effective handover management. Due to this, CAC-based handover management strategy was proposed in chapter five to reduce frequent handovers and ping-pong effects associated with dense femtocell deployment. The proposed strategy grouped the calls in the system into three viz: the new call, the call connected to the macrocell and the call connected to the femtocells. This was necessary to control how a call is admitted into the system to efficiently manage the handover through the algorithm proposed in chapter four. The existing Markov model was used for the modelling and analysis of the proposed scheme. Based on the results obtained, the handover probability of the femtocell calls, the blocking probability of new calls and the dropping probability of the macrocell calls were considerably reduced in the proposed strategy compared to the scheme without the CAC.

Having proposed a robust handover management strategy for densely deployed femtocells in LTE-A in chapter five, we have considered the Relay Node in chapter six as another small cell node used to improve and extend the network coverage. These play a major role in enhancing the capacity within the macrocell coverage area. In LTE-A HetNets, RN provides cost effective advantages over homogeneous network of macro eNB for network providers. The two relay types FRN and MRN have been discussed in this research work and MRN has been considered due to its deployment flexibility. However, due to the high mobility of a moving vehicle and the need to prevent frequent handover, MRN needs to maintain connectivity with the DeNBs to deliver UEs' services to the DeNBs. To achieve this requires a good strategy. Therefore, a group handover strategy was proposed for the MRN architecture. In the proposed work, we integrated a special mobile device called *mdev* to the MRN so that the location and direction of the target DeNB can be predicted for timely handover of the UE services by the MRN. The results revealed that when comparing the proposed strategy to the direct UE communication with the DeNBs and the FRN with the group handover, the proposed group handover performed better in terms of the reduction of the number of handovers and call dropping probabilities.

7.3 Future Research

This research work focused on handover management strategies for LTE-Advanced heterogeneous networks. However, much can still be done in this area as future networks will be dominated by these heterogeneous networks. Therefore, we have highlighted the possible areas that can be considered in the future.

In chapter three, a channel borrowing call admission control strategy was proposed to ensure that radio resources are effectively utilized during the handover initiation stages. While many researchers have also proposed other methods of utilizing radio resources efficiently, much attention is still required in the area of identifying and prioritising different call types. For example, in our research work we treat the handover call as one while new calls are divided into RT and NRT. In future studies, the handover can also be divided into

RT and NRT and the proposed dynamic channel borrowing can then be applied to prioritise calls with more stringent quality of service.

In chapter four, an enhanced handover algorithm was presented. In this research work, the speed of the UEs, mode access of the femtocells, capacity of the target femto/macro station and signal have been considered as conditions for handover. Further research can consider adjusting the power of femtocell access point dynamically to reduce unnecessary handover.

In chapter five, a CAC-based handover management strategy was proposed for dense femtocell deployment. People in the industry can take this research work further by performing real-life deployment of thousands of femtocells overlaid by the macrocell. The femtocells can be made to support self-organising capabilities because of their large numbers when deployed in real life.

Further research can be done on the Group handover strategy for mobile relays in LTE-A proposed in chapter six. The group UE traffic can be differentiated into different services, for example voice and multimedia services with research focussing on the QoS of multimedia services during group handover.

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