Capacity Enhancement Approaches for Long Term Evolution Networks

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Capacity Enhancement Approaches for Long Term Evolution Network

Capacity Enhancement-Inspired Self-Organized Networking to Enhance Capacity and Fairness of Traffic in Long Term Evolution Networks by Utilising Dynamic Mobile Base-Stations

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Abstract

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Keywords

LTE, LTE-Advanced, Self-Organizing Network, Mobile BTS, Ant-colony optimization, Packet Loss Rate, Delay, Intelligent Cellular Network

By

Mohammed **Alrowili**, May 2018

The long-term evolution (LTE) network has been proposed to provide better network capacity than the earlier 3G network. Driven by the market, the conventional LTE (3G) network standard could not achieve the expectations of the international mobile telecommunications advanced (IMT-Advanced) standard. To satisfy this gap, the LTE-Advanced was introduced with additional network functionalities to meet up with the IMT-Advanced Standard. In addition, due to the need to minimize operational expenditure (OPEX) and reduce human interventions, the wireless cellular networks are required to be self-aware, self-reconfigurable, self-adaptive and smart. An example of such network involves transceiver base stations (BTSs) within a self-organizing network (SON).

Besides these great breakthroughs, the conventional LTE and LTE-Advanced networks have not been designed with the intelligence of scalable capacity output especially in sudden demographic changes, namely during events of football, malls, worship centres or during religious and cultural festivals. Since most of these events cannot be predicted, modern cellular networks must be scalable in terms of capacity and coverage in such unpredictable demographic surge. Thus, the use of dynamic BTSs is proposed to be used in modern and future cellular networks for crowd and demographic change managements.

Dynamic BTSs are complements of the capability of SONs to search, determine and deploy less crowded/idle BTSs to densely crowded cells for scalable capacity management. The mobile BTSs will discover areas of dark coverages and fill-up the gap in terms of providing cellular services. The proposed network relieves the LTE network from overloading thus reducing packet loss, delay and improves fair load sharing.

In order to trail the best (least) path, a bio-inspired optimization algorithm based on swarm-particle optimization is proposed over the dynamic BTS network. It uses the ant-colony optimization algorithm (ACOA) to find the least path. A comparison between an optimized path and the un-optimized path showed huge gain in terms of delay, fair load sharing and the percentage of packet loss.

Declaration

I hereby declare that this thesis has been genuinely carried out by myself and has not been used in any previous application for a degree. Chapters 4 & 5 describe work performed by me in the presence and under the guidance and support of my supervisors, Dr. Rob Holton and Prof. Irfan Awan. Chapter 4 has been accepted for publication (as shown in the publication list). The invaluable participation of others in this thesis has been acknowledged where appropriate.

Mohammed Alrowili

Dedication

To begin with, I would like to dedicate this thesis to Prof Irfan Awan & Dr Rob Holton, whom passion for Research and Science inspired many others and I. Particularly, the insight and feedback they provided during my PhD research. In addition, I would like to mention that I am sincerely grateful for having them as my supervisors. They always gave me the encouragement and advice I needed to finish my PhD thesis. I wish them both the best in future endeavours.

To the bright memory of my mother, this is for you.

I would like to express a special gratitude to my family and friends for their warm companionship and assistance during my studies and hard times. Moreover, a special thanks to my father for all the wise comforting words and sacrifices made on my behalf.

Finally, I would like to thank my wonderful wife and children for their support and confidence in me. They helped me overcome difficult obstacles during my PhD journey. Words cannot express how appreciative I am. Thank you!

Acknowledgment

All praise and thanks to Allah the All-Merciful, the All-Beneficent, for granting me the ability and strength to complete this doctoral thesis.

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List of Acronyms

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
4G	4th Generation
ACOA	Ant-colony optimization algorithm
AI	Artificial Intelligence
BS	Base Station
BTS	Base Transceiver Station
CA	Carrier Aggregation
CSI	Channel State Information
DTN	Delay Tolerant Network
eNBs	eNode-B
HetNet	Heterogeneous Network
IMT-Advanced	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LTE	Long-term Evolution
LTE-Advanced	Long-term Evolution Advanced
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditure
QoS	Quality of Service
RoF	Radio Over Fibre
RPGM	Reference Point Group Mobility
RSS	Received Signal Strength
SON	Self-organizing network

TOA	Time of Arrival
UE	User Equipment
WCDMA	Wideband Code Division Multiple Access
MANET	Mobile ad hoc network
WSN	Wireless Remote Sensing Networks
NS2	Network Simulator Version 2
NAM	Network animator
RAN	Radio Access Networks

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Chapter 1

Introduction

As the future businesses, homes, health management, transportation and social lives are veered towards communication technologies, a greater number of mobile phones will be used. This suggests that more data rate will be required and many more base transceiver stations (BTSs) will also be required. Consequently, the present day BTSs may struggle in terms of scalability to cope with the anticipated user and (consequently) data growths. It will be difficult, expensive and time consuming to completely change an already existing BTS due to the increase in data rate demand or change in demography. Thus, either that the existing BTSs are expanded on the scalability basis or that new BTSs are enabled with scalability to accommodate the future mobile nodes that may need to connect to these BTSs.

In this thesis, the opportunities for scalability, capacity improvement and wider coverage design in existing, modern and future BTSs in order to cope with the increasing higher data rate demands in cellular networks are discussed. It involves the concept of designing and equipping modern and future networks with dynamic BTSs. These are described in greater details in the subsequent chapters of this work. Meanwhile, this chapter presents an introductory overview to the aims, objectives and tangible contributions made in this piece of research work. Also, an overview of the organisation of this thesis is also presented.

1.1 Introduction

In a given geographical location, a transceiver usually referred to as a base transceiver station (BTS) or a base station (BS) for short is used to enable a cellular network coverage of up to 35 km radius from the BS [1]. The coverage of such BS is usually referred to as a cell. Then, a cellular network is a wireless network coverage with a number cells. Each of these cells is served (most times) by one (macro) BS.

To ensure optimum quality of service (QoS) including bandwidth efficiency, these BTSs operate cells that can overlap. Also, to avoid interference due such overlap among the cells, each cell usually operates at a unique frequency (at least to its nearest neighbour) to differentiate it from its neighbours. Sometimes, the cellular network provides an environment that covers a wide range of other different types of transceivers for both fixed or mobile users (for example, mobile phones, tablets, etc.) in a geographical area identified in advance and supported by service providers.

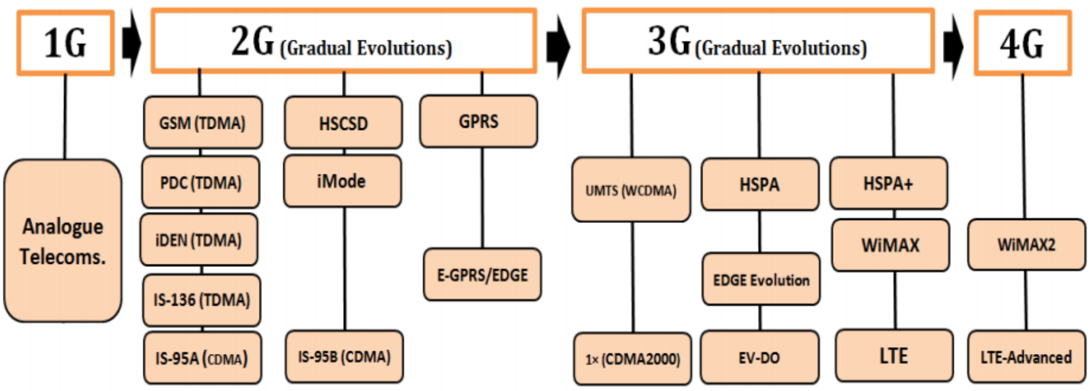

Figure 1.1 Evolution of Cellular Network from First-Generation (1G) Towards 4G

The BTSs are however implemented and supported by evolving technology standards (see Fig. 1-1). Except for the first generation network that is extinct, different geographical locations are supported by the second to the 4th generation network depending on the demography, city type or businesses within the area. Thus, the concept of a cellular network follows a gradual trend determined by the evolution of the first-generation (1G) towards 4G and thereafter, as indicated in Figure 1-1. The Fig. 1-1 also highlights the evolutional trend towards the 4G network newly-proposed by the Third Generation Partnership Project (3GPP) group for a network with additional capabilities to the third-generation networks (3G) standard. In other words, the 4G standard exploits the capabilities of the 3G standard for higher performance based on the added functionalities; it is worthy to note that this trend is still being pursued towards a 5th generation (5G) network standard [2]. Similarly, the capacity evolution of wireless communication network that has continued to fuel the refinement in the design of the standards is typified in Fig 1-2 [3].

From Fig 1-2, it is clear that the major driver in the development of newer network standards stemmed majorly from capacity. In the recent times, these additional functionalities unto the well-known 3G standard have been widely referred to as the long-term evolution (LTE) or 4G [4]. The LTE working partnership group categorised these additional functionalities in phases such that there exists LTE Release 1 to 10 [5-12] and beyond.

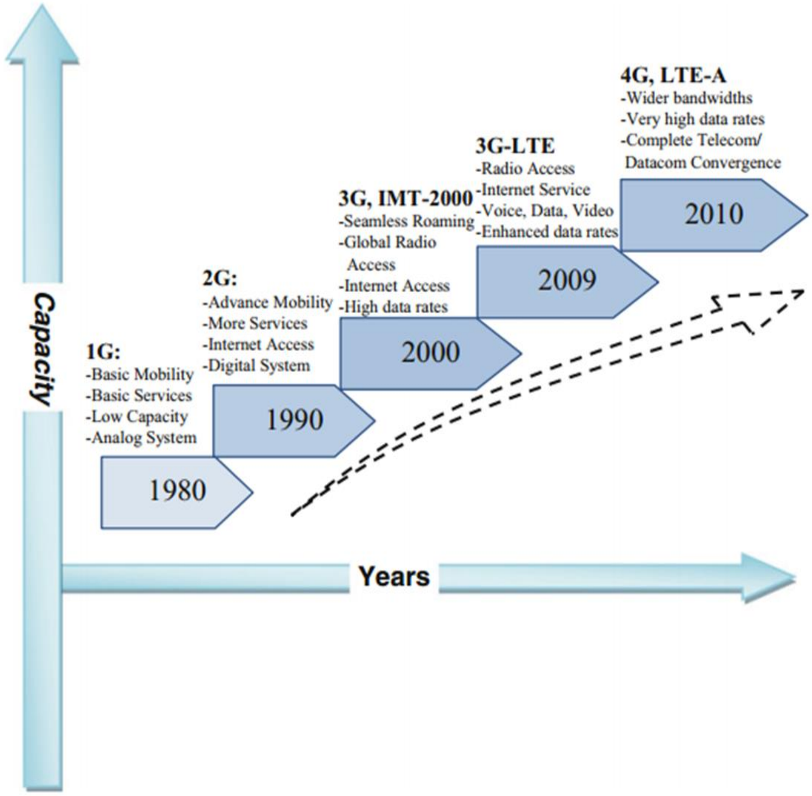

Figure 1.2 Capacity evolution with wireless network standards [3]

LTE standards introduced after LTE Release 9 have all been grouped together and referred to as LTE Advanced (LTE-A) [4, 8-10, 12-15]. Thus, with the increased development of cellular networks has come the LTE Advanced (LTE-A) and there are continual improvements on the development of the long-term (LTE) criteria of telecommunications standards towards realising the next generation network standard by 2020; this has been called 5G standard [16-18]. Unlike the earlier standards, the 5G network standard will operate within the mmWave band leveraging high data rate with a minimum of 1 Gb/s data rate [2, 19-22]. LTE-A has been unified recently in LTE Release 10 and beyond and approved by the International Telecommunication Union (ITU) and International

Mobile Telecommunications IMT-Advanced to be implemented during the current LTE systems.

In the 3G standard, the design was equipped with Wideband Code Division Multiple Access (WCDMA) and multiple input multiple output (MIMO) antenna configurations; specifically the MIMO configuration was introduced to increase the peak data rate of the system due to bandwidth constraints [23]. Consequent on the higher data rate drives (as all businesses are going mobile, using mobile apps), the 4G network was proposed to overcome the higher data rate demand. Although the LTE standard was expected to offer up to 3Gb/s data rate, unfortunately, the market drive led to its earlier release without fully accomplishing the IMT-advanced requirements. Such market rush led to LTE (4G) achieving only peak rate of 100 Mbps in 20 MHz channel (2Ch MIMO) downlink, peak rate of 50 Mbps in 20 MHz channel (Single Ch Tx) uplink, less than 10 msec latency from user equipment (UE) to server, and with full performance within only 5km; above this, say 5km – 30 km follows with slight degradation [24]. Other interesting details of LTE can be found in [25].

The usefulness of achieving high data rate over wireless communication provides advantages specifically, in overcrowded areas, while facing the least possible network interference. This style of telecommunications networks standard is governed by three key restrictions which can be summarized as data rate, delays and capacities. However, it has been shown in the foregoing discussion that although the LTE was developed to attain 3Gbps data rate through the adoption of MIMO and techniques of Orthogonal Frequency

Division Multiplexing (OFDM) technologies, but its earlier release led to the standard achieving less.

Of the previously mentioned three major problems that face the LTE network, the most important is delay; the major goal is to reduce the latency of a packet sent from the server to the customer. Also, with the increasing data rate demand, there is an insufficient capacity resulting from the terrestrial quality of service (QoS) of the comprehensive network. Also, appropriate methods must be deployed to ensure that the management of the cellular network spectrum is efficient. This study will explore the gap in previous research in this area and emphasise the need for intervention; it will also propose methods for mitigating the main characteristics that are degrading the entire LTE network performance and expectations.

Meanwhile, Self-Organising Network (SON) has been proposed recently in networking technology restructuring to improve the efficiency of spectrum technologies, wireless access and address coverage problems [26-29], such as the LTE Radio over Fibre (RoF) [30, 31]. The strategy of self-regulation and other internal coordination and interaction between its elements at different stages can enhance self-awareness, self-configuration and demand for the BTS architecture within the entire network. Therefore, the networks are able to adapt themselves for more effective outreach, taking into account the end-to-end objectives.

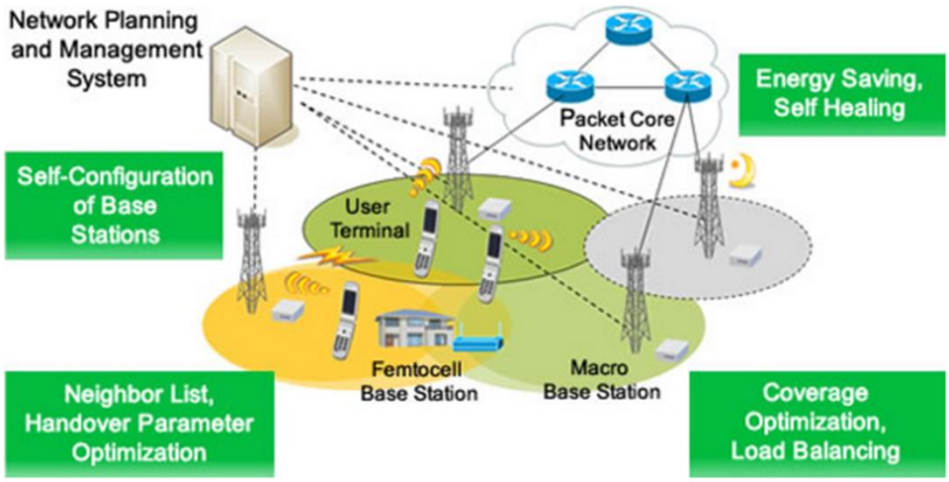

Figure 1.3 Typical representation of SON for LTE Network [32]

The unlicensed spectrum currently available is reaching its limits, while there are many demands for wireless access and applications. Therefore, an intelligent use of spectrum is immediately required to avoid latency and difficulties in broadband communications resulting from the overlap of radio frequency bands. This critical enhancement can be applied to the current LTE, which can improve the cellular interference during the spectrum usage. An example of a self-organizing network (SON) is depicted in Figure 1-3 for an LTE Network [32].

The innovative approach introduced in this research is to make the BTSs in LTE networks to be self-aware, self-adaptable and intelligent. In a conventional cellular network, BTSs will serve a number of mobile terminals using the strongest received signal strength (RSS), while the unwanted signals received from other BTSs are usually perceived as interference. To mitigate this problem, an intelligent LTE infrastructure is desired to provide cognitive coordination and management of resources among BTSs which can offer a significant enhancement in throughput and user experience as compared to a conventional system. Another problem which motivates this work is fluctuation in the traffic load among the network BTSs, in which, areas with higher densities of users will result in more extensive load on the BTSs and high blocking probability for newly-arriving user equipment as compared to less crowded areas, where some BTSs will be idle or under minimal user equipment (UE) loads. Consequently, a very unfair distribution of data traffic rates will occur across user terminals.

To address these gaps and limitations, this thesis provides the following contributions, namely;

- contributes to the knowledge of the literature by providing an important discussion of relevant work on enhancing the capacity of the LTE network and the advantages and disadvantages of various approaches;
- introduces the concept of fairness in traffic among different BTSs;
- proposes a model to balance the load in different BTSs of the LTE network by using the dynamic movement of BTSs to more highly dense user areas, consequently enhancing network capacity;
- uses bio-inspired optimization technique to obtain the best (shortest) path trailed by the mobile BTSs when finding the coverage holes.

Swarm Intelligence is an Artificial Intelligence (AI) scheme which is based on observations of collective behaviour in biological organisms like ants and bees, including division of labour, counting larvae, building, cooperative transport, etc. [33-35]. The number of artificial intelligence applications has begun to grow significantly in the field of communication networks, and has led to improvement of the vehicles and robotic ad hoc networks [36, 37]. Self-organization protocol via swarm intelligence is a useful solution which has already demonstrated advantages in terms of building an intelligent, self-organising router which tackles the traditional router problems, as well as balancing the problems of coverage in wireless communications [27].

The Ant Colony Optimisation (ACO) technique [37] is one example of swarm intelligence inspired algorithm that is widely used by researchers to solve 4G telecommunications problems [38-40]. Such an algorithm has been applied to the solution of routing algorithms in wireless networks adopting SON techniques, such as mobile ad hoc networks (MANETs), Wireless Remote Sensing Networks (WSNs), or delay tolerant networks (DTNs) [41-43]. This thesis makes use of ACO to make the BTSs self-organized based on pheromone density. The ant agent will be spread throughout the network to find overcrowded and idle or less crowded BTSs and in turn move the dense BTSs loads towards the less dense BTSs. This thesis also contributes in terms of enhancements in system throughput, addressing packet loss, and load on the system even in the case of high density networks. Besides this, these performance metrics (throughput, packet loss, and capacity) are used to evaluate the robustness of the proposed system.

1.2 Motivation

The exponential growth in wireless cellular data rate demand in populated urban regions has resulted in an increase in wireless data traffic. This rapid growth is expected to exceed 500 times the present mobile data traffic within a decade [44]. Meanwhile, the capacity of the existing wireless systems (fixed BTS) is insufficient in comparison to the current wireless data traffic trend. As a consequence, the performance of wireless cellular services will be (if not the case at the moment) inadequate within user-populated areas. This is due to the inability of fixed BTSs to adapt to their evolving environment. The wireless network operator reverts to traffic calming solutions instead of expanding the capacity of existing BTSs, based on technical and financial reasons. This illustrates that further advancement in existing wireless data services systems is required in order to provide scalable capacity and coverage to match current and expected growths in wireless data demand.

The recent advancements in self-driving vehicles can be exploited to bridge the gaps in wireless network coverage. In addition, the current developments in wireless energy transmission can provide a flexible and reliable power supply. These advancements unearth innovative capacity enhancement approaches. The proposed approach relies on implementing dynamic self-driven BTSs. Dynamic BTSs enable easy access to higher wireless system capacities, guaranteeing fairness in data traffic. Moreover, this approach enhances spectral efficiency to anticipate the future growth in the number of users of cellular data services. Finally, mobile BTSs allow the operator to adapt their wireless network to accommodate the high traffic demands in user-dense regions such as stadiums, festivals and shopping malls.

1.3 Aims and Objectives

The aim of this research is to introduce a scalable concept in the design of modern and future wireless networks to withstand sudden demographic change.

In order to achieve this aim, the following objectives have been set out, namely;

- ❖ To carry out an extensive literature review so as to understand and keep up to date with the earliest and most recent works done in this relation to this subject area;
- ❖ To review different network simulation software and identify which of them is best suitable for network modelling;
- ❖ To isolate which of the identified network modelling tools is most suitable for intelligent telecommunications technologies design within the spheres of OPNET, OMNET and NS2;
- ❖ To learn, understand and be able to use the identified network simulator to model cellular networks involving mobile BTSs, for example NS2;
- ❖ Review optimisation techniques to predict the most suitable styles that appeal most to network modelling and optimisation;
- ❖ Finally, to explore the option of collaborating and communicating research findings to wider research communities and audience through presenting own novel contributions at conferences, workshops and journals.

1.4 Contributions

This work investigates the state of the art in capacity enhancement approaches in LTE networks. Since LTE serves mobile devices and the main idea is to make the BTSs able to move, this work has been extended to cover and analyse BTS mobility. Both analytical and empirical investigations are used to validate the proposed work. Besides this, self-organizing network techniques, characteristics and the applicability of the LTE network are investigated in such wireless communication systems. In general, this thesis contributes to the solutions of scalability, capacity enhancement concepts and coverage problems of the LTE network as organized in the following manner;

- updated the literature by collating new findings of related work in enhancing the capacity of the LTE network, the advantages and disadvantages of these approaches;
- proposes a dynamic BTS model for scalable demographic management and coverage;
- introduces the concept of fairness of traffic among different BTSs;
- proposes a model to balance the load in different BTSs in the LTE network by using the dynamic movement of BTSs to the denser areas of users, consequently enhancing network capacity;
- studies the network performance under different BTS deployment densities for coverage solutions;
- the coverage problem based on moving the BTSs is addressed by employing the capability of the ant colony optimisation algorithm (ACOA); to find the optimal pilot BTSs to help them move to dense areas and serve the increased new UEs;
- tackles the problems of the fixed coverage scheme in reducing the ratio of coverage holes, proportion of coverage overlaps, and probability of

blocking new users through enhancing the overall performance of the network;

- contributes to enhancing system throughput, packet loss, and loading on the system even in the case of high dense networks.

1.5 Publications

The work in this thesis has been presented and published in parts at several international and local events. A list of the author's publication records is provided at the end of the leading chapters of this work.

1.6 Thesis Organisation

This chapter (**Chapter 1**) introduces the work and explains the motivation behind it, and also presents the research contributions.

Chapter 2 - In chapter 2, the related work carried out by other experts are reviewed. These reviewed studies subtend a veritable background to the study presented in the rest chapters of this thesis. Highlights of key areas revised include the technological standard and architecture of the LTE network, brief review of smarm optimization, scalabilities issues associated with the LTE network, QoS assessment metrics and capacity enhancement approaches.

Chapter 3 illustrates the problem of capacity enhancement approaches and how it can be implemented in a software, namely NS2. The chapter describes the proposed system model for moving the BTSs utilised, along with the model's components and parameters. Besides this, the research methodology adopted is explored by describing the simulator and assumptions used to build the study model.

Chapter 4 – In this chapter, the concept of fairness of traffic among different BTSs is introduced. Furthermore, this chapter proposes a model to balance the load between different BTSs in the dense LTE network by using the dynamic movement of BTSs to denser areas of users upon sensing overcrowding on the neighbouring cells.

Chapter 5 examines the resource management problem of moving BTSs by employing the capability of the ant colony optimisation algorithm (ACOA), which is applied to find the optimal pilot BTSs to help it move to dense areas and serve the increased new UEs. The ACOA helps in finding the best path that can be traced by the BTS to the crowding cell to maximise resources.

Chapter 6 – In Chapter 6, the individual contributions of the chapters are summarised. Based on the results and ideas subtended by the individual chapters, several recommendations are made on how to improve on the contributions of this thesis for future studies. Within the Chapter 6, the concluding remarks drive home on how the aims and objectives of this research have been met.

1.7 Summary

In this chapter, an introduction has been provided to the fundamental concepts of this research study highlighting the aims and the objectives of the research.

An organization of the thesis report in terms of chapters is provided to give the reader an instructive guideline on how to access specific materials in this thesis. In the following chapters, details of technical contributions are clearly provided.

Chapter 2

Literature Review

The Long Term Evolution (LTE) cellular network system or the fourth generation (4G) network standard was developed as an advancement to the former 3G-network design by the 3GPP working group [45-48]. LTE networks enhance the capacity and quality of service (QoS) using DSP (digital signal processing) techniques and modulation approaches [48, 49]. Such networks depend on the close synchronicity of macro base transceiver stations (BTSs) and Femtocell nodes as they work together. As a result, the system was precisely designed to prevent foreseen transmission challenges well-known in earlier standards such as the 3G network [50], namely scalability, coverage and capacity including constrained bandwidth which limits data rate, etc. To understand these problems, the preliminary information on the transition from 3G networks to 4G LTE are provided.

The aim of this chapter is to provide the fundamental technological background and information regarding the capacity enhancement approach for future networks. This permits a comprehensive evaluation of LTE Advanced networks (LTE-A) [5]. The aim will be accomplished by closely examining the modulation types, execution strategies and internal design features. Based on Release 8, other new features have been introduced into the 4G LTE standard to form new standards. LTE standards from Release 10 and above are commonly referred to as LTE-advanced (LTE-A) [4]. These additional standards also extend to cover the 5G network anticipated to be released by 2020 [2, 17, 18].

2.1 Background for LTE and LTE-A Standards

The evolution from third generation radio access networks (RANs) to the existing fourth generation systems (LTE) was motivated by the 3G standard inability to capacitate the exponential growth in cellular data transmission [51]. Moreover, innovative applications were developed to meet the requirements for a 4G network (also referred to as IMT-Advanced), such as LTE, LTE-A and Worldwide Interoperability for Microwave Access (WiMAX) [5]. Despite these viable proposals the International Telecommunications Union (ITU) decided to introduce LTE network as the fourth generation system (4G). The decision was made based on 8 specific requirements regarding the growth in cellular users, quality of service and cost of implementation [52] [53].

In other words, LTE-A is an enhanced version of the existing LTE system [5]. In LTE standard, the two innovative approaches HetNet (heterogeneous network) and SON (self-organizing network) have been introduced [54]. These two enhancements are to enable higher capacity and coverage strength. In addition to the two innovative approaches, the development of Multi-Input Multi-Output (MIMO) and Node Relay (NR) techniques were incorporated in the LTE network standard. By these enhancements, the overall performance and quality of the LTE cellular system was improved.

2.1.1 Features of LTE-A

Initially, LTE-A was formally submitted to ITU in 2009 as it satisfies all the requirements for IMT-Advanced standard [8]. In March 2011, this was accepted and standardized by the 3GPP as Release 10. LTE-A is considered an enhancement to the conventional LTE, which meets all the IMT-Advanced requirements [49]. Essentially, LTE-A is still considered a further improved version of 4G mobile LTE communication system. The technology components include extended spectrum flexibility, multi-antenna solutions, coordinated multipoint transmission/reception, and the use of advanced repeaters/relaying [8] which are meant to improve the general system performance of the conventional LTE standard. In this chapter, the important aspects of LTE Release 10 and beyond, commonly called LTE-A [4] are reviewed which include the added features of LTE-A systems and their importance to the network.

MIMO is a widely used form of multi-antenna communication technique [49, 55]. This technique exploits the variation of time, frequency and spatial diversity over constraint bandwidth to improve throughput, reduce fading probability, reduce the error probability of received signals and increase the signal power at the receiver [55-57]. In fact, the MIMO technique is well known and advantageous in spectrum efficiency management. The implementation of such complex technique enhances the robustness of the system over fading channels [11, 55]. Moreover, MIMO is not 3GPP exclusive; it was firstly introduced in UTRAN (Release 7) [54]. However, MIMO experienced significant developments in Release +10 (LTE-A). These improvements involve the enhancement of MIMO downlink and uplink [49].

MIMO approach used in LTE-A experienced considerable improvements by refining the radio interface channel mechanism. Conventionally, in MIMO systems individual transmission antennas send independent streams of data using frequency and time partitioning [49]. This concept originated from space time block coding STBC introduced by [58]. However, the LTE-A uses multiple input multiple out antenna configuration and thus exploits the possibility to transmit 2 or more signals occupying the same frequency, as long as they have different spatial codes [11, 59].

The MIMO approach implemented in LTE-A uses the combination of transmitters and receivers antennas to create new transmission channels. Moreover, exploiting a wider range of *M* (transmitting) and *N* (receiving) antennas establish new independent sub-channels [60]. This enables network operators to transmit more data at similar frequencies (but parallel channels) [49, 60]. As a consequence, LTE-A systems can capacitate higher cellular traffic demand in comparison to LTE. However, the integration of the new MIMO techniques requires large antennas and a high Signal-Noise Ratio (SNR) environment [49]. Although, LTE-A provides capacity solutions, adding new antennas to small data-hungry devices is problematic. For example, the design of antennas with separation in order of the wavelength is virtually impossible thus leading to mutual coupling. In all, MIMO provides a new solution to the exponential cellular data traffic growth.

Carrier Aggregation approach is the combination of 2-5 carriers into one aggregated carrier [54]. This technique was first adopted in LTE-A to expand the transmission bandwidth. Unfortunately, in Release 10 and 11 only 2-component carriers could be combined limiting the maximum aggregated bandwidth to 100MHz [49].

There are three specific ways to combine carriers [61]:

- Intra-band carrier aggregation (contiguous component carriers);
- Intra-band carrier aggregation (noncontiguous component carriers);
- Inter-band carrier aggregation.

In the first scenario, each carrier component is aggregated onto the same frequency band, forming a solid block in the spectrum. In the second scenario, all carrier components occupy the same frequency band, however there are gaps in between. In the third and final scenario, carrier components occupy different frequency bands, which results in obvious gaps between them.

Wireless Relaying combines the eNB and user equipment (UE) functionalities in small layer 3 (L3) repeaters (L3 relaying or self-backhauling) [8]. The L3 nodes are positioned around cell edges to enhance coverage and capacity. In addition, they could be used to remotely connect to various locations instead of implementing fiber connections [49]. Traditionally, repeaters deployed in relaying operation either amplify and forward received messages or they decode and re-encode the message before forwarding them. The advantage of the later over the former is that it does not amplify and retransmit noise.

Generally, two classes of repeaters are known (L2 and L3 repeaters) at high-level [8]. Although very similar in their basic characteristics (e.g. both introduces delays, neither suffers from noise amplification) the self-backhauling solution does not require any new nodes, protocols or interfaces to be standardized as the existing solutions are reused and may therefore be preferable over their L2 counterpart [8].

Relay nodes function using two radio links, backhauling and access links [54]. These links are configured differently based on the environment. For instance, in cases where the frequency band is limited, the two links can occupy the same frequency. In order to do so, there must be a delay in the time domain between the two links [49]. As a consequence, the system quality will regress from the time delay whilst relaying the cells.

2.2 Overview of the Capacity Enhancement Approach

The techniques used to develop the de facto LTE system primarily focused on implementing Coordinated Multipoint, Multiple Input Multiple Output, Resource Efficiency, Spectrum Extension, etc. [49]. A typical example of a coordinated multi-point transmission design for LTE network is shown in Fig. 2-1 [8]. It involves geographically separated antennas coordinated by a single baseband processing unit (in this case the eNodeB) for cost efficiency. Technically speaking, the baseband processing unit can be located miles away with only the antennas being seen on the surface.

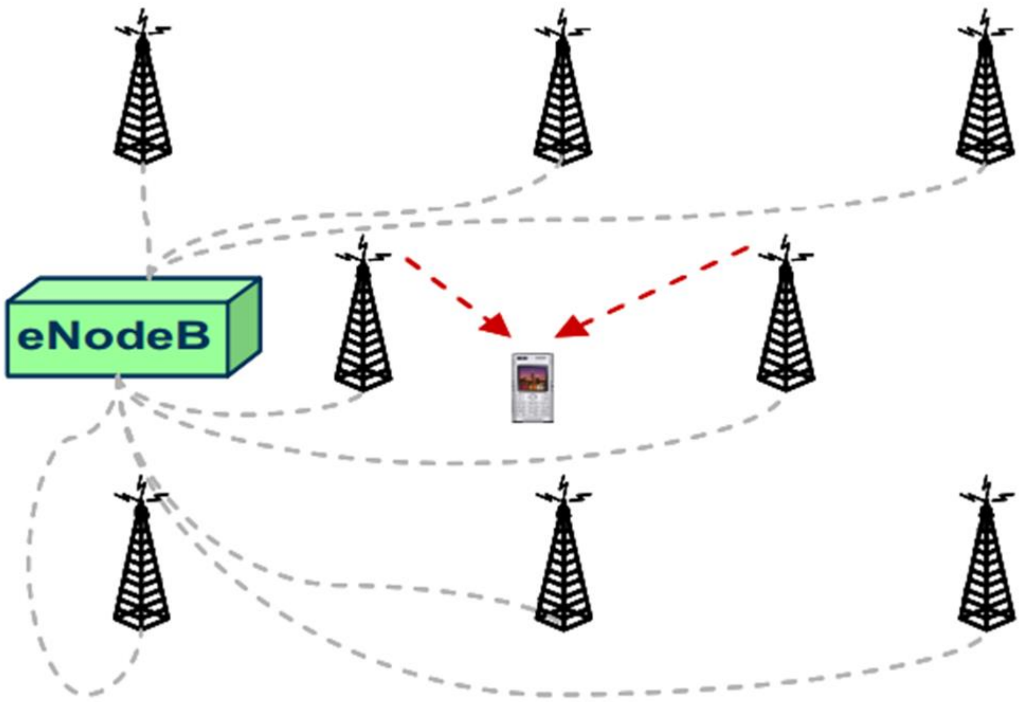

Figure 2.1 Coordinated multipoint transmission [8]

On the other hand, most of the LTE-A innovations build upon the principles of heterogeneity and self-adapting attributes due to its compatibly with the existing LTE system [26]. For instance, Carrier Aggregation (CA) introduced in LTE-A further enhances the Multi-Input Multi-Output (MIMO) and Node Rely (NR) techniques used in the LTE network. In addition, the development of the Carrier Aggregation (CA) in LTE-A increases data download speed by allowing the user to download data from eight sources simultaneously and five uplinks to upload [62]. Furthermore, a coordinated multipoint (CoMP) is implemented to enable transmitting cellular data using 2 or more BTSs simultaneously in an efficient manner [8, 53].

With the above knowledge, the following subsections will be dedicated to providing a fundamental background regarding the theory of Self-Organised (SON) Heterogeneous Networks (HetNets). This allows a better understanding of the innovation techniques implemented in LTE-Advanced networks. Additionally, the basic ideas of HetNet and SON and their underlying technical mechanisms are also described.

2.2.1 HetNet

The fundamental problem with fixed BTSs is that it cannot serve more than its designated radius even if the BTS is underutilised. Although the problems of cell-breathing and shadowing and other multipath fading effects have led to sectorization [63], cell-splitting [25], etc. to increase coverage, capacity and improve general quality of service (QoS), coverage and capacity problems (for example (crowd management problem) have continued to prevail. Recently, the combination of Macro and Micro BTSs has been suggested to leverage solutions to the above limitations [64, 65], but not in cases of crowd management as crowd gathering cannot always be predicted. Thus, cognitive dynamic BTSs that are able to sense cells with sudden demographic surge can be used to solve this problem permanently. In already dense deployments in today’s networks, cell splitting gains can be severely limited by high inter-cell interference [25]. Moreover, high capital expenditure cost associated with high power macro nodes further limits viability of such an approach [25].

A Heterogeneous Network (HetNet) is therefore a network that implement a fusion of various wireless infrastructural low-power and high-power nodes [25, 53]. HetNets are networks that deploy a hybrid of pico, micro and macro power eNodeBs including Femtocells and/or relay nodes as shown in Fig. 2-2 [25].

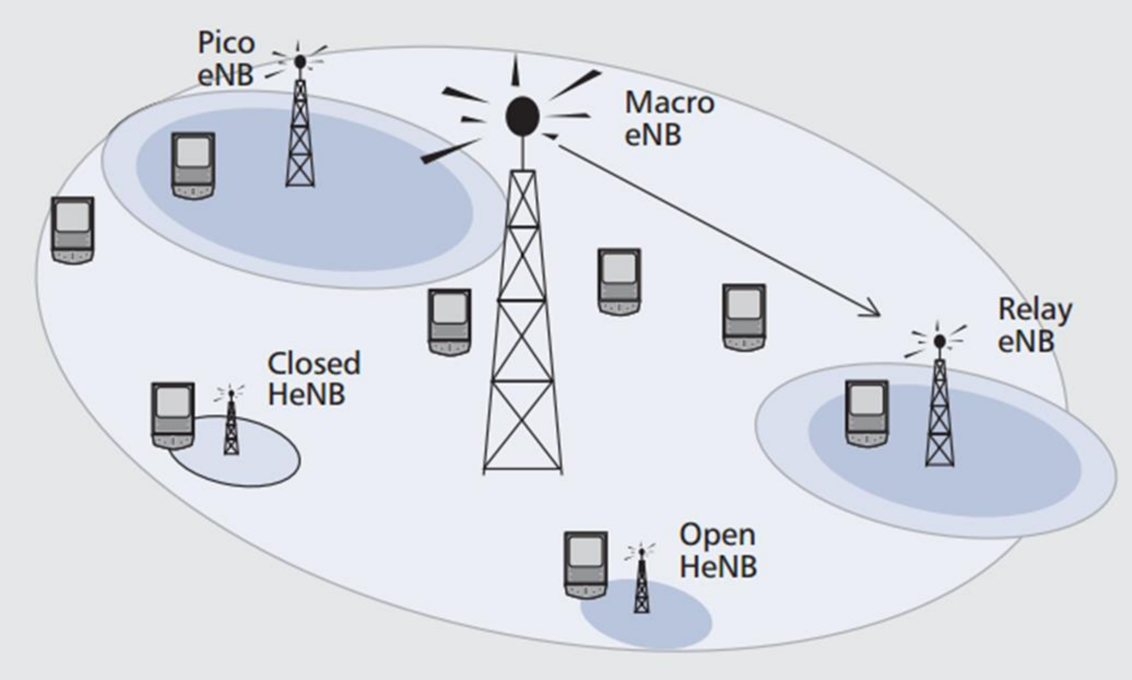

Figure 2.2 A heterogeneous network using a hybrid of high-power and low-power BTS nodes [25]

Each of these volunteers some distinct functions, capabilities and restrictions. Primarily, a HetNet approach incorporates different wireless access points infrastructure based on the surrounding domain. The HetNet employs multi-tier system techniques such as Radio Remote Heads (RRH), combination of femto and pico-cells, as well as placing two nearby BTSs that occupy the same frequency spectrum [49, 53]. As a result, the overall network capacity and quality of service is improved by offloading the data traffic on macro to femtocells. A major limitation in such architecture is the fixed nature of both the micro and macro power BTSs. This implies that irrespective of the overloading problems of the nearby cell, the architecture has not been provisioned to assist. In Chapters 4 and 5 of this thesis, a way out has been proposed.

2.2.2 Self-organizing Network

A self-organised network (SON) is a network concept designed to autonomously configure, optimise and heal LTE HetNets by limiting human intervention [60]. It was first introduced in LTE Release 8 in order to manage mobile cell coverage. This concept relies on artificial intelligence (AI) to analyse the network parameters network and take actions independently [11].

The theory behind this approach was driven by the exponential expansion of wireless cellular coverage and data traffic. In addition, the rapid evaluation of wireless cellular networks resulted in the parallel operation of 2G, 3G and Evolved Packet Core (EPC) systems [53]. As a consequence, continuous human supervision and interaction is becoming a problematic issue [26]. However, the implementation of SON aims to eliminate this issue by placing a complex SON coordination (Artificial Intelligence) to configure, optimise and heal the network more efficiently [60].

2.3 Challenges and Opportunities in LTE-A

The LTE-A emerged to explore increasing data rate via architecture and topology styles. In fact, the LTE Advanced network standard is about improving spectral efficiency per unit area [64]. Thus, the LTE network allows operators to use new and wider spectrum to complements 3G networks with higher data rates, lower latency and a flat IP-based architecture. Of course, since radio link performance is approaching theoretical limits with 3G enhancements and LTE, the next performance leap in wireless networks will come from the network topology [64]. Meanwhile, the LTE-A is beset by the following challenges, namely,

- because the BTSs are fixed, then LTE/LTE-A BTSs cannot leap to assist an over-utilized neighouring network even when it is idle;
- interference management among overlapping cells;
- improving data rate by the architectural and topology styles follow at energy saving expense which is duly detrimental to the environment.

Each of these aforementioned problems can also be leveraged for better designs. Generally, the opportunities of the LTE-A has been described in [3]. However, handy examples of these opportunities involve

- cooperative relaying among the HetNets such as from Ad hoc network and multihop relay networks which provide the opportunity for improvement in coverage and throughput of LTE-A cellular networks;
- since the LTE-A provides opportunities for hybrid network topologies, then efficient topology design can be accommodated;
- since the eNodeBs are the major signal processing boxes with several openly seen antennas, then the micro BTSs can be redesigned to communicate over a micro eNodeB box for cost-efficiency;
- eNodeBs can be made dynamic (mobile) instead of being fixed as to assist other neighbouring cells;

- eNodeBs can be equipped with reconfigurable physical layer (for example using reconfigurable antennas or beamforming for cognitive BTS to assist neighbouring cells by beaming coverage in that direction.

2.3.1 Energy Saving

The rapid expansion of wireless cellular coverage is proportionally affecting energy consumption worldwide; in other words increasing the CO_2 emissions. Data centres that house data traffics generated in the communication processes also contribute a huge deal to CO_2 emissions [66]. As a consequence, network operators are paying huge sums of money to keep their BTSs powered. For an illustration, Italian Telecommunication Operator (Telecom Italia) is the second-largest consumer of energy in Italy [67]. Moreover, the on-going development of 3G networks in developing counties (such as China and India) also increases energy consumption. These conditions, along with the future implementation of 4G systems globally will drive-up the energy consumption exponentially [67]. Thus, innovative energy saving techniques must be implemented to prevent a potential energy and environmental crisis. An example of such solution is reported in Chapter 5 of this thesis.

Exploitation of data traffic patterns by implementing a heterogeneous network is one of the keys to reducing energy consumption. The majority of BTSs do not fulfil their traffic capacity for many hours along their time domain. For instance, wireless cellular users at shopping malls and work offices only transmit data between 9am-6pm (approximation). Unfortunately, operators are unable to switch off BTSs outside peak times because that will create a coverage gap

[67]. As a consequence, BTSs are consuming energy non-stop. Meanwhile, with the HetNet approach used in LTE-A permits the operator to selectively enable and disable BTSs without affecting the wireless coverage [49]. This is due to the integration of various types of BTSs in the same area. Subsequently, the LTE-A femtocells in hotspots can be disabled to save energy, whilst macro-cells provide wireless coverage for UEs [67].

Although, the idea of switching BTSs on and off in HetNet based on data traffic seems simple, engineers are still challenged to establish a clear mechanism in their observation and measurement (O&M) system to enable/disable BTSs [49]. The prime challenge is that LTE systems do not have a centralised radio access control (RNC). Implementation of RNC enables the BTSs to decide between them using intelligent algorithms which nodes to switch on or off. Furthermore, if LTE nodes are disabled UMDC (universal mobile data collector) or EDGE can always substitute their functionalities. As a consequence, LTE-specific services become unavailable and the overall quality of services will regress. These challenges must be solved before operating at large-scale networks.

This proposal of implementing dynamic BTSs presented in this thesis overcomes the underlying technical difficulties. To begin with, although the idea of switching BTSs on and off is saving energy, it is extremely under-utilising the network’s infrastructure. By observing the user patterns and data traffic movement, it becomes evident that many BTSs (in malls and work places) barely occupy a fraction of their user-capacity half of the day (at night) [52, 68]. Thus, the LTE-A approach is incomplete from a financial-efficiency perspective.

Alternatively, Dynamic BTSs (DBTSs) can be used to process measurements of the network parameters transmitted by stationary nodes and mobile-cellular devices. The transmitted parameters are both power and quality reference signal [69]. The self-optimisation procedure enables the dynamic node to self-locate accordingly. This ensures that the network is continuously adapting to the fluctuating service demand.

Theoretically, Dynamic Nodes (DNs) are able to capacitate 200 users simultaneously. As a result, it regulates the load on stationary nodes. To illustrate this, consider a scenario where stationary node reaches maximum load-capacity. The dynamic nodes locate the over-congested node by repeatedly scanning neighbouring reference signals. As a result, it is able to self-position within the coverage range to off-load the traffic on the stationary node. In conclusion, the overall wireless traffic is moderated, which enhances the capacity and quality of LTE networks. Similar idea (of dynamic nodes) has been described for virtual network in [70].

2.3.2 Efficient Bandwidth Utilization

Given a block of frequencies, it is difficult to manage data traffic over these limited spectra. Consequently, wireless technology algorithms are deployed to maximize the transmission of data from one point to another. Thus, the wireless signal channels are the backbone of all wireless communication networks. These channels are configured based on the spectrum band obtained by the operator [69]. Moreover, bandwidth allocation involves a very precise and strict process. Its importance lies in preventing the overlapping of information signals propagating at adjacent frequencies bands [49]. Thus, operators must utilise the band allocated to them as efficiently and decisively as possible.

Conventionally, the authorised body (usually Governments) in the region allocate frequency bands for a diverse range of applications. For example, aerospace, mobile communication, private communication and marine industries are standardised within a strict bandwidth. Thus, telecommunication operators are legally obliged to obtain a frequency-band licence [69]. Commonly, operators in the UK transmit signals within a limited bandwidth. As a consequence, operators often seek compromise between the quality and capacity of their services. The restricted band boundaries assigned to Telecom operators limit the room for further improvement. Alternatively, LTE-A releases have developed approaches for further enhancements within a tight band frequency. Most notably, the establishment of a coordinated interference alignment system that aims to prevent interference between nodes in a heterogeneous network [54] is the most recent technique. This technique is usually presented with coordinated multipoint [71] to improve throughput [72].

Wireless Cellular device may prioritize connecting to a nearby Pico-node (supports cell-splitting) instead of pairing with a high-powered macro BTSs [26]. This is due to the superior data transmission capabilities of Pico-cell BTSs. Thus, the overall throughput of the network is enhanced [72]. However, allocating various nodes in close approximation spike the networks' interference [49]. Subsequently, a coordination mechanism between nodes has been introduced [71-74] and investigated for interference mitigation for users at the cell-edge [75]. This mechanism implemented in LTE-A makes nodes aware of the surrounding interference and adjust their operating frequency accordingly [60]. The frequency is adjusted by coordinating with nearby nodes to avoid frequency conflicts. Although, coordinating frequency bands between nodes is effective, it requires backhauling the de facto BTSs to re-configure their antenna as well as defining a self-organization mechanism [49]. As a consequence, network operators are less inclined to adopting this approach in populated wireless networks due to viability concerns.

On the other hand, upgrading the de facto networks configuration with the addition of dynamic BTSs offers very similar signal interference. To begin with, dynamic BTSs are compatible with the existing LTE BTS configuration. Moreover, they depend on the reference signals and nearby dynamic BTSs optimization in order to self-coordinate.

Dynamic BTSs are able to influence interference by shifting stationary node users to higher or lower bands based on acquired network parameters. Accordingly, dynamic BTSs autonomously locate themselves to achieve optimum impact against interference and cellular traffic congestion. As a result, the signal gain is enhanced and general system interference is capped. Thus, the overall network capacity is expanded resulting in smoother flow of data traffic and enhancements in service quality. In all, dynamism offers a feasible alternative solution to signal interference, it could be exclusively launched in networks with extremely high traffic demand.

2.3.3 Fuzzy Trust Management Techniques

The Fuzzy theory revolves around the truthfulness of statements; in many cases it is complicated to determine whether a statement is true, false or both. Fuzzy trust management framework (FTMF) may be biased relative to a user, maybe due to mood or state of mind at the prevailing time [76]. Moreover, in network systems it is difficult to timely determine the truthfulness of different system aspects [69]. The aim of this theory is to eliminate the grey area between the true and false classifications. This is accomplished by assigning precise and noticeable attributes for each case. Subsequently, the Fuzzy theory has a significant impact in various system designs [49, 76]. For example, the Peer-to-Peer (P2P) communication within a wireless network depends significantly on each peers' service quality. However, it is extremely difficult to determine the status of their respective connections due to the geographical node distribution, as well as, the diverse range of institutions operating nodes within the network. Therefore, a clear systematic classification approach is essential to providing optimum P2P service [49].

The fuzzy trust management techniques have been developed to clarify the classification process in P2P (reputation). The classification procedure revolves around the trustworthiness of the peers' connection. The aim of these techniques is to inspire nodes to share resources, prevent unexpected nodal behaviours and categorizing peers based on quality of resources. Moreover, such scheme regresses the side effects of poor quality services (due to limited resources) considerably. The 3-stage process defining requirements, categorizations and compatibility are essentially the backbone of the Fuzzy Trust management framework [76].

2.4 Self-Organizing Techniques

Self-Organising Network (SON) has a broad scope, involving a diverse range of applications. The aim of SON is to assist network operators by managing data traffic effectively. The Self-Organising Network (SON) utilises an innovative mechanism in order to operate autonomously without the intervention of an administrator. Moreover, this mechanism is separated into three operations namely self-optimisation, self-configuration and self-healing [49]. A typical self-organizing network is depicted in Fig. 2-3 [77].

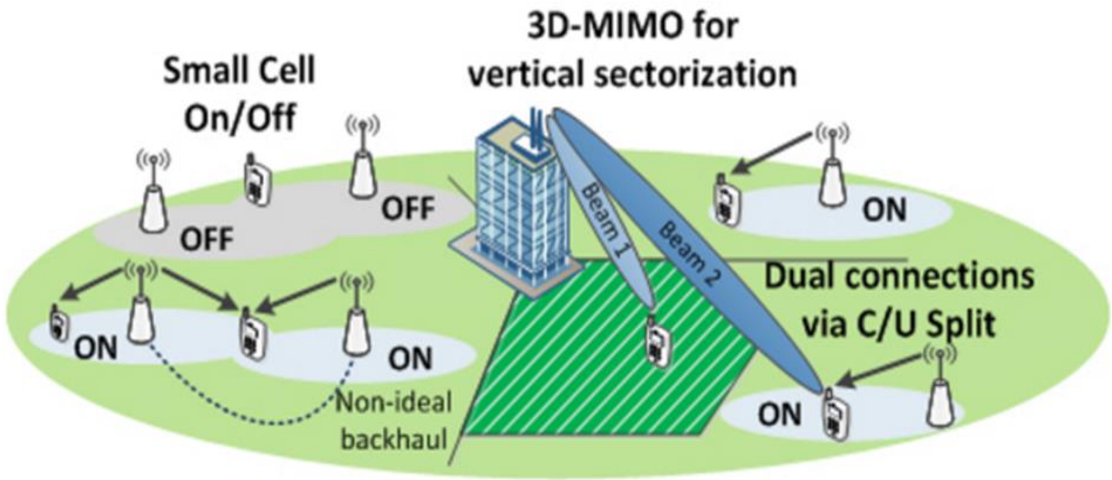

Figure 2.3 self-organizing network [77]

From Fig 2-3, overlaying small cells onto the legacy macro cell network is a well-established method of boosting cellular coverage as well as capacity [77]. A SON makes decisions autonomously based on the operator's configuration. This calibration of this configuration must be precise to ensure the system operates proficiently. Moreover, SON relies on the concept of Artificial intelligence (AI) to analyse the data acquired and make decisions accordingly [53]. AI uses a set of software algorithms designed based on acquired variables and observed patterns. For example, the cellular demand at a shopping or work environment varies considerably between day and night. As a consequence, the BTS is misusing its resources, which increases the energy consumption and subsequently the operator’s running costs [54].

The ability of a network to self-optimise is a complex procedure. Its operator must relay the network information to the SON. The measurement of the network parameters is accomplished by employing the dormant cells or UE classification techniques. The dormant cells approach utilises the cells listening capabilities to measure nearby noise levels. Whereas, the UE approach depends on other cells to transmit a Reference Signal (RS) for a short interval [49]. In addition, the UE coverage cells are asked to measure reference signal(s) [11]. The comparison between two RSs indicates which dormant cell will be switched on. Finally, the SON will optimise its self for optimum performance and efficiency.

A network is able to self-heal by troubleshooting technical issues and resolving them accordingly [11, 49]. The healing proceed is initiated when the SON picks up specific symptoms from the RS, such as interference or overload [54]. The healing process relies on pre-configured procedures programmed into the AI. In all, the system will be able to heal autonomously with no or very limited human contact and increasing the network recovery time [49]. Heated areas of research are currently focusing on how real-time small cell traffic conditions can be efficiently monitored and optimized by the core network, using enhanced SON mechanisms for fault diagnosis and avoidance [77].

Meanwhile, adapting the dynamic network system envisaged from this review is a novel area of future study. To contribute to the solution of this problem, methods of designing dynamic BTSs are presented in Chapter 3 using Network Simulator Version 2 (NS2). In Chapter 4, detailed deployment scenarios are simulated and analysed in terms of throughput, delay, capacity, coverage, packet loss rate and load balancing metrics. In Chapter 5, bio-inspired optimization methods are proposed to reduce the paths trailed by the BTSs for prompt response and services so as to reduce delay in the network.

2.5 Summary

In this chapter, it has been shown that the cellular networks techniques are extremely complex and advanced. However, 4G wirelesses communication systems remain overstressed in comparison to the growing service demand or during events. Thus, extensive research and engineering works are needed in order to sustain the high cellular-data demand. This is due to the fact that wireless cellular networks are continually evolving penetrating where it has not been able to penetrate earlier and providing novel styles of services it has not been able to provide earlier. A major constraint is that the frequency spectrum is finite and thus finite bandwidths are usually allocated to network operators. Different technologies are therefore being proposed and designed for coping with the data traffic. In the recent time, efforts that may further improve throughput, data rate, reduce latency, interference and provide wider coverage are functionally directed toward network topology due to bandwidth limitation. Consequently, different network topologies have been suggested to complement the existing technologies. The most recent technology that complements the recently released LTE (or 4G) technology standard has been described as the LTE-A. LTE-A is fundamentally a heterogeneous network deploying the intelligent functionalities of self-organizing network which includes self-awareness, self-adapting, self-organizing and self-configuration. It was found that the even with the intelligence of the LTE-A, several bottlenecks still abound. More suitable energy saving options are still being sought. It is thus resolved from these reviews that dynamic (instead of fixed) BTSs is a promising solution to these limitations; this will be demonstrated in Chapters 4 and 5.

Chapter 3

Methodology for Dynamic BTS Network Design

In the traditional design of radio networks for the highly increasing data traffics, the radio access resource namely, the base transceiver station (BTS), are usually fixed. These BTSs provide radio cells for mobile user equipment (UE) coverage and to enable radio access by these UEs. Each BTS has a conventional configuration to support a certain threshold of network users and disallow further connections using some call connection admission control (CAC) protocol. City and town plannings change such that user concentrations in a network radio cell do vary (increase) sometimes. Similarly, during events like football matches, festive events, etc. these BTSs may be loaded to maximum capacities. These may cause that call (and/or packet) dropping rate may increase. Cell breathing problems also increase. This research proposes how to cope with the capacity and coverage problems in modern communication network designs, for example, the long-term evolution (LTE) network by adopting some intelligent dynamic (mobile) BTSs.

At high traffic load, the over-stretching of a macro-BTS may lead to its total malfunctioning or failure thereby causing a total coverage hole or blackout. That dark-sport can be covered by some intelligent dynamic BTSs.

Sectorization [63] is known to help cope with the problem coupled the use of combined macro and micro BTSs [64, 65].

The enabling environment for investigating how to solve the problem is carried out on network simulator version 2 (NS2). A description on the procedural methods of developing platform of investigating the proposed solution is presented also. The BTSs will sense the network cells with high density of UEs and then migrate towards that location. The results of this design are presented in Chapter 4. Later in Chapter 5, the methods of enabling optimized BTS movement with minimum resources are presented including the results. No simulation result is shown in this chapter, only the methods followed to achieve the results presented in Chapters 4 and 5 are demonstrated.

3.1 Problem Definition

This thesis considers building a capacity enhancement solution in order to enhance capacity and coverage of the future mobile networks including the LTE technologies. Such networks combine devices with different software and hardware capabilities to serve users with different requirements which may be overlaid within the same geographical area. This is considered as a main problem of this research to permit the LTE devices (BTSs in this study) to sense the dense use of the radio technology and spectrum and consequently move towards the growing wireless traffic in order to meet the demandable increase in the capacity and improve link quality. The solution is built upon the requirements and dynamic characteristics of LTE network where dynamic, self-configuration, and heterogeneous networks are required. These concepts are needed in building such networks.

The findings of this study, summarized in Chapter 6, could also be applied to any future mobile networks as the aim of this thesis is to include the concept of dynamic BTSs to dense geographical areas; consequently enhance the capacity and quality including increasing data transfer rates thereby speeding up the network. To model and simulate the problem of capacity enhancement in LTE network, this thesis considers a mobile BTS which moves towards dense geographical areas with growing network traffic to enhance the capacity of the network based on the required LTE components. The LTE model components are discussed in the subsections which follow.

3.2 Objectives of the Proposed Problem Solution

The aim of the proposed capacity enhancement approach in LTE network is focused on offering data rate fairness to serve dense geographical areas when more terminals are located in the same place which results in decreasing the LTE capacity. It allows the BTSs to be mobile, scalable and flexible to be fairly distributed around the dense areas in order to satisfy the requirements of massive LTE deployment. The capacity improvement shall be investigated by several performance metrics including the total system throughput, packet drop, distribution of user data rate, and mobility performance of the BTSs. To define the applicability of the problem, a preliminary investigation has been done by simulating two scenarios of LTE wireless network.

3.3 LTE Model

The LTE network architecture is composed of three important components [11, 14]. The representative architecture of the LTE is shown in Fig. 3-1.

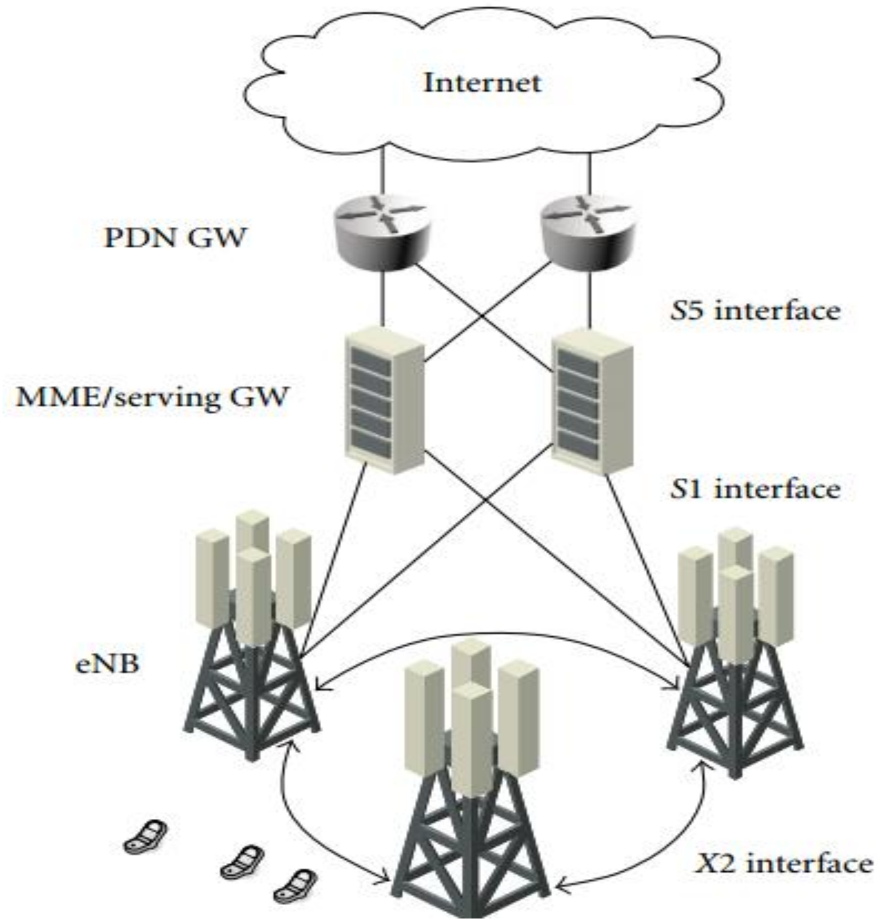

Figure 3.1 LTE Release 12 Architecture

A UE is connected with the *evolved universal terrestrial radio access network* (E-UTRAN). The E-UTRAN is then connected to the evolved packet core

(EPC) which is linked to the internet. Other components of the LTE architecture are described in the following subsections.

3.3.1 User Equipment (UE)

Any device such as mobile phone that is used by the users to connect to the network is known as UEs. They are connected to the eNodeBs (eNBs).

3.3.2 Evolved Universal Terrestrial Radio Access Network (E-UTRAN)

The E-UTRAN is used to connect each UE to the LTE network. It is composed of a set of eNBs which can be utilised to serve many cells in the LTE network. The aim of the E-UTRAN is to transmit and receive radio signals to/from the UEs and it can be beneficial in reducing the latency of all radio interface operations. X2 interface is used to connect the eNBs together while the S1 interface is used to connect them to the evolved packet core (EPC).

3.3.3 Evolved Packet Core (EPC)

The EPC contains five important elements, namely the serving gateway (SGW), packet data network (PDN), home subscriber station (HSS), and mobility management entity (MME). Direction of data packets between UEs and eNBs is conducted by using the SGW which serves as a router. Besides, it is also used as an anchor during the inter-eNB handover. The second element is the PDN which is used to connect the LTE network to the internet. It is used for packet filtering, traffic shaping and charging policies of users, and is also responsible for the establishing, maintaining, and deleting protocols such as GPRS. The HHS element serves as a database that contains information of users including user identification, user profile and authentication. The last element is the MME which is used to manage the UE contexts like the UE identity, mobile state and parameters used for security purposes.

3.4 Procedure of Research Methodology

To conduct the research, NS2 simulator is used. The underlying LTE components which are described in Section 3.2 are utilised to build the proposed scenarios. Three scenarios are required to be investigated using the NS2 simulator. Firstly, a heterogeneous topology with both fixed and mobile BTSs in which the movement of the mobile BTSs depend on the heavily loaded areas is simulated. Secondly, a heterogeneous scenario with both fixed and mobile BTSs are designed/investigated with dynamic BTSs within emulating heavily loaded areas. Finally, an LTE network with complete mobile BTSs scenario is investigated in order to verify the proposed capacity enhancement approach. In each scenario, different mobility patterns includes linear (horizontal and vertical) and diagonal mobility are also investigated. Besides, performance metrics like system throughput, packet dropping rate, distribution of user data rate, and mobility performance of the BTSs are evaluated using the NS2 simulator.

The details of the network simulator used, assumptions, and data collection used in this thesis are given in the following subsections.

3.4.1 NS2 Simulator

NS2 is an open-source discrete event simulator designed to support research in computer networking [78]. It involves various modules to help test several network components such as packet, node, routing, application and transport layer protocols. It is implemented using two types of languages, namely C++ and Otcl. Otcl script is used to manage parameters of protocols and C++ is used to implement models and algorithms.

Although there are several network simulators (e.g. OPNET) with different features in different aspects, NS2 is the most popular simulator in academic research for its advantages of open source and useful library of different network components. Compared to commercial simulators like OPNET, NS2 has the advantages of being open and consequently individuals or organisations can contribute to it with maintenance, finding bugs, and future improvement. Besides, NS2 allows researchers to integrate existing codes and consequently takes advantage of their validity in previous wireless protocols. NS2 is used to simulate an LTE network with generating traffic, setting up network topology, and links between different devices by several researchers. For these reasons NS2 is chosen to conduct this research.

The three important components of the LTE network presented in Section 3.2 including UE, E-UTRAN, and EPC are implemented in the simulation scenarios. To simulate the LTE network in NS2, the model needs to comprise a set of different components as follows. A number of servers, a number of access gateways (AGWs), a number of enhanced base transceivers (EBTs) and a number of UEs. Each component has an important role in setting up the network which illustrated as follow:

Servers: manage the incoming and outgoing data and perform the necessary responses.

AGWs: facilitate the transfer of data so that the data can reach the servers.

EBTs: provide signals that mobile devices can pick up so that they can exchange data with the internet. For LTE, the specific EBT is called eNodeB.

User Equipment: any devices that can create communication between users, in our case, mobile phones.

3.4.2 Mobility Model

The aim of this thesis is to allow the LTE's BTSs to be mobile and dynamically move towards dense geographical areas to enhance the capacity of the LTE network. Consequently, a mobility model need to be adopted to conduct the proposed scenarios, besides, mobility metrics and statistics for the mobility model are needed to evaluate the results. The performances of the network under the mobility model that need to be added to each eNBs in the network are also considered. Unlike other research in the LTE network, the positions of eNBs are configured as movable nodes herein and their movement is based upon the movement of UEs to sense the dense areas. However, the NS2 simulator can provide several types of mobility such as Random Point Group Mobility (RPGM) model [79].

The mobility model used in this thesis is the random way point (RWP) which is the most commonly used model in NS2. It is feasible and movement can be considered as realistic which is very similar to the real world movement [80].

3.4.3 Data Collection

This subsection provides information about the data sources, methods used to collect the data used in this thesis, and performance metrics used to analyse the collected data. Though NS2 has been considered as a leader among a vast number of network simulators [81], aspects of data collection do not have sufficient support and statistical analyses of the simulation results is most often achieved by the users themselves using their local codes, which are not integrated in the simulator [82]. However, NS2 provides trace files as the only source of data after each simulation. Trace files record some important parameters such as generation, queuing, forwarding, and dropping of packets. Each line in the file represents information of an event related to the packet in terms of size, source and destination addresses, TCP/UDP port numbers, and some additional fields. In this thesis, after simulation of each scenario, a trace file is used to analyse the proportion of throughput and packet drop ratio to evaluate the total performance of the LTE system. Comparison with fixed eNBs scenario is done to evaluate the proposed capacity enhancement approach. Some additional information needed for the research analyses cannot be obtained using the NS2 trace files, such as the mobility performance is collected during the simulation and could be saved to text-files. An AWK script [83], which is a programming language primarily designed for processing structured data records containing text, is written for the trace files to read the results and for each text-file to analyse the results.

3.5 Methods of Experimental Implementation

In this section, the procedural steps of reproducing the results reported in this thesis are presented. It has been carried out in an NS2 simulator environment with the help of [78]. Although other network simulation tools abound, such as OPNET [84], ONET++ [85, 86], etc. NS2 has been studied by researchers in comparison with these simulators but it was shown that NS2 results are usually better [81, 87-89]. It is also difficult to access the OPNET simulator thus limiting its use and wide distribution; online information and help to use OPNET are also scarce. Consequently, NS2 has been preferred in this study based on these advantages.

3.5.1 NS2 Requirements

In order to use the NS2 simulator to design and successfully implement the virtual LTE network, there are been minimum requirements that were considered. These simulation environment requirements are enumerated in Table 3.1.

Table 3.1 NS2 Requirements

Operation system	Version	Download Links	
Ubuntu	14.04.4	http://releases.ubuntu.com/14.04.4/	
Application	Version	Download Links	
Network Simulator	2.34	http://www.isi.edu/nsnam/ns/	
Devices	Amount	Stats	Application Used
UE nodes	4	virtual	LTE-NS2
BTS nodes	3	virtual	LTE-NS2
Server nodes	1	virtual	LTE-NS2

From Table 3.1, it is clear that 4 UE nodes are required to implement the virtual LTE network and with 3 BTS nodes. Only one server has been used.

3.5.2 Establishing NS2 virtual environment

To study and analyse the proposed capacity enhancements approach using dynamic mobile BTSs, a virtual environment design to simulate the LTE performance was required. However, the NS2 virtual simulator is used in this thesis to apply the concept of the proposed approach to represent a real network, for several reasons including the following:

- NS2 is the widely used environment by several researchers to test wireless communication systems including mobile ad hoc networks (MANET), wireless sensor networks (WSN), vehicle ad hoc network (VANET), long term evolution (LTE), etc.

- As it is an open simulator, consequently researchers can edit, extend, and add new models and consequently can control them.
- This virtual network produced by the NS2 is flexible to make any changes in the LTE devices or in network configuration to implement different scenarios with different parameters.
- The virtual network can be a useful environment to test new models includes the capacity enhancement approach proposed in this thesis and consequently can be applied to the real network after testing it.

3.5.3 Simulation Setup

Wired and wireless network can be simulated by different network simulators to investigate the performance of the LTE networks. However, NS2 is chosen in this thesis because of its popularity in networking research community. To use LTE network in NS2, a number of settings need to be followed by researcher to patch and install the LTE model. LTE model is built in NS2 to introduce how to build an accurate enough LTE/SAE-system architecture evolution-model in NS2, so that other optimization features can be tested. The simulation model includes traffic model and network model which concentrates on the air interface and S1 interface. Vivid evidences (screenshots) are shown in the following subsections of this chapter (Chapter 3) to demonstrate how to use this model. The architecture, performances and methods of implementing LTE/SAE in NS2 have been described in [90-92].

3.5.4 Installation procedure of NS-2

NS2 is an open software than can be installed directly on a personal PC. In order to install the NS2 simulator, it is required to download a full package of **ns-allinone-2.34.tar.gz**, from the formal website; the website contains essential components and other optional components that will be used in running the network simulator. After successfully downloading the NS2 from the formal website, the following steps should be typed in the command prompt (i.e. the terminal which can be opened using the shortcut Ctrl+Alt+T) to start the NS2 installation.

- *Tar-XZF ns-allinone-2.34.tar.gz*
- *cd ns-allinone-2.34*
- *./install*

After successfully installing the NS2 simulator, it is now possible to explore its packages that have installed on the "**Home**" directory. Ns2 contains different files which are used to simulate, test, and analyse results of the simulated environment. These include the following

- *TCL*
- *NAM*
- *Xgraph*

To test if the NS2 was successfully installed, validating command should be run in the terminal to check the installation.

- *cd ns-2.34*
- *./validate*

To finish the installation of NS2, the following commands were used to finalise the installation;

- *Setting up Unix Ubuntu operating system, NS2 and Nam.*
- *Install and setting up LTE model.*
- *Testing.*

The above steps have been used to enable a functional standalone NS2 on an Ubuntu operating system. Recently, it has been observed that it is also possible to enable a functional standalone NS2 on a Windows Operating System [93]. This has also been described in [78].

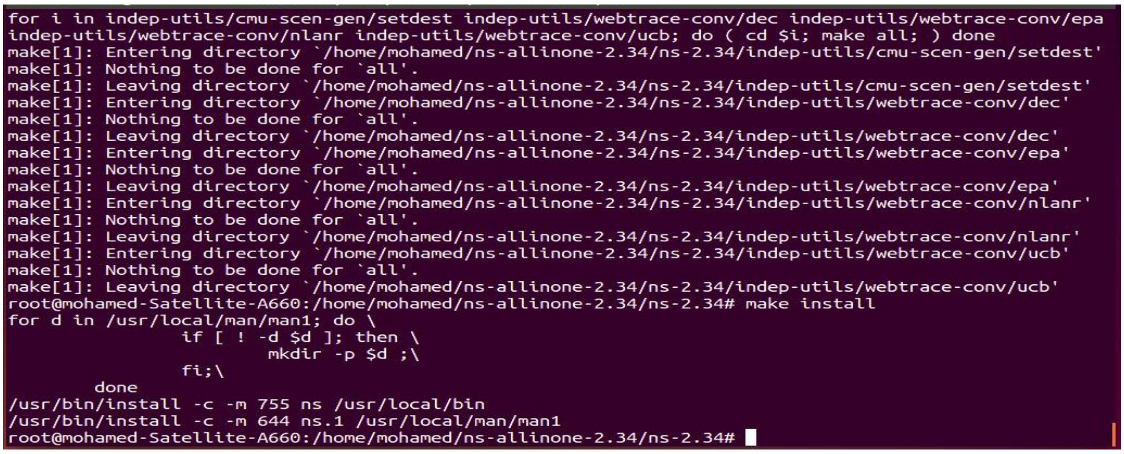

Figure 3.2 NS2 setup

Figures 3-2 and 3-3 illustrate the final steps of NS-2 installation in Ubuntu operating system.

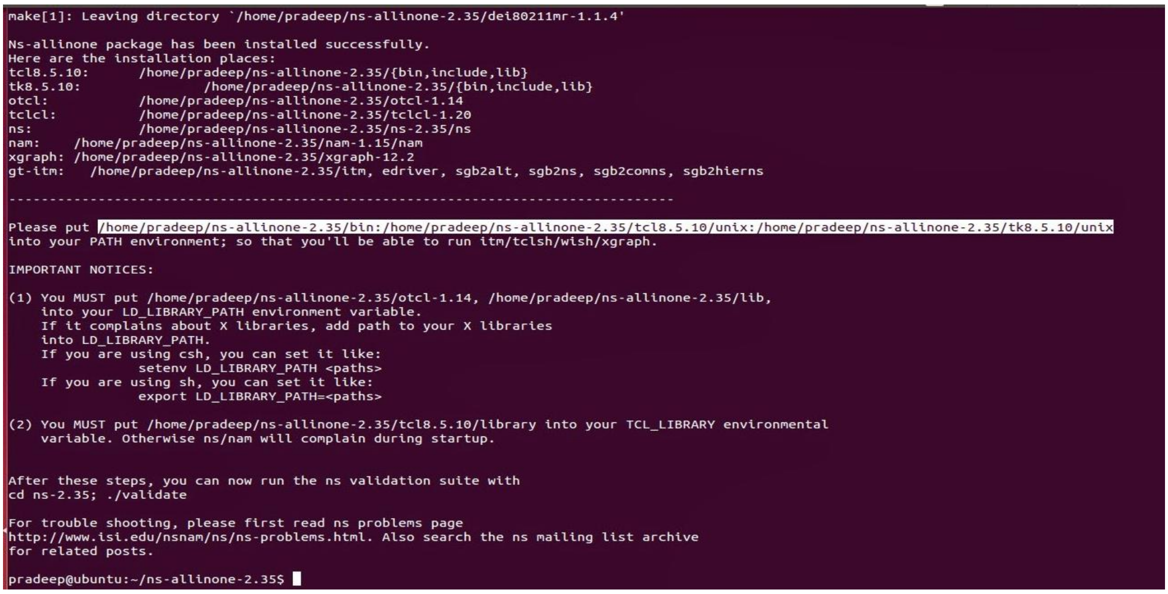

Figure 3.3 Success installation of NS2 simulator

NS2 simulator is usually accompanied by some scripting files written usually in TCL (or Object-Oriented TCL) and C++ [78]. However, the TCL scripts are used to simulate LTE network.

3.5.5 Setting up environment and running simulation

A TCL script is written to simulate the LTE model with the adopted mobile BTSs. LTE network which consists of one server, three BTSs, and four mobile users are used to test the proposed models in Chapter 4 and 5. Meanwhile, the following screen shots show the steps used to set up and run LTE model using NS2:

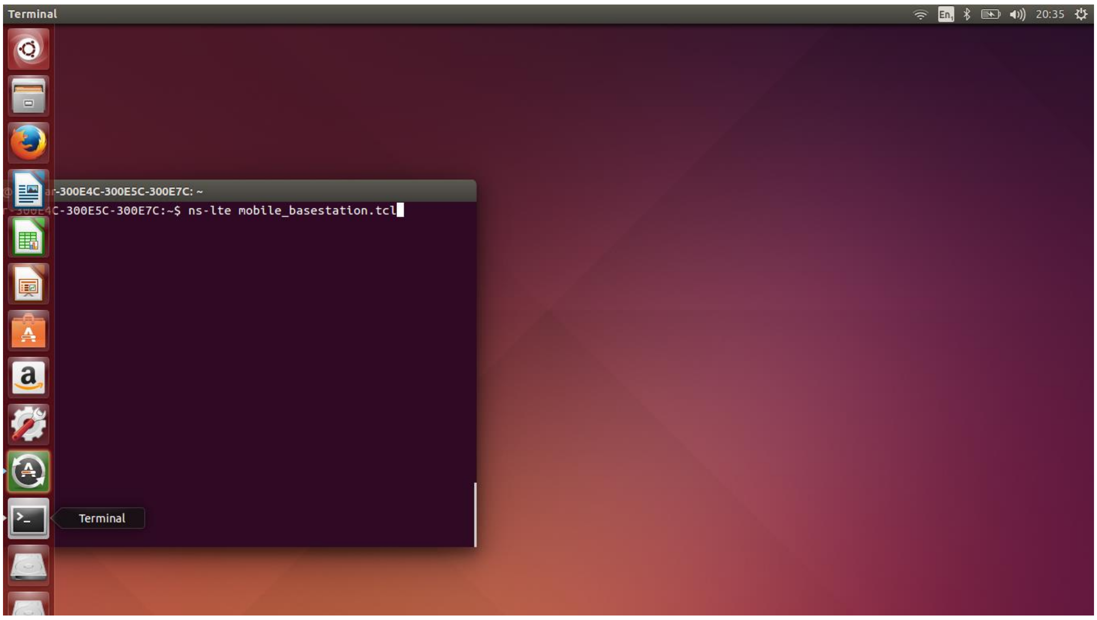

Figure 3.4 Run TCL file using Ubuntu terminal

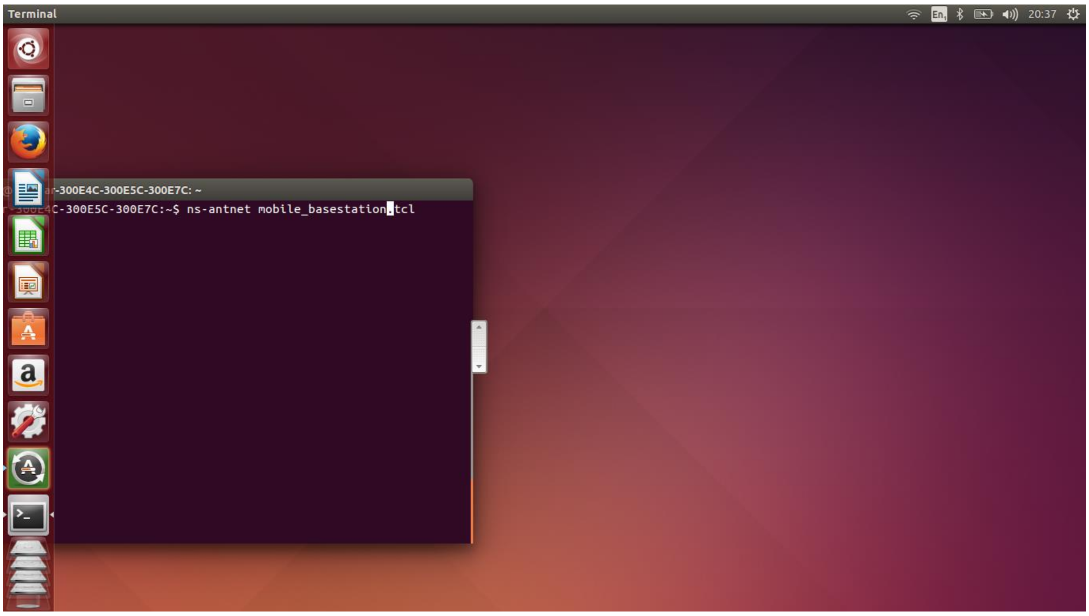

Figure 3.5 Run TCL file using Ubuntu terminal with antnet

- **Creating the network animator (NAM) environment**

The NAM environment is created by using the “nam” command and then the filename; a typical window observed is shown in Fig. 3-6.

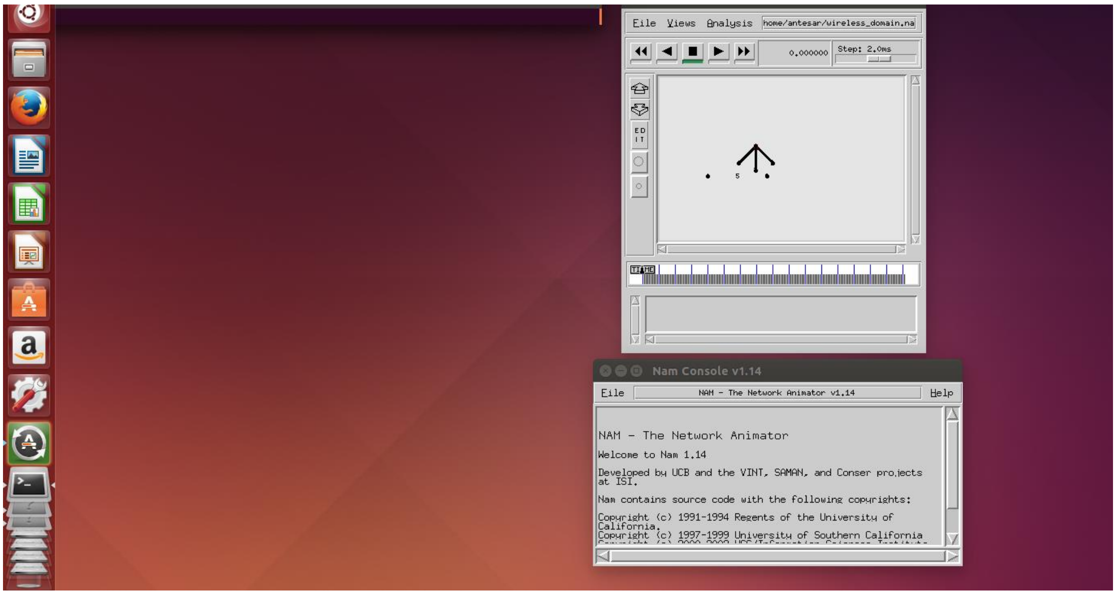

Figure 3.6 NAM file running

The TCL files are then linked with NAM to create the following results in Fig.3-7.

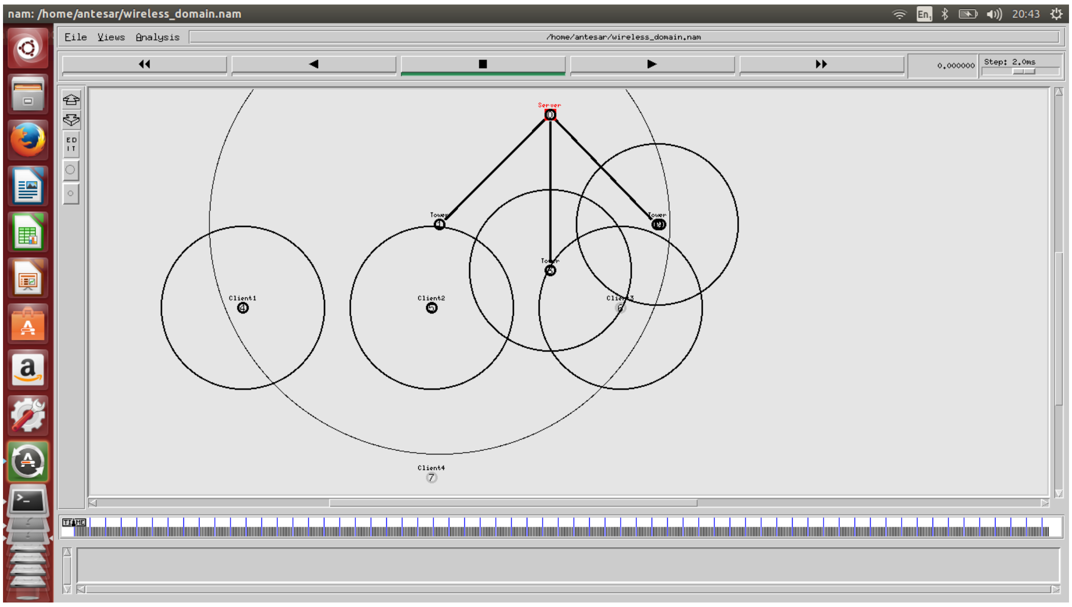

Figure 3.7 TCL file running in NAM

In Fig. 3-8, the TCL files are used to enable the BTSs to move as shown by the red-dashed lines.

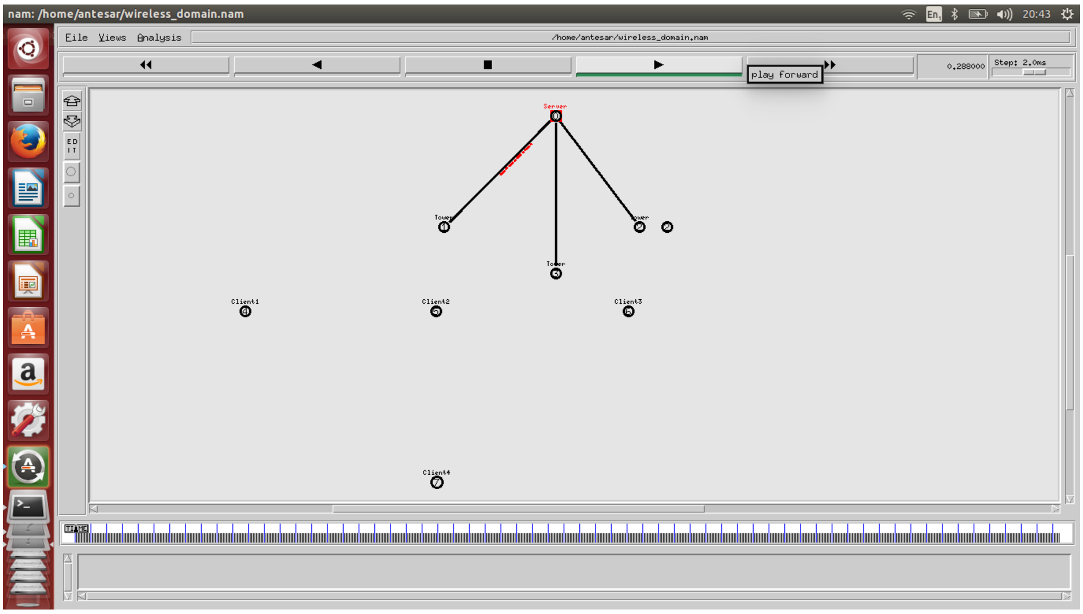

Figure 3.8 Base station (tower 2) starts moving.

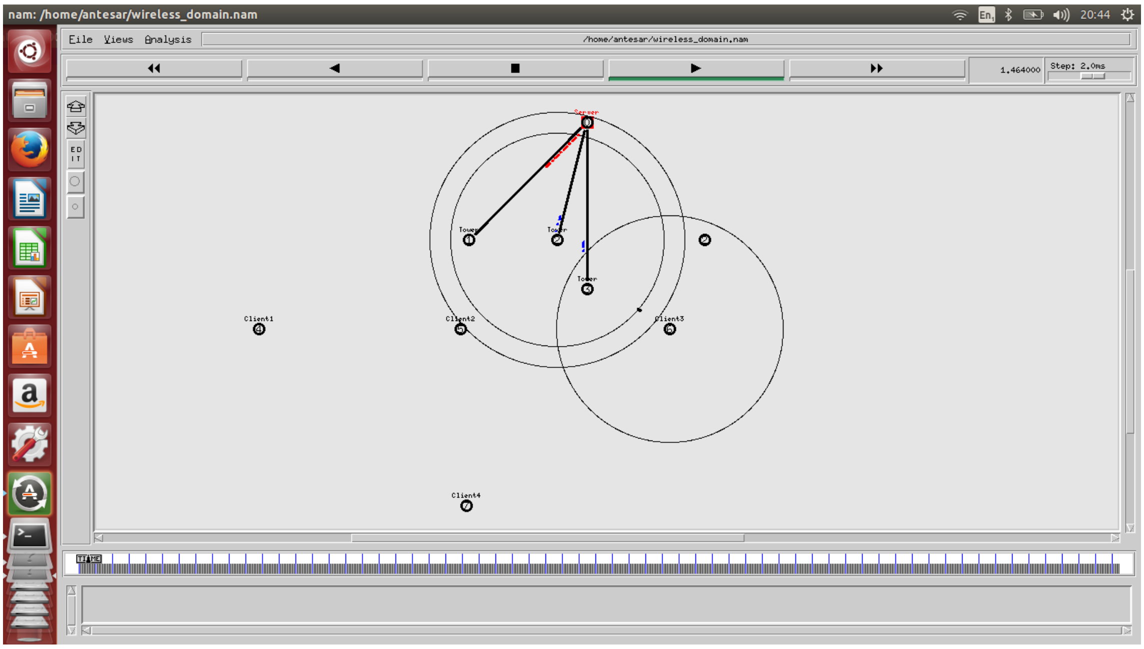

Figure 3.9 Base station (tower 2) continues moving

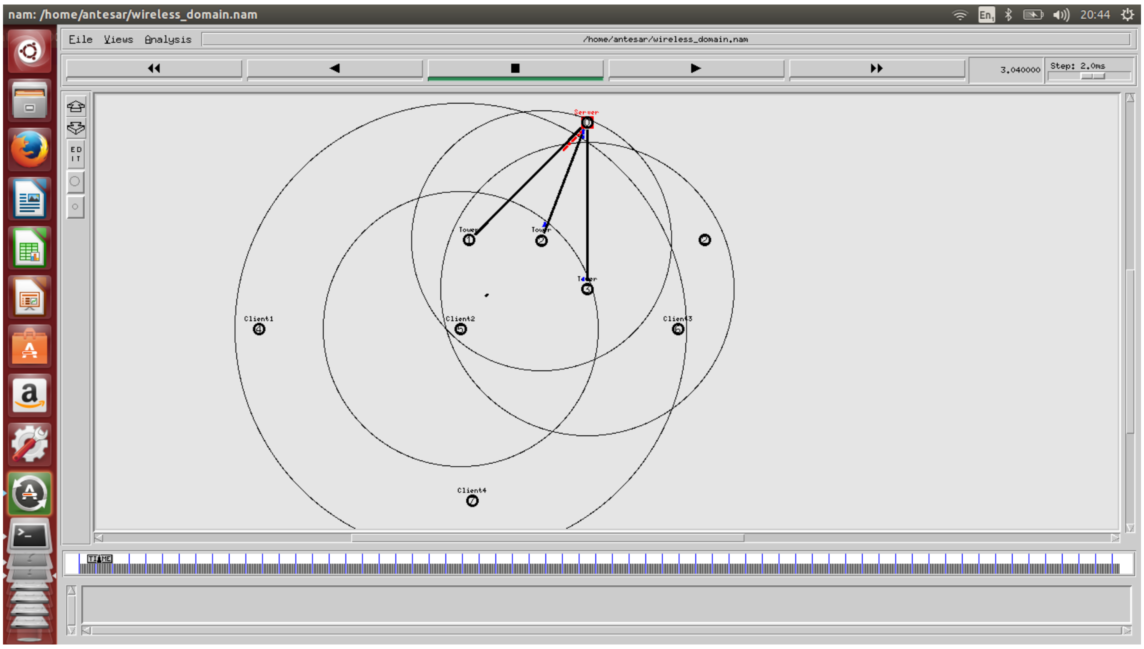

Figure 3.10 Base station (tower 2) reaches the desired position

3.1.1 Simulation model overview

It has been mentioned in the previous section that NS2 has used to test the experiments of enhancing the capacity approaches by using a dynamic self-organised BTSs. The trace file has been automatically created as a result of running the simulation file “mobile_basestation.tcl”. The trace file was stored and analysed by using a variety of scripts, this trace file is named “wireless_domain.tr”. Trace file counts the number of packets successfully delivered and packets dropped due to different reasons as well as other important parameters such as throughput and delay. Additional files were created to capture different information from the simulator and used to produce a useful analysis. This data is analysed by AWK file and Microsoft EXCEL to simply produce graphs. These steps are shown in Figs. 3-12 until 3-17.

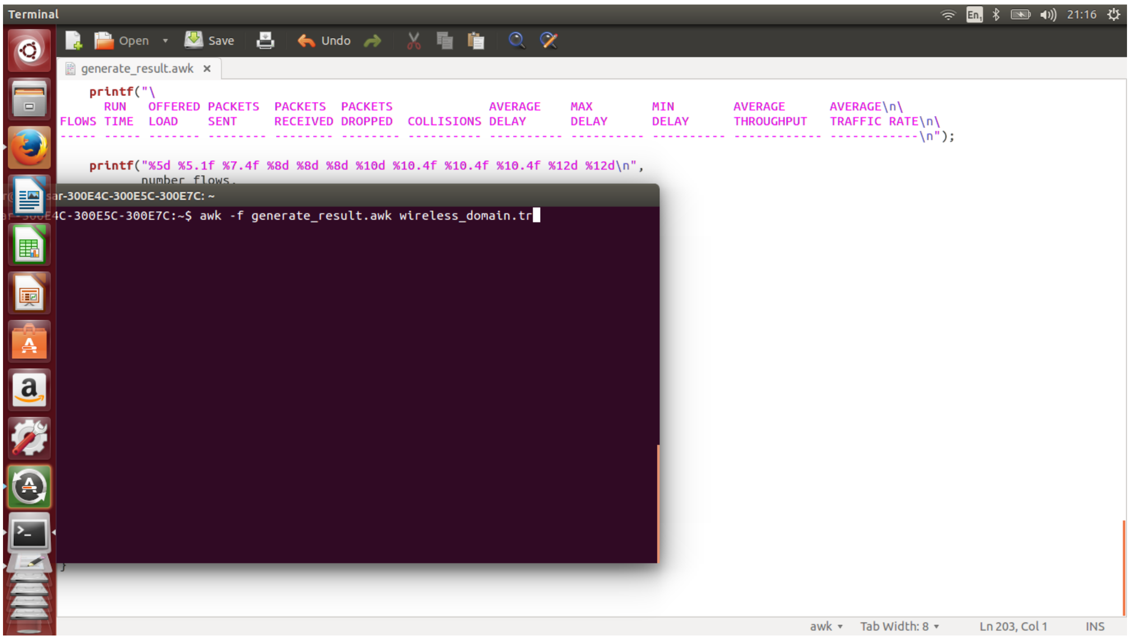

Figure 3.11 AWK file running to read trace file

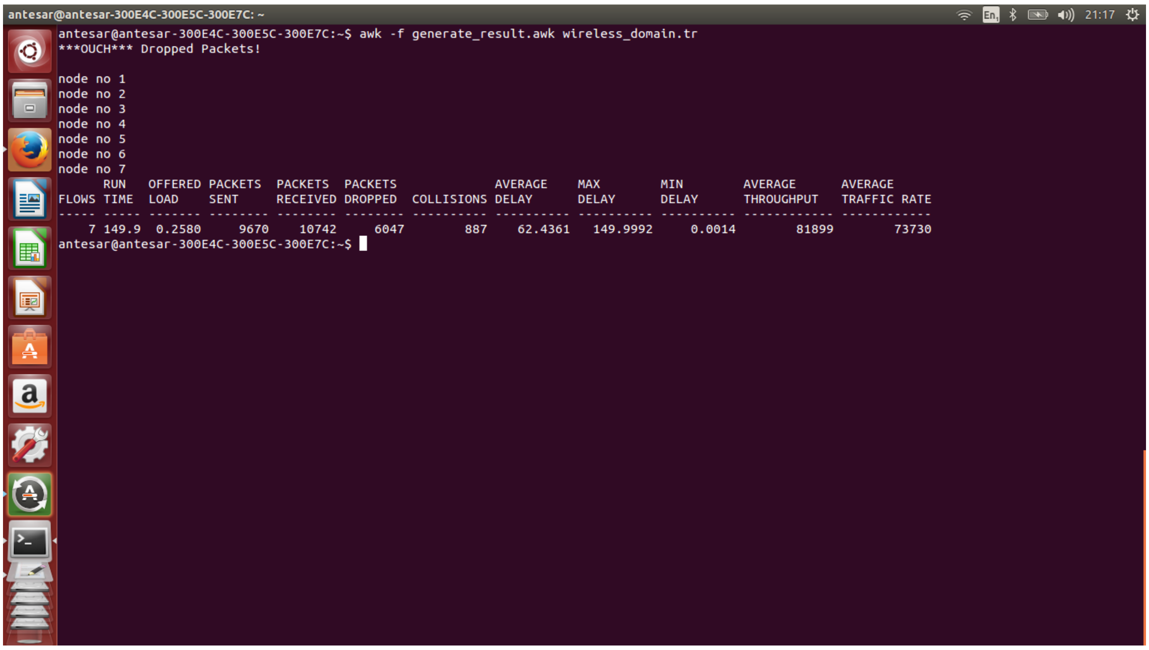

Figure 3.12 AWK file results

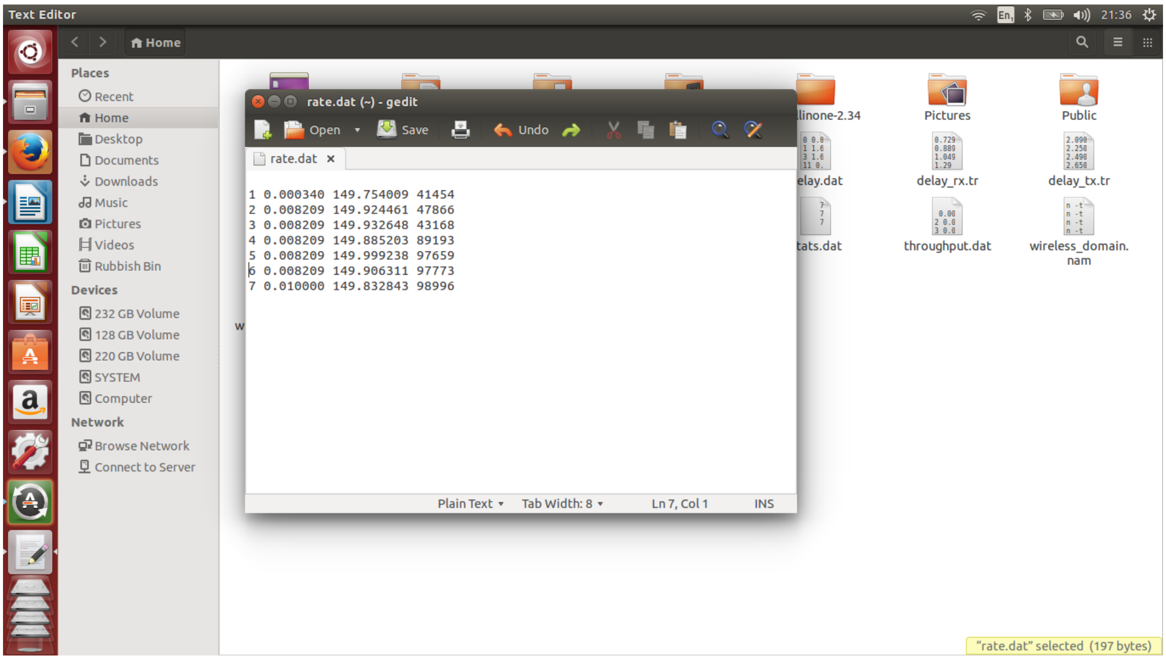

Figure 3.13 Additional result file-rate file

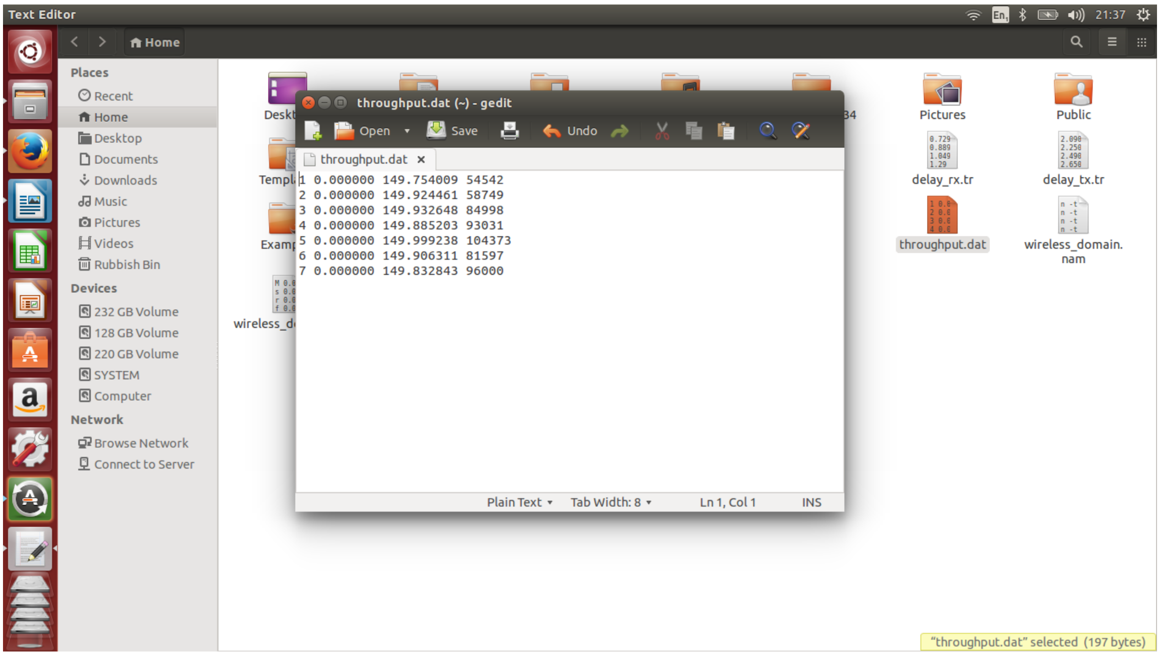

Figure 3.14 Additional result file-throughput file

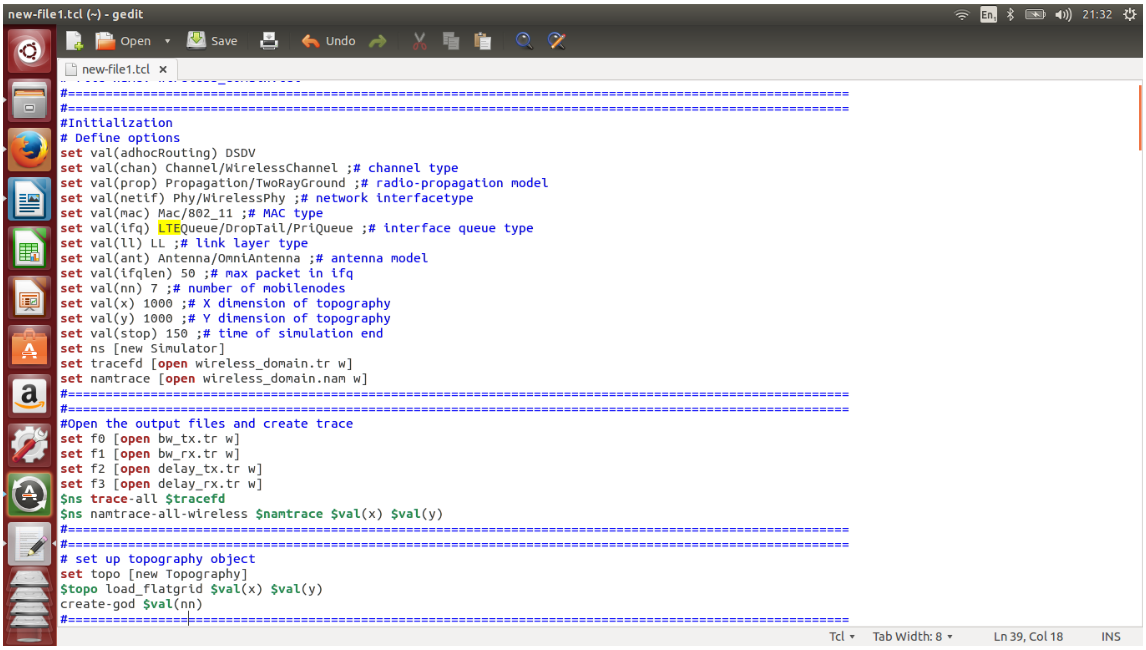

Figure 3.15 TCL file-LTE configurations

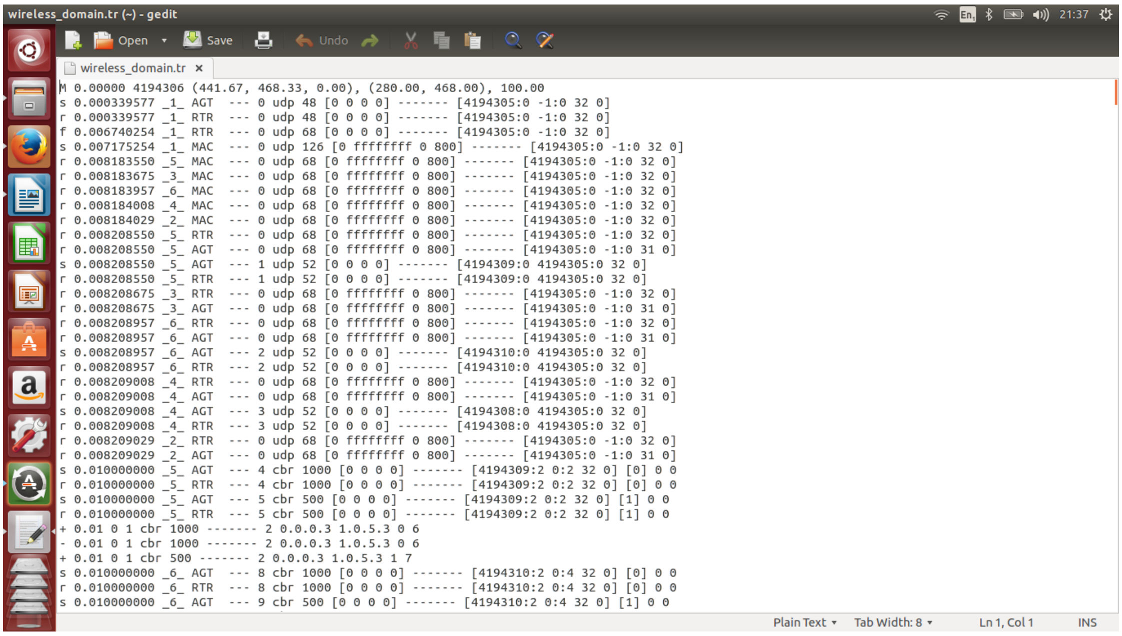

Figure 3.16 Trace file

The above methodological steps are fundamental. In Chapters 4 and 5, the configuration settings along with added components for each experiment are followed similarly to develop any further additional functionality. The results are presented and analysed also in these Chapters 4 and 5. Consequent on these results, the conclusion is drawn in Chapter 6.

3.6 Summary

An illustration of the problem of capacity enhancement approach, which has been considered as the basis of this work is provided. Backgrounds for simulating the LTE with fair distribution of eNBs are examined to evaluate the usefulness of the data rate fairness concept. An illustration of the important components of the LTE model and the LTE architecture in Release 12 is given. Further, the adopted research methodology is explored. An explanation of the simulator, assumptions, mobility model, and the way data is collected which are used to build a capacity enhancement approach is provided. To reproduce the results reported in Chapters 4 and 5 of this thesis, the following summarized steps must be followed;

- Setting up Unix Ubuntu operating system, NS2 and Nam
- Install and setting up LTE model
- Testing
- Setting up environment and running simulation
- Read and understand the trace file which contains the results of the simulation file
- Write an AWK file to read and analyze results included in the trace file
- Collect and understand results and plot it using EXCEL spreadsheets.

It is possible to choose other result analyses tools, such as MATLAB. However, Ms-Excel has been followed due to its simplicity to use.

Chapter 4

Capacity Enhancement Using Mobile Base Stations for Traffic Fairness in LTE Network

4 Background

The huge increase in wireless data traffic makes it crucial to search for approaches to further improve the already-known spectrally efficient systems, for example, in the LTE network systems. This has been achieved in low frequency bands using advanced spectral efficiency techniques. Against these improvements, the viability of such improvements may be hampered due to the limitations on the hardware implementation and channel conditions, as well as, the increase in the system complexity due to the use of these advanced techniques.

To solve the problem of growing usage and demand for wireless data, different capacity enhancement approaches must be used. These include exploiting the advantages of moving up into some unused spectrum bands in which huge bandwidths are available. Comparing with approaches that rely on the use of highly complex techniques, moving up the frequency bands can be a promising approach to guarantee the fairness of traffic and achieve high data rates. A capacity enhancement approach to enhance fairness of traffic in LTE network by moving up the unused bandwidths towards dense or crowded areas is proposed in this chapter; achieved by dynamic mobility of base-transceiver stations (BTSs). The approach is empirically tested to show the scalability evolution unto higher system capacities and improve the spectral efficiency where data demands further increase.

The results presented in this chapter are based upon a number of experiments. Besides, the experimental work is carried out using an NS2 simulator; the method of developing a simulation network environment and obtaining the results have been described extensively in Chapter 3 of this work.

4.1 Introduction

The continuous increase in the data traffic in cellular networks at an exponential rate requires further improvement in the efficiency management of the acquired system spectrum and efficient utilisation of higher frequency bands [25, 94]. To cope with the capacity and coverage problem in the LTE network, some high power macro nodes (macro BTSs) are utilized to increase the node density in the LTE network [25, 95] (see Fig. 4-1); this provides the advantage of cell splitting and traffic load management.

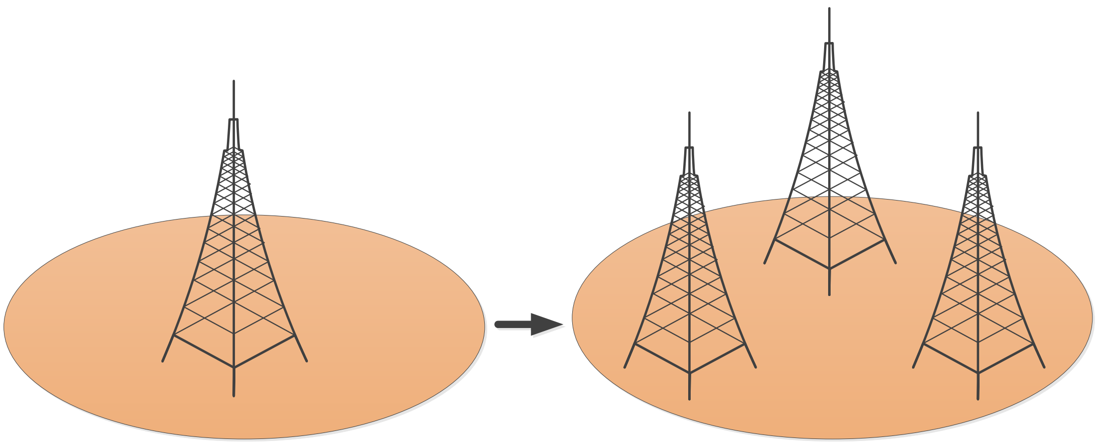

Figure 4.1 Increasing macro BTSs density

Meanwhile, several challenges are associated with the deployment of traditional macro base stations (m-BTSs). For example, there is the significant reduction of cell splitting gains due to already severe intercell interference. Besides, the expenditure of high capital cost associated with high power m-BTSs limits the feasibility of the approach.

To overcome the challenges of traditional high power base stations, another approach of utilising an LTE heterogeneous network is proposed [14, 64, 96]. A mix of traditional high-power base stations and low-power base stations are designed to solve the capacity problem. Pico, femto, and/or relay base stations are an example of the deployment of low-power nodes which are utilised to increase the nodes density and achieve the system gains (see Fig. 4-2).

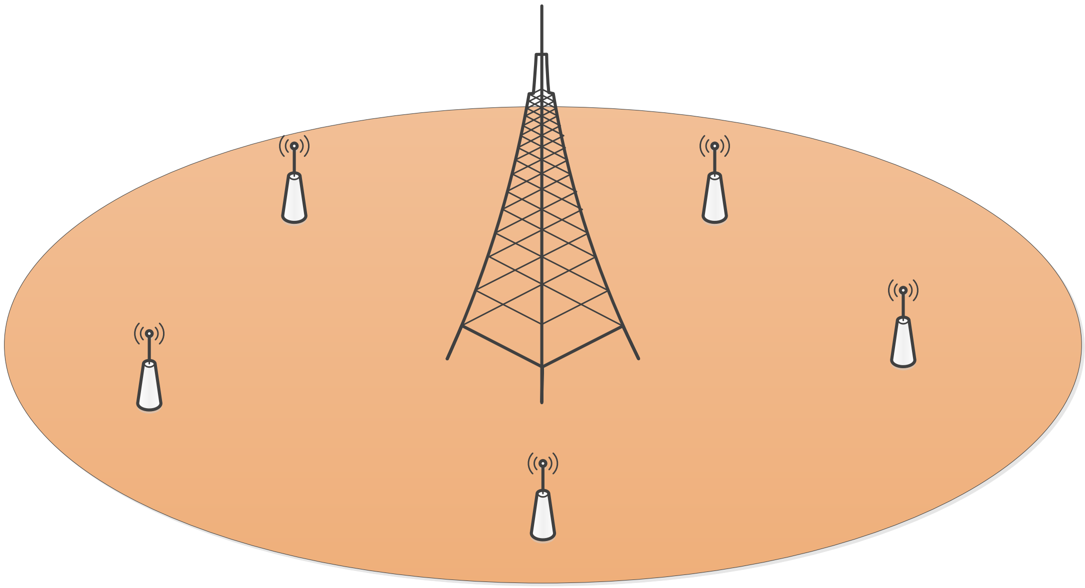

Figure 4.2 Mixture of high and low power (Pico, femto, and/or relay) BTSs

Although the heterogeneous mixing of both macro-BTS and the micro-BTSs (μ-BTSs) provided several advantages, several challenges emerged as well. For example, this type of networks is characterised by huge differences in the transmit power used by different types of nodes. Also, there exists severe intercell interference between the macro and the low-power BTSs [97]; an example is by using BTS timeslot resource management [98]. This is the main disadvantage of the hybrid macro-BTS and the micro-BTSs solution due to different power classes which makes the low power BTSs (pico, femto and relay) less advantageous comparing to the high power BTSs (macrocells) [99]. Moreover, developing an effective way of sharing physical resources such as time or frequency with macrocell is an open challenge. Avoiding the creation of coverage holes in the macro network caused by low power BTSs is also an unsolved problem.

Kishiyama et al in [100] proposed an efficient utilisation approach of both lower and higher frequency bands by separating the frequency between wide (macro-cells) and local (µ-cells) areas. This approach in [100] is used to solve the problem of scarcity of spectrum in the lower frequency bands. However, the exploration and utilisation of higher frequency bands can be significant in the LTE future. The lower frequency bands is used to provide mobility and basic coverage and high-speed data transmission in local areas (µ-cells) by the utilisation of separate frequency bands such as the higher frequency bands. This involves a wider spectrum bandwidth in the higher frequency bands in local areas which are suitable for smaller or denser cell deployments. However, there exist several limitations that accompanied this approach, namely, the difficulty of accommodating the higher frequency bands in terms of radio frequency equipment, the antenna size, and coverage limitations.

The work in [101] proposed to use cognitive BTSs in LTE networks to enhance the functionality of femtocells base stations. Specifically, femtocells BTSs will be able to perform several functionalities that are traditionally supported by the macro-cell BTSs in order to alleviate heavy-signalling operations and control more efficient radio resource management protocols. The idea of utilising cognitive BTSs is to make the femtocell BTSs act autonomously and support a diversity of service requirements. Consequently, this will result in producing more sophisticated base stations that are capable of increasing the LTE networks coverage by supporting considerably higher data rates. The use of unlimited base stations antennas in evolved wireless networks is proposed by [102] to achieve more enhanced throughput over the systems that use limited base stations antennas. In such approach, even though the assumption of an unlimited number of antennas at the base station can significantly simplifies the analysis of the system and illustrates its desirable effects of operating with a large excess of antennas, issues like the optimal number of antennas is not discussed. Besides, cost associated with this approach can be large and also is not effectively mentioned. The approach of utilising multiple and dynamic mobile base stations that have the ability of periodically changing their locations according to the network density as a method of transferring coverage is considered by several researchers to increase the performance of the wireless networks [103]. From the discussion above, the principle of adding multiple BTSs antennas even with a very noisy channel estimate is always beneficial.

The effects of fast fading and disappearance of uncorrelated noise make it easier for the LTE system network to recover from low SNR conditions by adding a sufficient number of antennas [102]. However, the introduction of more BTSs with more intelligent capabilities to become self-aware and self-adaptable can form a strong motivation. For example, the self-adaptability in terms of changing their behaviour according to the number of users, other BTSs and dynamic changes in the radio frequency motivates quicker response to loads (and requests) in the network. Therefore, a simple and cost-effective approach is proposed, herein this work, to enhance the capacity of the LTE network by utilising the concept of using multiple and mobile BTSs in order to use the unused bandwidth caused by none operational or less dense BTSs.

4.2 The proposed approach

The aim in this chapter is to make the BTSs in the LTE networks able to be self-aware, self-adaptable and intelligent. In a conventional cellular network, BTSs will serve a number of mobile terminals using the strongest received signal strength (RSS), while the unwanted signals received from other BTSs are usually preserved as interference [104]. To mitigate this problem, some intelligent LTE equipment are desired to provide cognitive coordination and management of resources among BTSs which can offer a significant enhancement in the throughput and user experience as compared to a conventional system [27, 105-107].

The fluctuation in the traffic load among the network BTSs for areas with more density of users will result in more extensive load on the BTSs and high blocking probability to the newly arriving user equipment (UE) as compared to less dense areas where some BTSs will be idle or under low load; this is another problem that motivates the proposal in this work. Consequently, a very unfair distribution of data rates will occur across user terminals. Therefore, balancing the load between different BTSs in the LTE network by using the dynamic movement of BTSs to the more dense areas of users will enhance the network capacity [108-111]. The aim was to enhance the system throughput, minimize packet loss, and the load of the system as performance metrics in order to prove the system viability.

In this study, we approach the problem by considering a densely deployed LTE network in which the BTSs' coverage overlap and the traffic load fluctuate over time and space. The network consists of N wireless nodes or terminals denoted as UEs in the network, and M BTSs which are denoted as eNode-B (eNBs); these are regularly placed in a unit area. The eNBs are neither data sources nor data receivers. They are only used as relay nodes and engaged in routing and forwarding data for the mobile nodes. It is implemented in such a way that the eNBs are connected together by a wired network and the link in the wired network is capable of managing all the traffic; impliedly, there are no bandwidth constraints in the wired network. All the eNBs have the same energy level and the same consumption technique. Due to the increased cost and consumption of power caused by eNBs movement, this approach assumes that eNBs are designed as light BTSs with low transmit power and can be deployed indoors or outdoors in an unplanned manner when hot-spot areas are not expected. A location based user density approach is used to determine the initial position of

BTSs at feasible sites. The number of users (UEs) in a specific area is used to define the density of an eNB. Each UE is associated with one eNB based on the RSS metric and on the arrival to the specified area ratio. The rate requirement is fixed for each UE and denoted by r_i for UE_i. For UE_i associated with eNB_j, the spectral efficiency is denoted as ω_{ij} then the bandwidth b_{ij} needed is given by

$$b_{ij} = \frac{r_i}{\omega_{ij}} \tag{4.1}$$

When a new UE arrives, if there is not enough bandwidth to be allocated to the desired eNB, the UE will be blocked. Herein, this work is motivated to minimise the blocking probability and provide services to every UE by utilising the fairness concepts in distributing traffic load and coverage by the dynamic movement of the eNBs under low load. An algorithm which proposed in [112] is utilised to select idle or low load BTS by generating of a 0-1 matrix $X = X_{ij}$; where $X_{ij} = 1$ which means that the UE_i is associated with eNB_j, otherwise $X_{ij} = 0$. As each UE can only be served by one eNB, the sum of each column in X is 1. As there are many UEs which arrive within the network's lifetime, each active eNB will reserve some bandwidth for the newly arriving UEs. The proportion of bandwidth reserved in eNB_j is denoted as α_j, where $\alpha_j \in [0, 1]$ and consequently the idle bandwidth for eNB_j is given by

$$\tilde{B}_j = (1 - \alpha_j) \cdot B_j \tag{4.2}$$

The number of UEs associated with eNB_j is denoted as μ_i and the traffic load (denoted as L_i) of eNB_j is given by

$$L_j = \sum_{i \in \mu_j} \frac{b_{ij}}{B_j} \quad (4.3)$$

where b_{ij} is the bandwidth needed by eNB_j, and B_j is the total bandwidth for eNB_j.

After receiving the network information on the idle or low dense BTSs, the selected BTS eNB_j wants to move to the desired location at time (*t*) which is denoted as $eNB_{j(mov)}$. Now, the UEs served by BTS eNB_j are handed over to the neighbouring BTS or to the nearest relay of eNB_j which denoted as eNB_N to serve the UEs. Thus, the handover traffic of the eNB_j that are moving out of the serving area would be served by eNB_j's neighbour; these are represented as eNB_n in which $n \in N$. The traffic load by the neighbour of eNB_j which is denoted by $L_{j(mov)}$ is given by

$$L_{j(mov)} = \sum_{i \in \mu_n} \frac{b_{in}}{B_n} \quad (4.4)$$

Each UE will select the eNB by itself according to the measured channel conditions and the traffic load of eNBs in the area. As the eNBs in the area reserve bandwidth for newly arrivig UEs, the reservation parameters of traffic load information and bandwidth can be obtained by broadcasting control signals from eNBs. The UEs regularly select the eNB with high load and high spectral efficiency. A predefined threshold is used to specify the maximum load involved in allowing the UE_i to be associated with eNB_j; which means UEs prefer those eNBs with high load and high spectral efficiency, but not to exceed the predefined threshold. The components of the algorithm and the procedure of BTS movement are described in the following next subsections.

4.2.1 The Base station Movement Metrics

Quality of service (QoS) measurement of the wireless channels by the mobile users (UEs) to the BTSs is a very important concept required in the assessment of the performance of the network. It is required that the UE is always equipped with the capability to measure the quality of the link by either tracking the mobility and monitoring the signal strength or by sharing the channel state information (CSI) for adopted link. However, there are different categories of measurements in wireless networks that can be used as a metric for moving the BTSs. Measurements can be typically directional between mobile users and BTSs. Parameters measured include the angle of arrival (AOA), or related to relative distances between mobile users and BTSs, such as the time of arrival (TOA), the time difference of arrival (TDOA), and the RSS [113]. All of these measurements can be used as metrics of movement to make a dynamic mobile BTS which have the ability to change their locations according to the changes in the environment. In this approach, we assume that both the UEs and eNBs are equipped with intelligent capabilities such as coordinated multipoint (CoMP) transmission and reception techniques introduced in [99]. For each UE, the CoMP techniques assumes there are multiple eNBs that can communicate with the UE and it can be possible for the neighbouring eNBs to transmit signals as desired. UEs can perform the handover operation based on the signal strength received from each eNB. As consequence, the eNBs can identify the dynamic characteristics of the UEs and change their location based on these characteristics. Handoff operation among different locations is handled as the user and mobile BTS moved to the desired dense areas to avoid the severe limitations caused by such operation in both the number and efficiency of service flows.

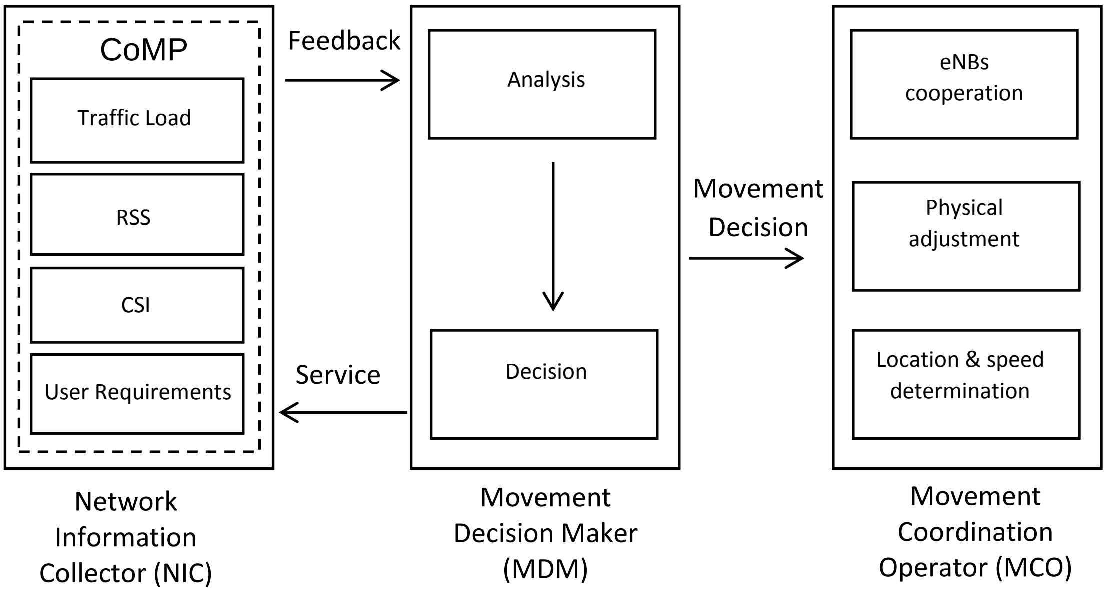

Figure 4.3 The Proposed Algorithm Components

4.2.2 The Base Station Movement Components and Procedure

To implement this approach, the components that are used to build the model which illustrated in Fig. 4-3 need to be specified. The first component is the network information collector (NIC); a virtual component in the network, which can be either implemented in the gateway or distributed into the BTSs or the UEs. The NIC will first sense the network state information to decide whether (or not) to move the desired BTS such as traffic load, channel conditions and user requirements. This information can be collected using the CoMP technique as mentioned earlier.

Some control messages will be utilised to accomplish the information collection stage. After collecting the required information, another component is used to achieve the movement decision stage; this is the movement decision maker (MDM). The MDM is responsible for analysing whether there are opportunities for moving the desired BTS or not and consequently make decisions based on the results of analyses.

If the decision of movement has been made, a coordination stage with the neighbouring BTSs would be conducted using the movement coordination operator (MCO). The MCO's role is to assure that no coverage gaps will accrue by moving the desired BTS through the cooperation between BTSs such as using the relay technique which is utilised in 3GPP LTE-A as an important technique to help fill the coverage gaps that might be caused by moving the eNBs by relaying the traffic from the eNB under heavy load to the eNB under light load. Besides, it is used to announce some required physical adjustments such as managing the transmit power and antenna settings. The last stage is the movement by allowing the base station to dynamically move to the desired location with the suitable speed based on the information collected from the main components.

After sensing the network information by the collector components, the MDM decides to move the BTS under a light load. While the movement coordinator coordinate the cooperation between the BTSs, and other parameters required for movement. The detailed procedure of the algorithm is described in Algorithm 4-1 as follows.

Algorithm 4-1: Base station Movement Algorithm

1. ***For*** each new UE_i ***Do***
2. ***Initialize*** $L_j = 0$, $X_{ij} = 0$
3. ***Calculate*** the b_{ij}, $\tilde{B}_j$, L_j according to Eqs. 1, 2, and 3.
4. ***If*** $(L_j B_j + b_{ij} \leq \tilde{B}_j)$ ***Then***
5. ***Associate*** UE_i with UE_j
6. ***Else***
7. ***Block*** UE_i
8. ***For*** all eNBs in the network ***Do***
9. ***Calculate*** the $L_j B_j$ ratio
10. ***If*** $(L_j B_j = 0$ || $(L_j B_j \leq ratio\_threshold)$ ***Then***
11. ***Move*** the eNB under low load towards the eNB_j
12. ***associate*** the UE_i in μ_j to the moved eNB
13. ***Use*** Neighbouring eNB to fill coverage holes
14. ***End If***
17. ***End For***
18. ***End If***
19. ***End For***

4.3 Simulation and Analysis

An experiment to test the proposed approach and its applicability to the LTE network is conducted. An LTE network environment with two types of nodes, namely wired and wireless mobile nodes, is simulated. The first type of the network comprises a server and the gateways which behave according to wired protocols, while the other type comprises a set of mobile nodes which act as transceiver nodes to the gateways. The main aim of the investigation is to evaluate the contribution of the proposed approach in enhancing the capacity of future LTE networks and introduce BTSs with the capability of acting intelligently by detecting the connected mobile nodes requirement and resources. Consequently, the impact of the approach on the network performance in terms of throughput, packet loss and system load are tested.

4.3.1 Experimental Setting

The simulation is conducted using the NS2 simulator; methods of developing network simulation environment in an NS2 simulator have been described in Chapter 3 of this thesis with the help of [78]. A network with 8 nodes placed in a unit area of 1000×1000 and then simulated. One node act as a server and connected to 3 BTSs eNBs with a wired links, besides 4 mobile nodes that act as UEs and connected to the eNBs by using wireless links and they randomly move in the area around the eNBs. The traffic between the BTSs and mobile nodes transmits packets with a Constant Bit Rate (CBR). The packet size is 512 bytes and the simulation time is 150s. Figure 4-4 shows the network architecture for the simulation environment described in this chapter. The parameters used in configuring the network for this experiment are presented in Table 4.1.

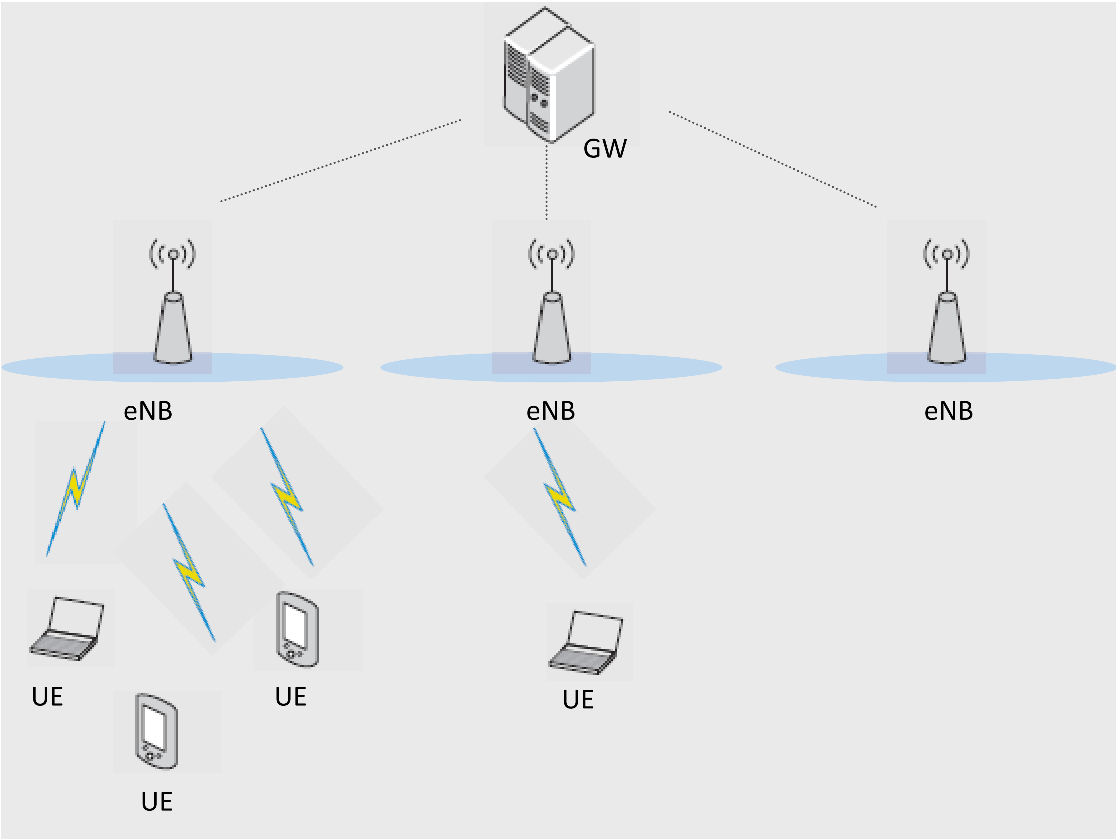

Figure 4.4 Network architecture for capacity enhancement

Table 4.1 Network configuration

Parameter	Value
Nodes	8
Area	1000 X 1000 m^2
Speed	10 m/s
eNodeB coverage area	100 m
Movement	Random waypoint
Routing Protocol	DSDV

Parameter	Value
MAC	802.11
Transmitting capacity	2 Kbps, 4 Kbps
Number of active users	4
Application	CBR
Packet size	512 B
Simulation time	150 s

4.3.2 Experimental Results

In this section, the results and analyses of the comparison of two different scenarios, one without moving the base station and one with moving the base station, are presented. A discussion of the results of both scenarios is also provided based on the network performance. The simulation results are shown in Figs. 4-4 to 4-6. These results introduce the evaluation of the performances of three important measurement parameters of the LTE network in terms of throughput, packet loss and system load.

It has been described above that the LTE network is aimed at benefiting from the intelligence capability of BTSs to dynamically move to dense areas. Thus, it follows that an important evaluation metric involves the consideration of the adaptation of the proposed approach in enhancing the network performance, as shown in Figs. 4-4 and 4-6.

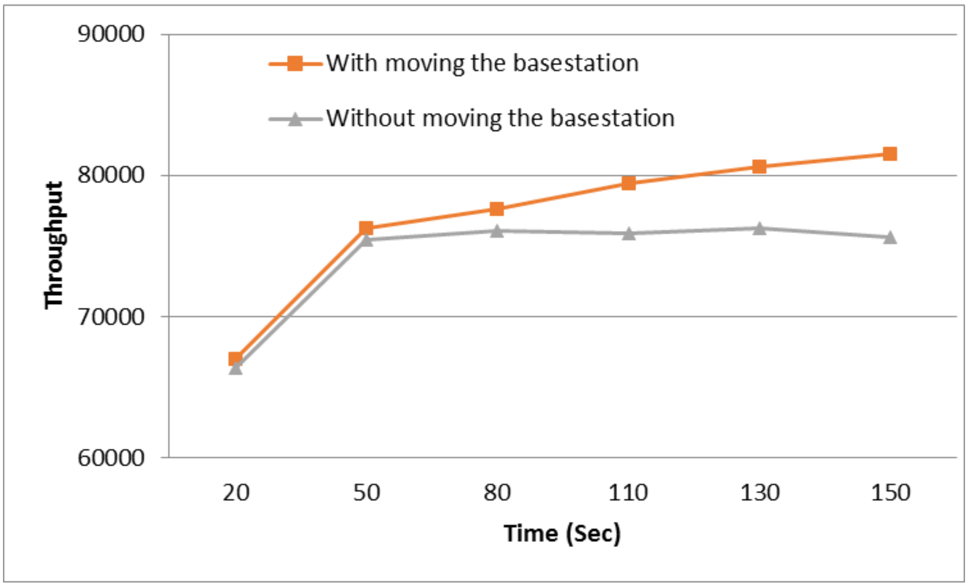

Figure 4.5 Throughput Network Performance With and Without Moving the Base stations Over the Time of Simulation

In Fig. 4-4, the results are presented for the network throughput of both moving and non-moving BTS scenarios depicted as “with and without moving basestation” respectively. The figure shows that the throughput for the proposed approach when moving the BTS towards dense area performs better than the scenario when the BTSs become fixed in their initial location. In the nearly first 50 seconds the performance of both scenarios, for example, the results nearly converged to the same percentage performances because the BTS will take time to identify the coverage hole and start to move towards the desired location. When the coverage holes are successfully discovered as the time increases the performance of the network in terms of throughput outperforms the fixed BTSs scenarios. With moving the BTS the LTE network enhances the capacity of the network with 5000 b/s throughput better than the “without moving the BTS” scenario at 120 seconds. This trend continued as the time increases. For example, at 150 seconds the “with moving the BTS” scenario achieved an extra 1000 b/s in addition to the 120 seconds scenario making it attain even more better performance than the “without moving the BTS” scenario; a total of 6000 b/s.

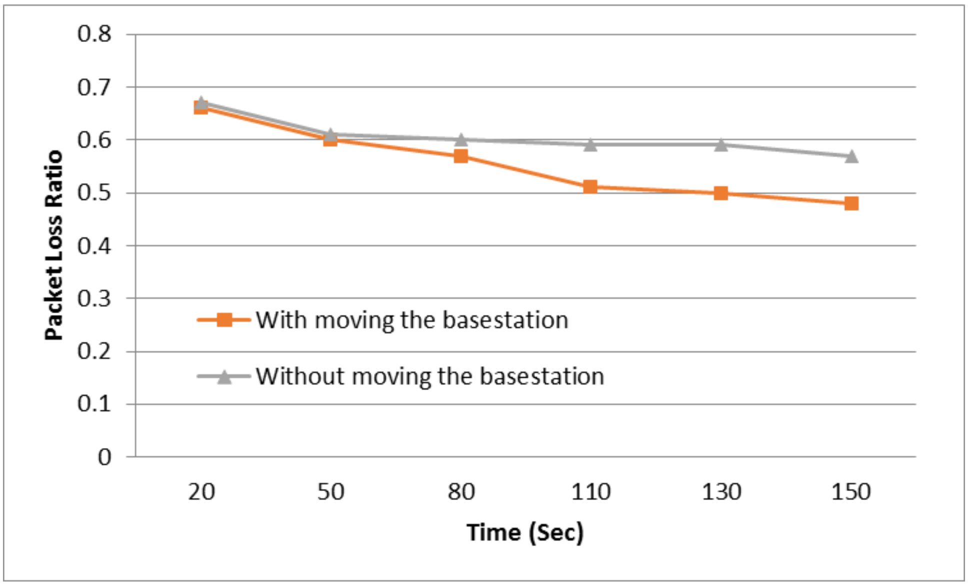

Figure 4.6 Packet Loss Ratio in the Network With and Without Moving the BTSs

Similarly, Fig. 4-5 the LTE system network performance for “moving and without moving the BTS” scenarios are presented and evaluated in terms of packet losses. In Fig. 4-4, it was shown and described that for 50 seconds, the BTSs sought the hole in coverage of the LTE network. Consequently, the performances of the two scenarios were fairly close. Since the performances of the two schemes were fairly close in terms of throughput (b/s), similarly the performances of the packet losses must also perform nearly similarly since the throughput metrics are subtended by the packets as depicted in Fig. 4-5. Unlike the throughput that was measured in b/s in Fig. 4-4, the packet loss ratio (PLR) is measured in percentage (%) in Fig. 4-5.

Meanwhile, by increasing the movement time of the BTSs, the network can use their capability to serve more users and fill the coverage gap. This will lead to less packet loss ratio caused by moving the BTS scenarios compared with more packet loss ratio caused by the fixed location of BTS scenario. Numerically, the moving BTS achieved 10% performance advantage better than the static BTSs at 110 seconds. As the time increased further, the percentages of PLR dropped in both the static and moving designs. This is because of the full (better) awareness of the CSI which leads to a better CSI knowledge at the transmitters which leads to better reception of transmitted packets. Notwithstanding, the “moving BTSs” outperforms the fixed BTSs at 150 seconds by fairly 10% PLR. In general, the PLR in the fixed BTSs is 10% more than the moving BTSs design.

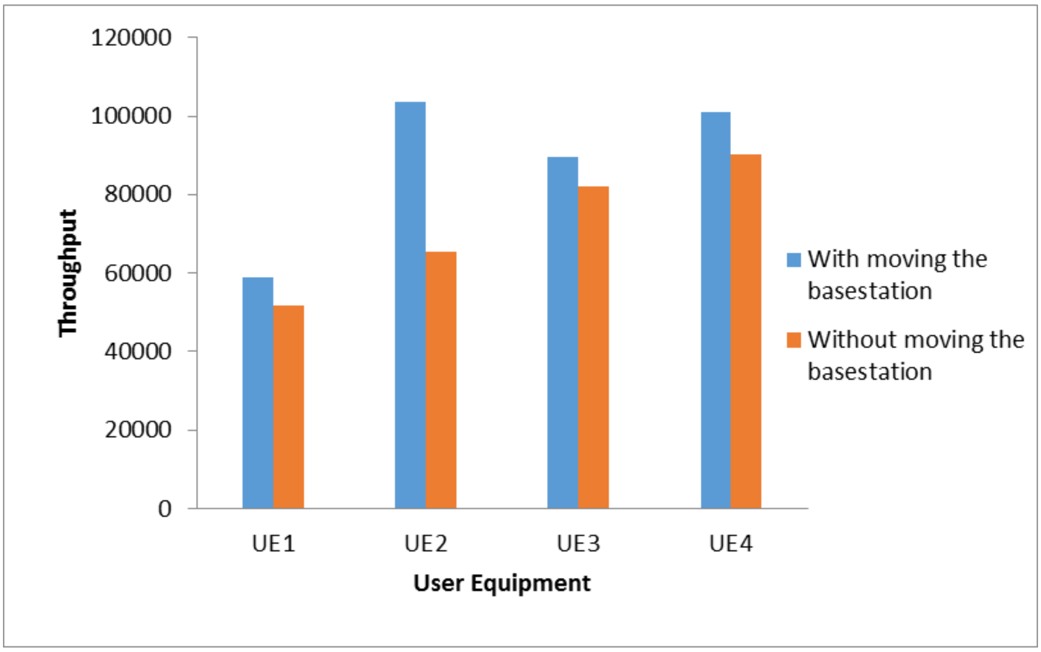

Figure 4.7 Comparison of Throughput between the UEs With and Without Moving the BTSs

Besides the general analysis for throughput performance of fixed and moving BTSs in which the moving BTSs achieved better performance than the fixed BTSs, the throughputs for individual UEs are compared also as shown in Fig. 4-6.

From Fig. 4-6, the moving BTSs designs are seen to outperform the fixed BTSs in all cases. The variation in the performances can be attributed to the length of time of the investigation and the proximity of the BTS to the UE. Clearly, the UE2 showed the best performance 40 Mbps throughput better than the fixed network. It follows that it is best to move the BTS in other to cover up dark network areas and provide better capacity performances.

The throughput of the network is further investigated are also considered relative to when the BTSs are moved or fixed for the eNBs. These are presented in Fig. 4-7.

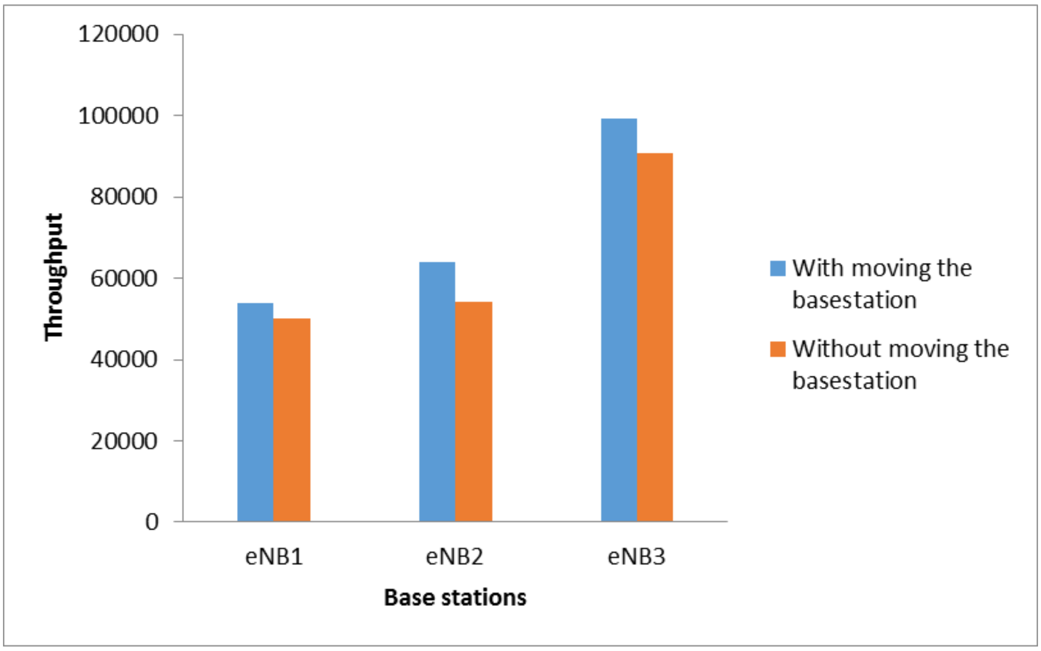

Figure 4.8 Comparison of Throughput between the eNBs With and Without Moving the BTSs

The results also corroborate the throughput performances earlier reported and discussed for Figs. 4-4 and 4-6. Among all the eNBs, it is found that the network performs best when the BTSs are moved relative to when they are fixed in terms of the throughput metric. Numerically, the moving BTS outperformed the fixed BTS for eNB1 by 5 Mbps. Similarly, the two styles of networks are compared for eNB2 and eNB3 respectively; the moving network achieved 10 Mbps better than the fixed BTS for the eNB2 and another 10 Mbps for eNB3 respectively. The strengths of the last two designs involve the parametric settings of the investigation since the configuration involved CBR packets.

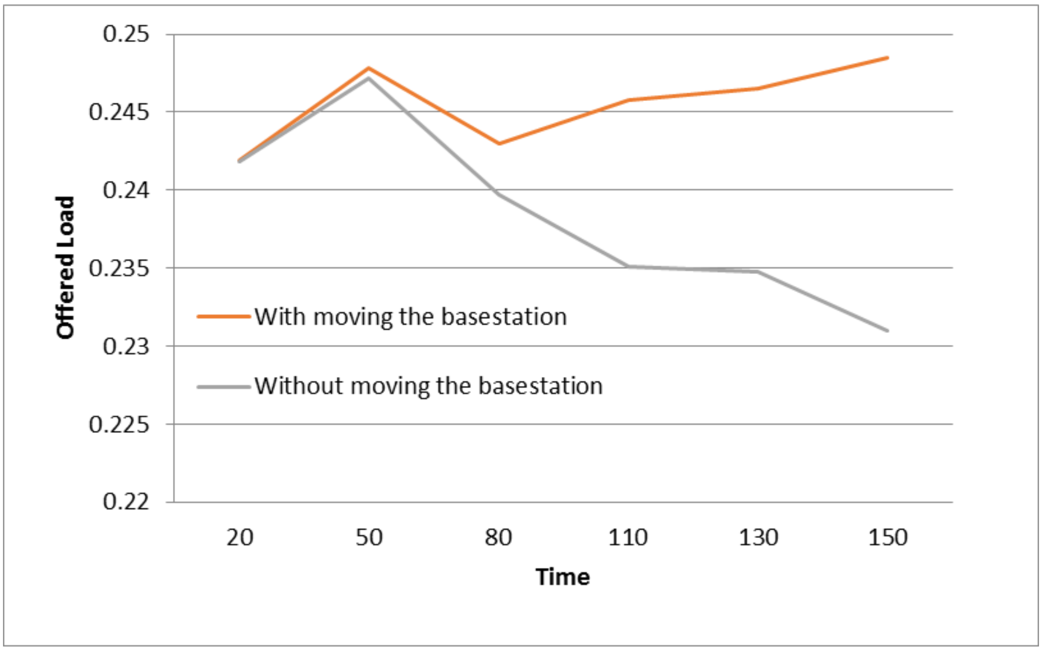

Figure 4.9 Offered Load Percentage in the Network With and Without Moving the BTS Over the Time of Simulation

Finally, the loads offered by each of the architectures to the network are considered in Fig 4-8. For example, the moving network moving BTSs offered fairly similar loads within the first 50 seconds when the network is trying to find the holes within the coverage areas. Moving the network further than 50 seconds, the loads offered by moving BTSs fluctuatingly increased slightly while that of the fixed network significantly diminished consistently.

The offered load for the system with moving the base stations is higher than the offered load for the system without moving the base station. Consequently, this enhancement in the offered load leads to better achieved throughput, link quality, and traffic.

4.4 Cost of the Algorithm

LTE Mobile networks are characterised by the incredible increase in the use of wireless data traffic. Further improvement on the spectral efficiency using the capacity enhancing approaches is an important type of research such as advanced spectral efficiency techniques. There exist limitations on the hardware implementation and channel conditions that may limit the viability of such approaches. One of such pronounced limitations is in the system complexity due to the use of advanced techniques. Therefore, any proposed model or algorithm for enhancing the capacity of the network must reflect the trade-offs between achieving the capacity enhancement objective and issues related to the network performance such as blocking newly arriving mobile nodes or causing coverage holes in the network.

The proposed algorithm in this study used the decision making strategy to enhance the movement decision based on the network information and user requirements collected by the suitable components. Besides, it is able to use the cooperation techniques between BTSs to recover any coverage holes caused by moving the BTSs. Some physical adjustment needed as a result of the movement can be viable to help continue the network activities, reduce the blocking probabilities and enhance the network performance.

However, as in all the mobility models, the way of movement and/or speed of mobility can raise difficulties in the applicability of this approach in which mobile BTSs can take hours to tour to the desired location. It is because of the design constraints of the BTSs that make it difficult to increase the speed of the BTSs which can increase costs and the consumption of power. However, in this approach, the BTSs are assumed to be designed as light BTSs with low transmit power and can be deployed indoors or outdoors in an unplanned manner when hot-spot areas are not expected. Besides, BTSs cooperation is very important to ensure the efficiency of this approach. In the absence of BTSs' cooperation and coordination, additional interference can be caused, as well as, the production of additional coverage holes. Therefore, a coordination component is utilised in the proposed algorithm to cover such problems and ensure the QoS to newly arriving UEs in which neighbouring BTS can act as relays to relay packets of existing UEs in the areas of the moved BTSs.

4.5 Summary

In this chapter, a capacity enhancement approach was introduced to enhance the fairness of traffic in LTE network. The BTSs were equipped with intelligent capabilities of dynamically sensing the dense areas of mobile users and consequently moving towards desired areas with more mobile users. A location-based approach was introduced to select the effective position of BTSs in order to fill any coverage gap in the LTE network. The model was shown to be a cost-effective approach in which the capacity of the network uses the unused bandwidth by non-operational or less dense BTSs by dynamically moving them to the dense areas. Fairness of traffic approach was investigated to ensure that LTE's terminal or user equipment can effectively send their traffic with high quality of service. The network performance metrics were computed to test the validity of the approach. Metric parameters, namely throughput, packet loss ratio and the network load of the LTE network were evaluated using NS2 simulator to show the increased network gain. Moving the BTSs volunteered higher throughput, less packet loss ratio and more load than the fixed BTSs. The used approach, simulation, and experiment in this chapter were sufficient to show the capability of the base stations of being intelligent and able to change their locations dynamically based on the behaviour of the terminal or user equipment. Extensive work on finding the effective solutions to the problem of capacity enhancement approach are considered in subsequent chapters. In Chapter 5, the problem of movement model and different speed as well as number of mobile base station moving within the area are investigated. These are realized by using more effective ways of newly emerging intelligent capabilities of future LTE network.

The findings of this chapter have been published, and the reference is as follows: Alrowili, Mohammed, Rob Holton, and Irfan Awan. "Mobile Basestations as a Capacity Enhancement Approach to Improve the Fairness of Traffic in LTE Networks." *Future Internet of Things and Cloud (FiCloud), 2016 IEEE 4th International Conference on*. IEEE, 2016.

Chapter 5

Optimization of Self-Organized Mobile Base Stations

Self-organized Network (SON) with the capabilities and robustness of artificial intelligence technology is critical for the future paradigms of LTE networks [26, 29, 114-117]. It has the ability to enable entities in a system to be self-configured, self-optimized and self-healed such as in [29, 117-121]. Swarm-intelligence (SI) inspired techniques is an SON technology based on Artificial Intelligence (AI) scheme that utilises observations of collective behaviour in biological activities like ants or bees, division of labour, sorting the larvae, building nests, cooperative transport, etc. [122]. These bio-inspired technologies now extend to the optimization solutions of network architecture design problems. For example, the AI applications in the fields of communication networks, and improvement of the fusion robots has seen some exponentially growth within the last decade [123]. Networks with self-organization involving swarm intelligence is a useful solution in building intelligent self-organising router that tackle the traditional bottleneck routing problems [124-126], as well as balancing the problems of coverage in wireless communications [127, 128].

On the other hand, Ant Colony Optimisation (ACO) technique [129] is one of the SI-inspired algorithms that is widely used by several researchers to solve 4G telecommunications problems [122]. The ACO algorithm has been applied to the solution of routing algorithms in wireless networks using the SON notion such as mobile adhoc networks (MANETs), wireless Remote Sensing Networks (WRSNs) or delay tolerant networks (DTNs).

This chapter uses the ACO to make the mobility of BTSs introduced in Chapter 4 self-organized based on the pheromone density. Mobile ant agents will be disseminated throughout the network to find the overcrowded, idle or less crowded BTSs and in turn move the idle or less crowded BTS towards the dense/overcrowded BTS. The approach is empirically tested to show the easy evolution to higher system capacities and improve the spectral efficiency where data demands further increase. The results presented in this chapter are based upon a number of experiments; in addition, the experimental work is carried out using an NS2 simulator [78].

5.1 Introduction

In an LTE cellular network, it is practical, when a BTS fails to serve its UEs due to overload issues or other technical reasons, the user equipment (UEs) can be served by their neighbours in a device-to-device (D2D) communication style [130]. A handover operation will be performed to connect the UEs of the failed BTS with assigned neighbour [130, 131]. In Chapter 4, it was explained that UE blocking occurs when a threshold of UE arrival in a network has been attained. The fluctuation in the traffic load among the network BTSs for areas with more density of users will result in more extensive load on the BTSs. Consequently, there exists a high blocking probability to the newly arriving UEs as compared to less dense areas where some BTSs will be idle or under low load. Then, a BTS failure or even a critical situation where blocking probability is too high in very dense areas can be solved by the intelligence and capability of artificial systems based on SON. This may be adopted to improve such critical situations by utilising mechanisms such as Replacement Roles (RR) [28]. In RR, entities in the network are made to change their roles, temporarily, to fulfil the upcoming needs in the network.

The critical feature of 3GPP LTE/LTE-A is based on the capabilities of artificial SON; the Evolved Node B (eNodeB) has already been integrated with the properties of self-configuration and self-optimization, self-healing, and plug-and-play capabilities [27, 132, 133]. The Home eNodeB (HeNodeB) is also implemented to use the SON concepts to simultaneously reduce the operational expenditure (OPEX) cost and improve the femtocell coverage [41]. In addition, femtocell systems are also incorporated into the LTE/LTE-A standard based on the SON functionalities, such as self-maintenance, self-optimization and adaptive coverage coordination. Furthermore, advanced features of the fourth generation (4G) mobile communications networks such as Multi-Input Multi-Output (MIMO) signal processing, also benefits from SON coordination in controlling the MIMO mode selection [134]. Capabilities of self-organization including some high quality properties like autonomous capabilities of individual NEs, scalability of network, distributed control and fault tolerance models, will also emerge in future communication network.

Bio-inspired techniques such as ACO algorithm (ACOA) has been investigated by a vast number of researchers for more than a decade and shown its advantages in improving the intelligence of artificial SON systems [135-137].

However, the accomplishment of such powerful technique is still significantly open and challenging task.

In Chapter 4 of this work, the deployment of traffic rate fairness in LTE networks was considered as a promising way to cope with the exponential growth in mobile traffic demand and enhance the blocking probability of new UEs joining the network. In this chapter, the performance of the network coverage is studied under different deployment density of BTSs. The coverage problem based on moving the BTS is enhanced by employing the capability of ACOA. For example, it (ACOA) is applied to find the optimal pilot BTSs to help it move to dense areas and serve the increased newly arrived UEs. This scheme tackles the problems of fixed coverage scheme, reducing the ratio of coverage holes, proportion of coverage overlaps and probability of blocking new users which enhances the overall performance of the network.

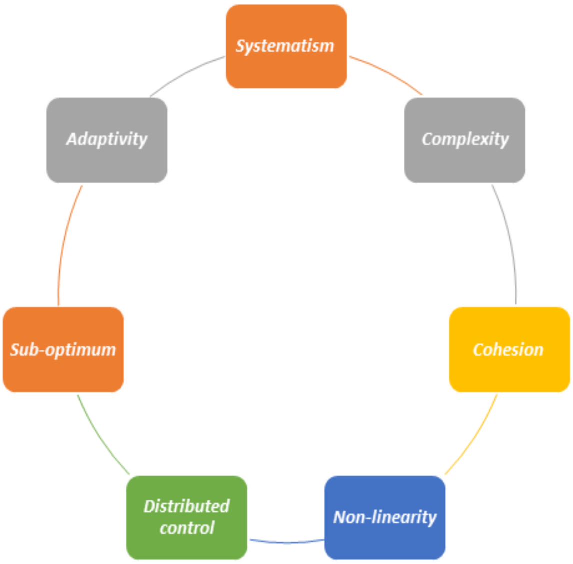

Figure 5.1 LTE Self-Organisation Network Characteristics

5.2 LTE Self-Organisation Network (SON) Characteristics

In this section, a number of the essential properties of SON mechanisms are summarized [122] in Fig. 5-1 and each component discussed separately in the following subsections.

5.2.1 Systematism

SON is a coherent system with a wide activity which includes parts, interactions, structural relationships, behaviour, state, and a border that separates it from its environment.

5.2.2 Complexity

SON is a complex system and difficult to implement and in turn difficult to predict its behaviour due to the self-organization properties deployed in a distributed manner without centralized control; a large extent of the parts combine the system, and connections between those parts.

5.2.3 Cohesion

Cohesion in the SON system suggests the closeness of the causal relationships among the parts of a dynamic system that is resilient to internal or external variations, which may result in the disruption of the system's integrity.

5.2.4 Non-linearity

SON is a process that results from the emergence of higher-level functionality of the system which has numerous interactions among the lower-level components and without an internal or external control/intervention.

5.2.5 Distributed control

SON systems are based on the application of a distributed control to permit the fulfilling of global tasks. Entities inside or outside of the SON system has no authority to guide, direct or control the system. Collaboration between these entities that work on their own intention is essential to accomplish the global tasks.

5.2.6 Sub-optimum

One of the most fundamental principles in designing SON systems is to reduce global state information by achieving the needed effects based on local information or probabilistic approaches only. However, this may not necessarily lead to the desired global optimization of the systems.

5.2.7 Adaptivity

SON systems are capable of adapting to changing environments and being resilient to failures and damages. A small change in environmental parameters may result in a big change in the systematic behaviour.

5.3 Significance of the SON Capabilities to the LTE Networks

The capabilities of SON can be utilised to support the future of the LTE network in which a number of SON properties are important like self-configuration and self-optimization as depicted in Fig. 5-2.

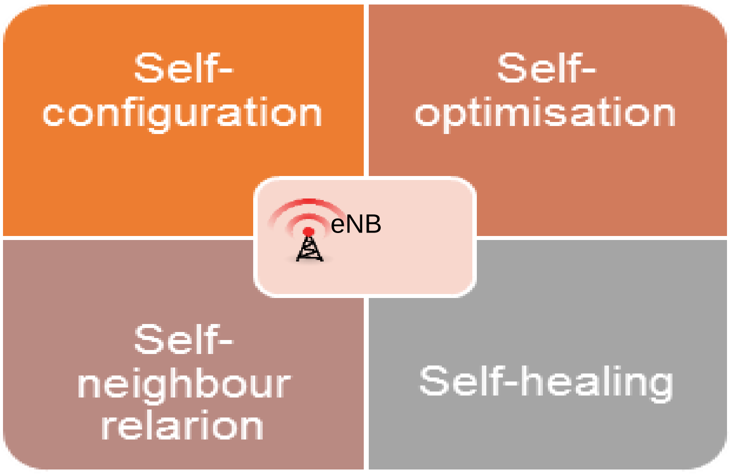

Figure 5.2 SON Capabilities to LTE Network

The capabilities of SON that support the proposed system in this chapter are summarized as follows:

5.3.1 Self-Configuration

In the LTE network, self-configuration can be described as a process of deploying eNodeBs with the capability of automatic installation procedures such that the network is able to gain basic parameters and download necessary software for operation [29, 117, 121]. It is important for the proposed model to employ the eNBs with self-configuration capabilities to be able to adapt to changes in the environment and sense the density of other eNBs neighbours. Self-configuration is usually executed during the installation or recovery phase of UEs or eNodeBs and results in significantly reducing the network deployment time and human involvement.

5.3.2 Self-Optimization

It is important in any LTE proposed system to dispense with a self-optimization technique [29, 117, 121, 138]. This enables the LTE network to optimize their algorithms and parameters to yield an optimal performing network; the parameters such as capacity and service coverage react to the environmental network changes. Given the usefulness of self-optimization, thus self-optimisation is crucial for the operation and maintenance of the proposed system earlier discussed in Chapter 4 of this study and has been adopted. Specifically, self-optimization functionality of coverage/capacity optimization based on ACOA is utilised in this chapter.

5.3.3 Neighbour relationship

Establishing and updating cell relationships about neighbours is a significant property of eNB in LTE networks [27, 139]. It facilitates easy handover by finding correct neighbour relationships in place and in turn reduces the probability of dropping calls as a result of handovers failing to complete properly.

As the manual update of neighbour relationships become more complicated, there are the sophisticated needs of evaluating if it is possible to handover to a neighbouring cell with a similar radio access technology or with different technology. The elements of SON will help to provide some automatic neighbour cell configuration; this can be largely automated and in turn, network performance will also benefit from adopting such property by enhancing handover operation and reducing the network load.

5.3.4 Self-Healing

Self-healing is an event-driven process which aims to solve problems such as the loss of coverage or capacity in the cases of failure due to BTSs being overloaded [29, 140]. This is considered in this work. Self-healing is critical to assist operators in recovering a collapse (failure) in the LTE network.

5.4 Categories of Bio-Inspired Optimisation Techniques

There are steps and approaches to bio-inspired optimization methods in relation to solving communication network algorithm optimization problems. These categorized bio-inspired optimization steps and techniques are described in each of the following subsections and represented in Fig. 5-3.

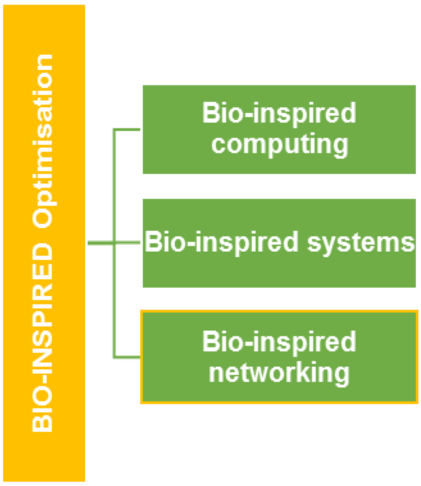

Figure 5.3 Bio-Inspired Optimisation

5.4.1 Bio-inspired computing

This represents a class of algorithms focusing on efficient computing based on living biology systems [141]. It can be effectively used for a great number of problem spaces, such as optimization problems, exploration and mapping, and pattern recognition, etc.

5.4.2 Bio-inspired systems

Bio-inspired systems rely on architectures of massively distributed and collaborative systems to enable functionalities of distributed sensing and exploration. It explores the Swarm Intelligence, Artificial Immune System, Cellular signalling pathways, computational viruses and network intrusions identification including integrated cellular networks [142].

5.4.3 Bio-inspired networking

Bio-inspired networking is a class of strategies for efficient and scalable networking under uncertain conditions [143, 144]. It has influenced the realizations of communication and networking technologies such as cognitive radio networks, sensor and actor networks, quantum communication networks, terrestrial next generation, etc.

In recent years, a great number of bio-inspired approaches have been proposed for improved efficiency [141, 143-146]. The primary concepts of some of the well-known bio-inspired research fields are to maximize resources and minimize OPEX.

5.5 The System Model

The aim of this chapter is to make the BTSs in the LTE networks able to be self-aware, self-adaptable and intelligent by the use of ACO algorithm. In order to present the principle of the proposed approach, it is important to illustrate the behaviour of ants and the way they conduct themselves to solve a problem.

5.5.1 The Ant Behaviour

As illustrated in Fig. 5-4, the optimization technique by ants' colony is inspired by the behaviour of ants during their search for food [124, 128, 129, 135-137]. They show the path of their food using a volatile chemical substance known as pheromone which evaporates with time. A remote ant generally moves randomly and while moving, a quantity of pheromone is deposited by the ant on its trail. Other ants will select the path with the highest pheromone intensity which represents the most attractive way for ants. When an ant follows a path, it strengthens the trail by adding its own pheromone. At the end, this results in a collective behaviour of which there is more than one path with high pheromones; the higher the pheromone, the higher is the number of ants that follow it.

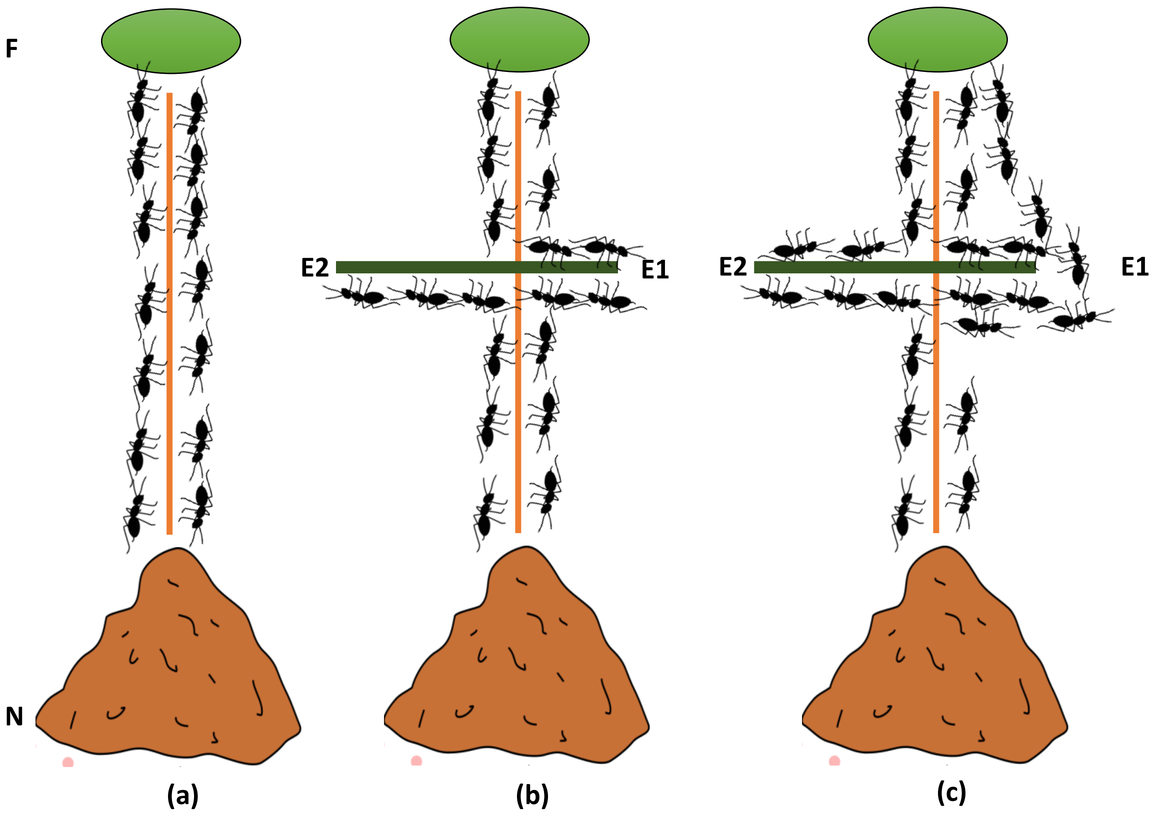

Figure 5.4 Ant Behaviours of Searching for Food

To explain the behaviour of the ant optimization, it is important to illustrate an example. Consider a set of ants moving from their nest *N* to a food source *F* in a straight line (see Fig. 5-4a). An obstacle is put across this path from *N* to *F* with two sides E1 and E2; side E1 is longer than side E2 (see Fig. 5-4 b and c). The ants will decide on which direction they need to take to reach their food; either E1 or E2. A random direction will be selected by the first set of ants and in turn will deposit some pheromones along their paths. There are two paths to be selected by the ants, long path and short path. Ants taking the path NE2 to F (NE2F) or FE2 to N (FE2N) will arrive first, consequently depositing more pheromones on their paths than ants that will take the way NE1F (or FE1N). The following ants will decide to take the path NE2F rather than the path NE1F because their decision is influenced by the pheromone intensity which stimulates them to select the shortest path (Fig. 5-4c). The ants are then able to find the shortest path between the nest and the food source.

The proposed system will be simply modelled by autonomous agents who represent the artificial ants. The time is considered as discrete and ants are not completely blind. Each ant has a visibility field that controls their movements and ants move from point i at time t, to point j (i.e. to follow the path i; j) according

$$P_{i,j}(t) = \frac{(\tau_{i,j}(t))^{\alpha} \cdot (\eta_{i,j})^{\beta}}{\sum_{(i,k)\in C} (\tau_{i,j}(t))^{\alpha} \cdot (\eta_{i,j})^{\beta}} \tag{5-1}$$

where $(\tau_{i,j}(t))$ represents the pheromone intensity at time t on the path (i, j) and $\eta_{i,j}$ is the ant's visibility field on the path (i, j) with an assumption that there is food at the end of this path undertaken by the ants. The parameters α and β control the relative importance of the pheromone intensity compared to ant's visibility field. C represents the set of possible paths starting from point i where (i,k) is a path of C.

Each ant, a, following the path (i, j) adds a pheromone quantity represented by $(\Delta\tau_{i,j})^{a}$.The pheromone is considered as the substance that evaporates and its intensity on the path (i, j) at later time which represented with $t+1$ is equal to that which remains after evaporation at time t, added to the sum of the quantities left by all ants that followed this path at time t. These metrics can be summarized in the following expression as

$$\tau_{i,j}(t+1) = \sigma \cdot \tau_{i,j}(t) + \sum_{a=1}^{m} \left(\Delta \tau_{i,j}\right)^{a} \tag{5-2}$$

where σ is a coefficient such as $(1-\sigma)$ represents pheromone evaporation between times t and $t+1$. Its value is lower than 1 in order to avoid pheromone accumulation and premature convergence. a represents an ant after it has successfully deposited a quantity of pheromone on the path (i, j), while m is the number of ants having taken the path (i, j) at time t.

5.5.2 The Proposed Algorithm

Optimization of the new location of the mobile BTSs is modelled by an ant colony movement going from one location to another looking for food. During the food search, the ants will visit the frequently attended cells by the mobile UE. At the end of the algorithm, the pheromone deposited by the ants will accumulate on the cells. As each cell will be served by a mobile BTS, the cell having the most pheromone intensity is considered as the most dense cell of the mobile and its serving BTS will require movement from idle or less dense BTSs. This method is also used to predict the moving BTS towards the dense cell of mobile users. The less pheromone quantity cell means less or unused BTS, thus it will be the future moved BTS. The proposed algorithm to predict the movement of the BTSs will be launched when a mobile user enters a location. It creates an *N*-entries table called Movement Table (MT). The content of this table will be fed by the cache which has history of mobile user’s movement behaviour in the case of period (i.e. work day or holiday) or when there is an event (i.e. a football match in a stadium cell). The table will include the most recent entries corresponding to the mobile, with the same source BTS and destination BTS. The number of entries for a mobile user is denoted by N1. If MT is not full which means N1=0, the system will fill it using N2 entries corresponding to other mobiles with the same source cell and the same period or event which assume that mobile users in the same cell can have the same direction.

The algorithm will ensure that BTSs managing the cells can update their users' history movements or directions towards other BTSs and deduce their future locations according to their current location and their behaviours. If a new mobile user enters in the system and the BTS does not have history for it, it can use the history of other mobile users that have the same mobility profile. In the case of public events such as a match in a stadium, a new user will more likely travel from the city, to the stadium. Typical coverage provided in this case is represented in Fig. 5-5.

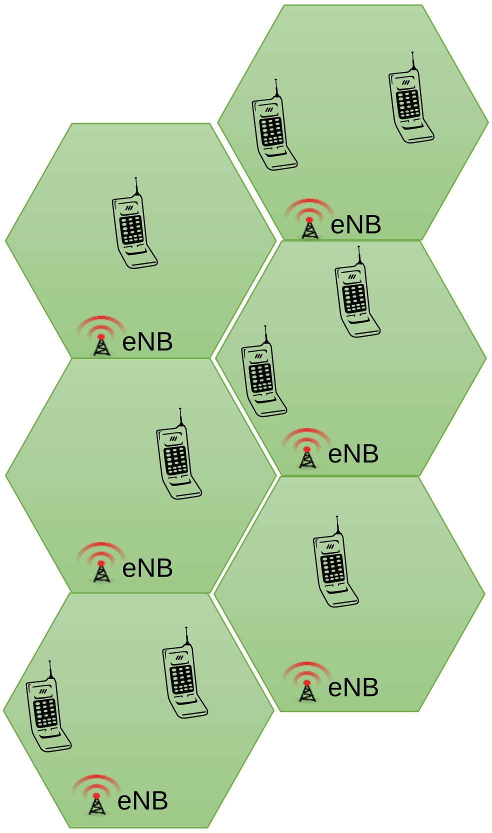

Figure 5.5 System Example of Coverage

The system then creates a colony of ants whose size is equal to the movement table (MT) size. Each ant $a_i, \forall i = 1, \cdots, N$ is associated with the line i of the movement table. Two fields are used to define the structure of an ant, the visibility field and the pheromone field. The visibility field is considered as a vector η of R elements corresponding to the number of adjacent cells. Each element of this vector represents the visibility of an adjacent cell by an ant. This field is activated to reflect the fact that ants prefer an already visited cell when they search for food. If $\eta_{i,k}$ represents the visibility of the cell for ant a_i, then

$$\eta_{a_i,k} = \begin{cases} X \quad if \ MT_i(Destination\ BTS) \neq k \ or \ if \ MT_i \ is \ null \\ X \cdot \mu \qquad\qquad\qquad if \ MT_i(Destination\ BTS) = k \end{cases} \tag{5-3}$$

where $k = 1, \cdots, R$ which represents the adjacent cells, X is a value > 0 and $\mu > 1$ is the parameter to increase the cell degree of visibility if it was already visited by the mobile. MT_i represents i^{th} the entry of the movement table. The field pheromone represents the quantity of pheromone that the ant will deposit in the adjacent cells during the search for food; this can be expressed as $Q > 0$.

To keep the trace of the pheromone deposited by the ants, we use a vector τ with R elements. Each element of the vectors corresponds to the quantity of pheromone in a corresponding cell. This vector will be initialized to $\tau_k(t_0) = Q$ for $k = 1, \cdots, R$ (k represents the cell k and (t_0) represents the initial time).

The search process proceeds in a set of iterations in which each ant moves towards an adjacent cell, deposits the quantity Q of pheromone in this cell to encourage the other ants to go towards it. It then returns towards its nest (i.e., the current cell) in order to repeat the same process. Each ant chooses the future cell according to its degree of visibility and the intensity in pheromone of the cell. At a moment t, the ants a_i chooses to go to the cell K according to the probability

$$P_{a_i,j}(t) = \frac{(\tau_k(t))^{\alpha} \cdot (\eta_{a_i,k})^{\beta}}{\sum_{j=1}^{R} (\tau_j(t))^{\alpha} \cdot (\eta_{a_i,j})^{\beta}} \tag{5-4}$$

After each iteration (time $t+1$), the pheromone intensity in the locations are updated according to ants' contribution and the evaporation rate. For each location k, we have

$$\tau_k(t+1) = \tau_k(t) \cdot (1-\sigma) + m \cdot Q \tag{5-5}$$

where σ, $(0 < \sigma < 1)$ represents pheromone evaporation rate. A small value of σ generates slow pheromone dissipation and a high value generates a faster dissipation. Notice that m represents the number of ants that choose location k. The proposed algorithm in this study provides the ability to integrate a mobile's behaviour, the existing infrastructure and other mobiles' behaviour in the prediction process (mobility prediction based on an ant system).

5.6 Simulation and Results Analyses

An experiment to test the proposed approach and its applicability to the LTE network is conducted. An LTE network environment with two types of nodes, namely wired and wireless mobile nodes, is simulated. The first type of network comprises a server and the gateways which behave according to wired protocols, while the other type comprises a set of mobile nodes which act as transceiver nodes to the gateways. The main aim of the experiment is to evaluate the contribution of the proposed approach in enhancing the capacity of future LTE networks and introduce BTSs with the capability of acting intelligently by detecting the connected mobile nodes requirement and resources. Consequently, testing the impact of the approach on the network performance in terms of throughput, packet loss and system load.

5.6.1 Experimental Setting

The simulation is conducted using the NS2 simulator; the setting-up of the simulation environment has been influenced by [78]. A network with 8 nodes placed in a unit area of 1000m×1000m is simulated. One node acts as a server and connected to 3 BTSs eNBs with a wired links as depicted in Fig. 5-4.

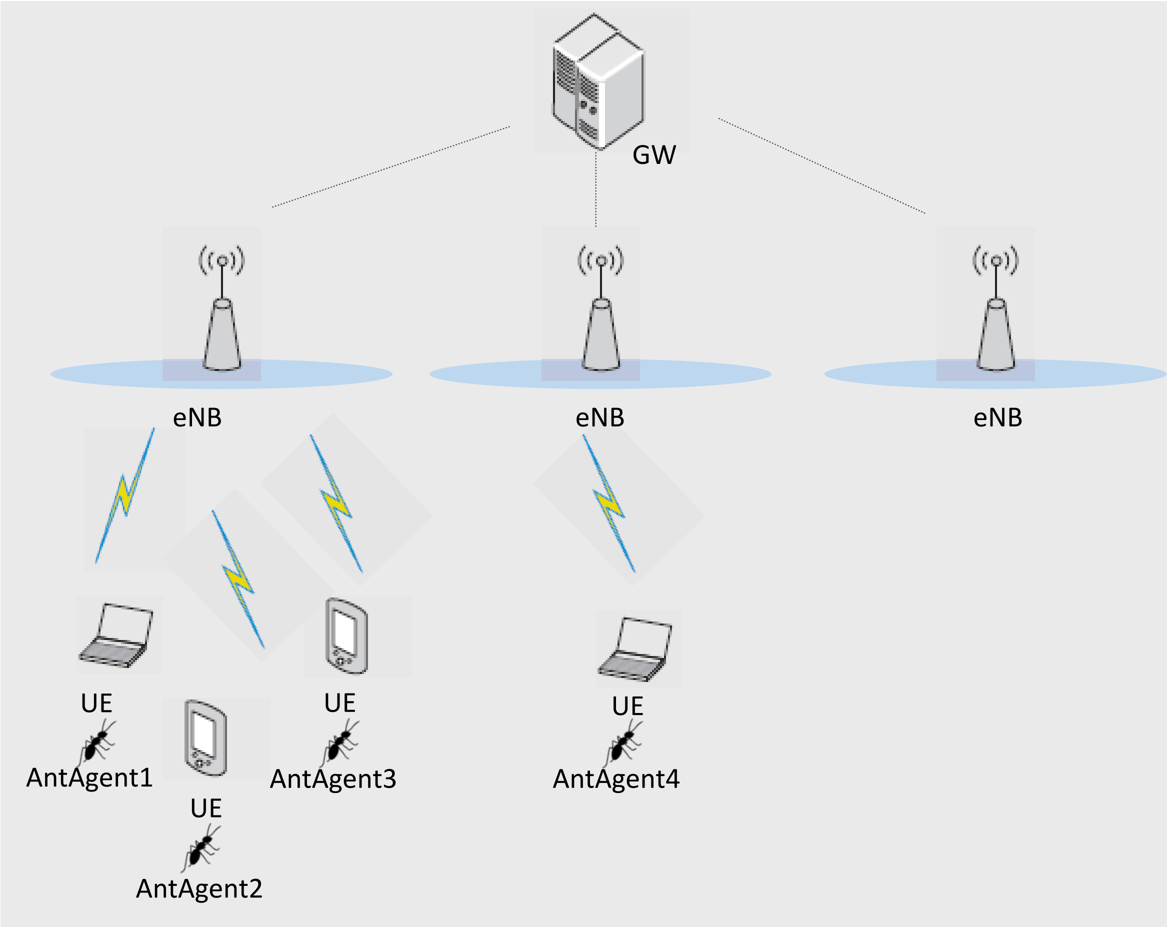

Figure 5.6 Network architecture for simulation and evaluation

There are 4 mobile nodes that act as UEs and connected to the eNBs by using wireless links; they randomly move in the area around the eNBs. Number of mobile ant agents is 4. The traffic between BTSs and mobile nodes transmits packets with a Constant Bit Rate (CBR). The packet size is 512 bytes and the simulation time is 150s. In Fig. 5-6, the network architecture is represented.

Table 5.1 Network configuration

Parameter	**Value**
Nodes	8
Area	1000 X 1000 m^2
Speed	10 m/s
eNodeB coverage area	100 m
Movement	Random waypoint
Routing Protocol	DSDV
MAC	802.11
Transmitting capacity	2 Kbps, 4 Kbps
Number of ctive users	4
Number of ant agent	4
Application	CBR
Packet size	512 B
Simulation time	150 s

Table 5.1 shows the parameters used in configuring the network for this experiment.

5.6.2 Experimental Results

In this section, results and analysis are presented for the comparison of two different scenarios; one with moving the BTS normally without the use of the ant optimization algorithm and one with moving the BTS using the ant optimization algorithm. A discussion of the results of both scenarios on the network performance is also provided. The simulation results are presented in Figs. 5-7 to 5-10, which describe the performances of two important measurements of the LTE network in terms of throughput and packet loss. In these simulation experiments, the aim is to allow the LTE network to benefit from the intelligence capability of BTSs to dynamically move to dense areas using the ant optimization algorithm: thus, an important evaluation metric is to consider the adaptation of the proposed approach in enhancing the network performance, as shown in Figs. 5-7, 5-8, 5-9 and 5-10.

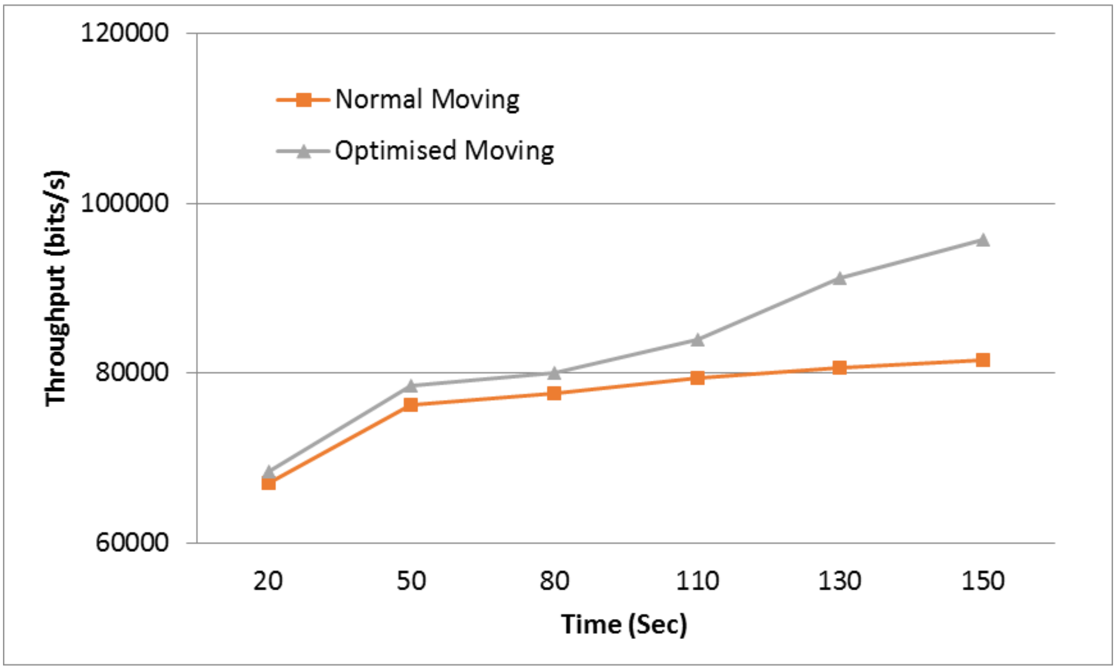

Figure 5.7 Throughput Network Performance With Normal Moving and With Optimized Moving the BTSs over the Time of the Simulation

In Chapter 4 of this thesis, it was shown that moving BTSs to dense locations improve the throughput. Herein Chapter 5, the path trailed by the BTSs when finding and subsequently moving to the areas of dense locations are considered to be influential to the performance of the proposed scheme. By using ACO technique, it is possible to reduce OPEX cost if the best path to be trailed in the search for the area of dense UE concentration by the BTS, for example during a football match, can be determined and incorporated in the design of LTE networks. This is first measured in terms of throughput as shown in Fig. 5-7. Comparing the proposed method in Chapter 5 and the optimized technique as depicted in Fig. 5-7, it can be found that optimized algorithm significantly outperformed the conventional method. Within the first 50 seconds, the BTSs find the coverage area and both the normal and the optimized algorithm performed fairly similarly, with the optimized algorithm outperforming the normal technique. The performance increased and becomes significant at 110 seconds with up to 5Mbps throughput. At 150 seconds, the throughput of the ACO algorithm improved the moving BTS algorithm so that it achieved 18 Mbps better than the ordinarily moving the BTS.

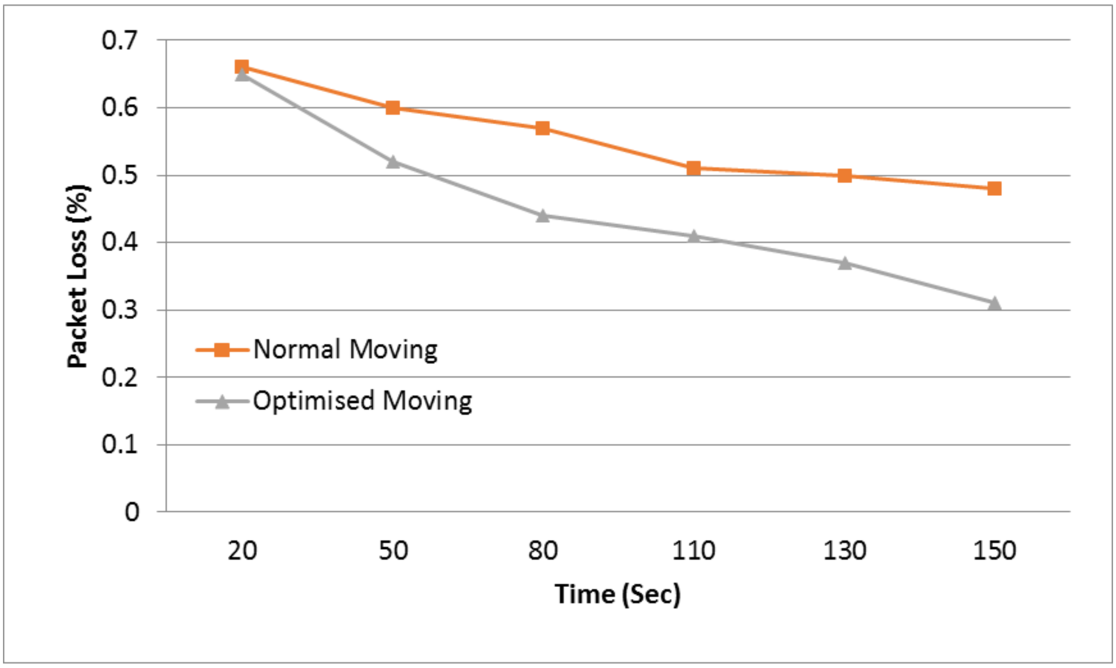

Figure 5.8 Packet Loss Ratio in the Network With Normal Moving and With Optimised Moving the BTSs over the Time of the Simulation

The packets lost are a measure how well an algorithm performs. This is assessed and its results shown in Fig. 5-8.

Applying the ACO algorithm to the moving BTS algorithm shows a better reduction in the percentage of packet loss as shown in Fig. 5-8 for all time considered. At 20 seconds, a slight performance gain is noticed. As the time increase, the ACO tend to establish better (or shorter paths) to the UE dense locations. Comparing the normal moving and the optimized moving, the optimized clearly achieved better performance by 19% at 150 seconds than the normal moving technique.

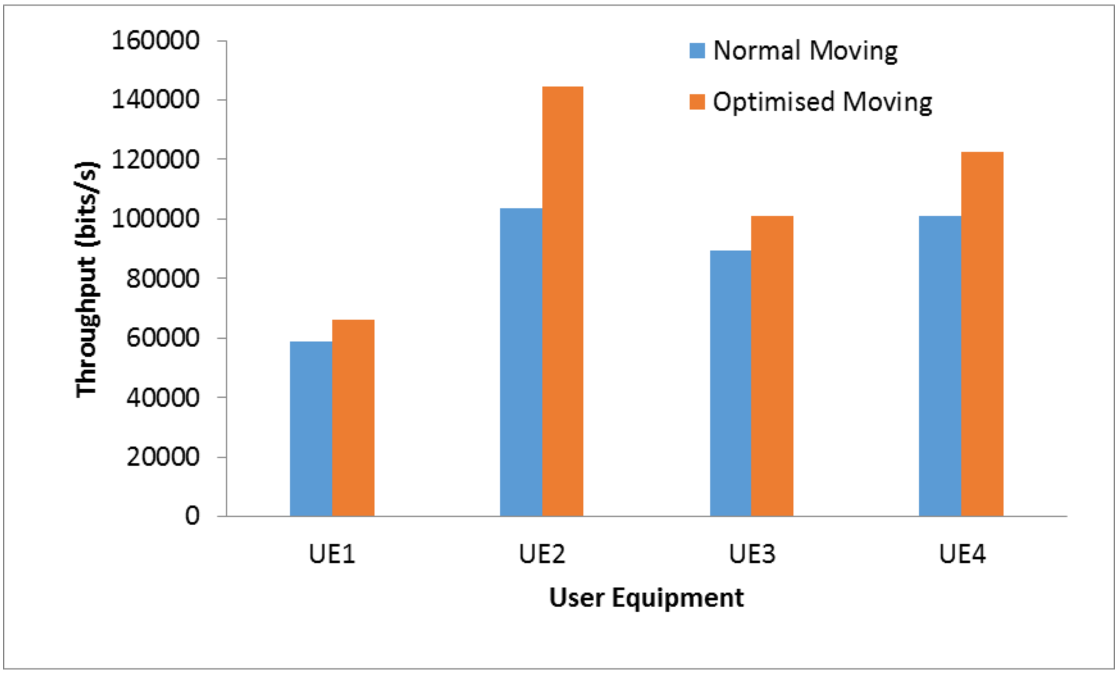

Figure 5.9 Throughput Network Performance With Normal Moving and With Optimised Moving the BTSs over the Time of the Simulation

For user equipment, each user's experience for moving the BTS is recorded and evaluated in Fig 5-9. Generally, all the optimized designs showed that each UE achieved experienced improved throughput compared to normal moving of the BTSs.

For UE1, the optimized algorithm achieved 6.92 Mbps (7083 bits/s) better than the normal algorithm. Similarly the optimized algorithm achieved 41010 bits/s (40.05 Mbps). The ACO algorithm was also applied to the UE3 and UE4, the optimizing moving BTSs achieved 11.07 Mbps and 21.29 Mbps respectively.

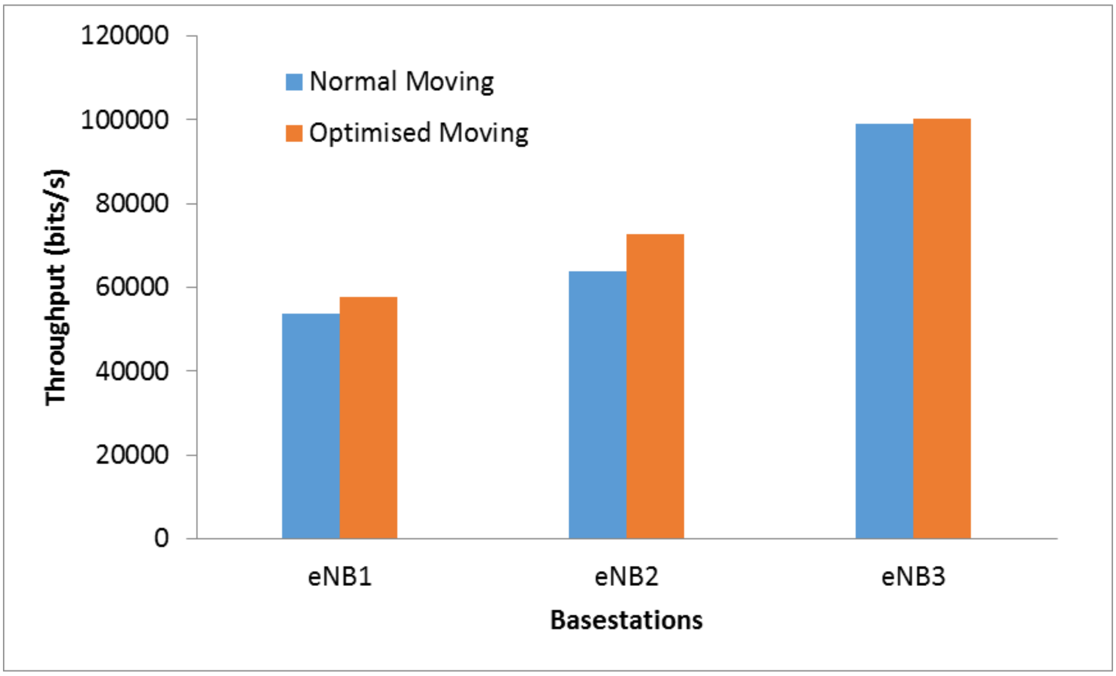

Figure 5.10 Comparison of Throughput between User Equipment With Normal Moving and With Optimized Moving the BTSs

These investigations are further extended to throughputs achieved at each eNBs when the BTSs are moved. Recall also that in Chapter 4 of this study, it was found that the throughput achieved at each eNB when the BTSs are moved compared to when they are fixed are better. In this Chapter 5, the optimization of the moving BTS is compared to when the BTS normally senses UE increased density in a cell as shown in Fig. 5-10.

Results show that at eNB1, there is a 3 Mbps throughput gain in using an optimized moving BTS compared to normal moving BTS. Similarly for eNB2 and eNB3, the use of ACO algorithm influenced the optimized design to achieve gain throughput 8.50 Mbps and 0.98 Mbps gains respectively.

5.7 Summary

In this chapter, an attempt has been successfully made to design the BTSs of LTE networks such that they are able to be self-aware, self-adaptable and intelligent using the Ant Colony Optimization algorithm. It is based on the biological ant-food search phenomenon in which higher density of pheromones implies higher likelihood of paths trailed by other ants in search for food. In such search, paths created and usually trailed by many more ants point to the shortest route and distance to the source of the food. This extends to the search of UE density at a place by BTSs. The use of the ant-colony optimization is used to minimize the path trailed by the moving BTSs; the idea of the moving BTSs has been developed in Chapter 4 in order to increase coverage capacity by throughput increase and packet loss ratio reduction. Results show that applying the ant-colony optimization algorithm to the moving BTSs technique improves the throughput significantly by up to 40 Mbps and reduces packet loss rate in the network by up to 19%. It is also found that for all use equipment and micro-BTSs, the performances of the optimization algorithm further holds. This finding can be significantly influential in the modification of the present day LTE networks and in the design of future networks. The proposal here also finds application in event managements such as football match arenas.

Chapter 6

Conclusions and Recommendations for Future Studies

In today's telecommunication business, the increasing number of mobile nodes is one of the major drivers for the increasing higher data rate demands in telecommunication network services. This quest must be continually satisfied as a social quality of service parameters to keep at pace with the trend. Meanwhile, from the foregoing discussion presented in the earlier chapters of this thesis, the prevailing transceiver base station (BTS) designs cannot predict the next point of demography growth. Consequently, modern BTSs must be designed to be scalable, intelligent, self-aware, self-organizing, self-configuring and able to adjust (and cope) with unprecedented change in demography. Being able to portend these characteristics, the scalable and cognitive BTSs are, by this thesis, proposed to be mobile so as to move towards the areas of sudden demographic surge in order to assist in crowd control and management including event management; scalability.

It is worthy to identify that in a traditional sense, wherein BTSs are designed without these cognitive characteristics, data packets from mobile nodes aspiring to join in the network will be dropped once a BTSs attains a threshold of call admissions by administering call admission control protocol thereby dropping excess connections. With mobile BTSs, these problems can be well addressed.

It is proposed in this work, using bio-inspired optimization method namely ant-colony optimization algorithm (ACOA) from the swarm optimization algorithm to find the best (least) path to be traced by the BTSs; mechanism that will cost resources efficient, increases response rate, reduces latency (or delays) and sustains emergencies response rate also.

In the following subsection, the practical conclusions drawn from the work presented in separate chapters are enumerated. Subsequently, some suitably useful suggestions for future studies in this area of research are also presented with demonstrable diagrams where necessary.

6.1 Conclusions

The fundamental problem with fixed BTSs is that it cannot serve more than its designated radius even if the BTS is underutilised or idle. Although the problems of cell-breathing and shadowing and other multipath fading effects have led to sectorization, cell-splitting, etc. to increase coverage, capacity and improve general quality of service (QoS), crowd and event management problems have continued to prevail.

Recently, the combination of Macro and Micro BTSs has been suggested to ameliorate the above limitations [64, 65], but not in cases of crowd and event managements as they cannot always be predicted. Thus, cognitive BTSs that are able to sense cells with sudden demographic surge can be used to solve this problem permanently. Consequently, this thesis proposed the concept of dynamic mobile BTSs as a capacity enhancement approach to improve capacity and fairness of traffics in Long Term Evolution (LTE) Networks; an example of BTSs with such cognitive capability. To overcome the challenges of traditional high power base stations, another approach involves deploying a heterogeneous LTE networks (HetNets). This uses a hybrid of traditional high-power BTSs and low-power BTSs to solve the capacity problem. Presently, Pico-cell, Femtocell, and/or relay BTSs are examples of low-power nodes utilised to increase capacity and coverage. It has been demonstrated in this research work that the micro-power HetNets BTS nodes can as well be deployed as dynamic mobile BTSs also; with intelligent capabilities of dynamically sensing the dense areas with dense radio frequency usage and consequently moving towards desired areas with more mobile users. This technique were shown using simulation results carried out on Network Simulator Version 2 (NS2) environment as capable of improving load balancing, increasing capacity, coverage and throughput while reducing packet loss rate, latency and energy consumption.

Also, a location-based approach was introduced to select the effective position of BTSs in order to fill any coverage gap in the LTE network. Metric parameters, namely throughput, packet loss ratio and the network load of the LTE network were presented and evaluated using the NS2 simulator to show the increased network gain. Moving the BTSs volunteered higher throughput, less packet loss ratio and more load than the fixed BTSs. For example, moving the LTE network BTS enhances the capacity of the network by 5000 b/s to 6000 b/s throughput better than the "without moving the BTS" scenario over a period of 120 to 150 seconds. This trend implies that over longer time instances, dynamically equipped BTSs can further enhance the capacity and throughput of the LTE network. This can also imply that as more users find that they can connect to the network, other more users will join the network. This further explains why the 10% packet loss rate (PLR) improvement was achieved in using dynamically equipped BTSs networks than the fixed LTE BTSs. Numerically speaking, different scenarios of the mobile-supporting BTSs of the coordinated eNodeBs achieved 5 Mbps and 10 Mbps better than the fixed BTSs coordinated eNodeBs and so on. These results are practically convincing and imply huge improvement in realistic quality of service metrics.

The paths traced in the delivery of this service by the dynamic BTSs in the LTE network are assessed also. For instance, if the time taken by a BTS to move to save an overcrowded network is too long, then the packet loss rate will be high due to high ratio call dropping from the call connection admission control protocol. To find the best (least cost) path and minimize the time taken to find the dark coverage areas, the ACOA was used. Under the first 1 minute, both the normal and the optimized dynamic BTSs found the coverage area such that the normal and the optimized dynamic algorithm performed fairly similarly, with the optimized algorithm slightly outperforming the normal (un-optimized path) dynamic BTS. At 150 seconds, the throughput of the ACO algorithm improved the moving BTS algorithm so that it achieved 18 Mbps better than the ordinarily moving the BTS. It follows that applying the ACO algorithm to the moving BTS algorithm yields significant reduction in the percentage of packet loss (due to reduced time to find the dark coverage area from the ACOA) so that the throughput is increased. Comparing the normal moving and the optimized moving BTSs, the optimized clearly achieved better performance by 19% at 150 seconds than the normally moving technique.

In general, it can be concluded from the foregoing discussion that the capacity and fairness of traffic in LTE networks can be managed using some intelligent and cognitive characteristic properties such as the self-organising and self-aware networks and concepts of replacement rules.

Dynamic mobile BTSs can solve the problem of unbalanced traffic and density of UEs in the LTE networks. For example, idle or less densely populated BTSs can be self-organised to replace/assist any overcrowded neighbour to enhance traffic flow, reduce coverage holes, and reduce blocking probability of new mobile users. This thesis also proposed a model to balance the load between different BTSs in the LTE network which was developed in Chapter 4 of this work. The implementation of this approach led to some enhancement in the system throughput, percentage of packet loss and load balancing which can be adopted in the design and deployment of high density networks.

6.2 Summary of Chapter Conclusions and Contributions

In this section a summary of the contributions from different chapters that made up this thesis are briefly presented as follows in terms of each of the chapters; these include

Chapter 1 introduced the basic concepts of the research work reported in this thesis. It also described the motivation, aims and objects explored to achieve the aims tabulated in this research. Chapter 1 also presents the summary of the research contributions including introductory guidelines to the reader for all the chapters in this thesis.

Chapter 2 reviewed related work contributed by different experts in this field in relation to the design of self-adaptable, self-configuring, and cognitive BTSs to assist in the handling of demographic changes. This was shown to be peculiar to LTE networks; the LTE-Advanced network comprising the standard LTE with added functionality. LTE-Advanced are heterogeneous networks (HetNets) with self-organizing (SON) capability. Although it LTE-Advanced network standard is equipped with cognitive BTSs, it was identified that making these BTSs dynamic would serve better in crowd and event management; implemented in Chapter 4. Mentioning was made of optimising the network architecture and technologies which was studied in greater details in Chapter 5 of this thesis. The network QoS assessment metrics and capacity enhancement approaches were also enumerated. It was seen that under sudden demographic surge conditions (leading to high density of radio frequency resource access by the mobile users) that the LTE-Advanced network does provide scalable coverage and capacity to sustain the suddenly increased user equipment (UE); this style of radio network architecture was then proposed for future design of modern and future networks.

Chapter 3 demonstrates the state of the art of modern LTE network design. Also, the method for using the NS2 to study network modelling was demonstrated. Although the relevant literatures were explored, an overview of the state of the art necessary to define the capacity enhancement approaches and self-organising networks based on multiple sources of information was presented including an overview of the state of the art of ant colony optimisation techniques and their suitability to wireless communications.

Chapter 4 explored the concept of fairness of traffic among different BTSs. Among which, Chapter 4 was used to describe a dynamic BTS system network over the fixed BTS for balancing the loading mechanism during events such as football matches, in malls and other sudden population surge for an LTE-Advanced network. LTE BTSs developed in the model were modelled as dynamic BTSs that can sense and assist denser areas of mobile users upon sensing overcrowding on the neighbouring cells. Results showed that the proposed concept consequently enhanced the network capacity as well as increased scalable coverage and the general network performance in terms of other quality of service parameters. The implementation of this approach led to enhancement in the system throughput, reduction in the percentage of packet loss and load balancing.

Chapter 5 was used to examine resource management problem of moving BTSs and network performance by employing the capability of the ant colony optimisation algorithm an aspect of swarm intelligence optimisation. This technique was applied to find the optimal pilot BTSs to help it move to dense areas and serve the increased new UEs. It tackled the problems of the fixed coverage scheme in reducing the ratio of coverage holes, proportion of coverage overlaps, and probability of blocking new users through enhancing the overall performance of the network. The ACOA helps in finding the best path that can be traced by the BTS to the crowded cell to maximise network resources. The scalability performance of the network coverage was studied under different BTS deployment densities. The ant-colony optimization was used to minimize the path trailed by the moving BTSs; the idea of the moving BTSs has been developed in Chapter 4 in order to increase coverage and capacity by throughput increase and packet loss ratio reduction. The throughput, packet loss, and loading on the system were evaluated even in the case of high dense networks. This extends to the search of UE density at a place by the dynamic BTSs. Results showed that applying the ACOA to the moving BTSs technique improves the throughput significantly by up to 40 Mbps and reduces packet loss rate in the network by up to 19%. It hereby recommended from this finding that a modification of the present day LTE networks and the design of future networks should capture this vital improvement.

Chapter 6 – Herein Chapter 6, the individual contributions of the chapters were summarised. Based on the results and ideas subtended by the individual chapters, several recommendations are made on how to improve on the contributions of this thesis for future studies. It can as well be stressed that in addition to the pilot BTS, the assisting BTSs be made dynamic and scalable in any modern or future heterogeneous network.

6.3 Recommendations for Future Studies

In this section, a number of suggestions for the future work are provided for the continuation of the work presented in this thesis.

6.3.1 Dynamic BTSs over OPNET simulation environment

OPNET is an alternative network simulation tool that is used in the study of network architectures, technologies and topologies. A method for modelling LTE network over OPNET environment has been demonstrated in [147-152]. Although its (OPNET) use and popularity has been protracted by commercial restrictions and limited availability of library files, most researchers find it daunting delving into research using the OPNET tool. However, it is worth trying it out since it provides results comparable to that of the NS2 used in this study. In fact, the first investigation in this thesis was conducted using OPNET simulator which was discontinued due to the above named constrains including that the tool required a license. More scenarios with sophisticated configuration examples under different density settings are suggested to be considered for the future study of this thesis.

6.3.2 Channel State Information Sharing and Quality of service (QoS) measurement

The quality of service (QoS) measurement of the wireless channels by the mobile users (UEs) to the BTSs is important in characterizing the real-life channel behaviour. It is required that the UE should be always equipped with the capability to measure the quality of the link by either tracking the mobility and monitoring the signal strength or by sharing the channel state information

(CSI) for adopted link. Further research can be focused on methods of self-organizing network (SON) management algorithms to measure the quality of the link and share the state information. On the other hand, there is also a need to investigate the capacity resulting from the on-ground quality of service (QoS) of the comprehensive network, and thus deploy appropriate methods that are necessary to measure the management requirements of spectral efficiency. These interventions are the crucial for assessing the factors affecting the main characteristics that can degrade the entire network performance and expectations.

6.3.3 Exploration of Further bio-inspired optimization tool

With regards to the bio-inspired optimization techniques to move the appropriate BTS and balance the number of mobile users allocated to each BTS, further study about other bio-inspired techniques to build the SON capabilities is required. Other intelligent and dynamic mobility prediction techniques [33, 122] need to be comprehensively investigated for the rest future work.

6.3.4 Optimal Handover Processes

Mobile BTSs proposed in this thesis require handovers between BTS neighbours [116, 153-156]. The future work in this direction is additional study to explore and implement further systems to control and obtain further improvements in handover optimisation processes. Minimising the repeating handovers, identifying the high-speed users and the allocating process are important area of research that can be investigated further to allow the application of the proposed mobile BTSs scale well.

6.3.5 Moving the right BTS

Around any given cell, there are more than one neigbouring BTSs. Each of these BTSs may have some degree of overlapping cells with one another. However, the distance of one BTS to the stressed BTS may be further than another as shown in Fig. 6-1.

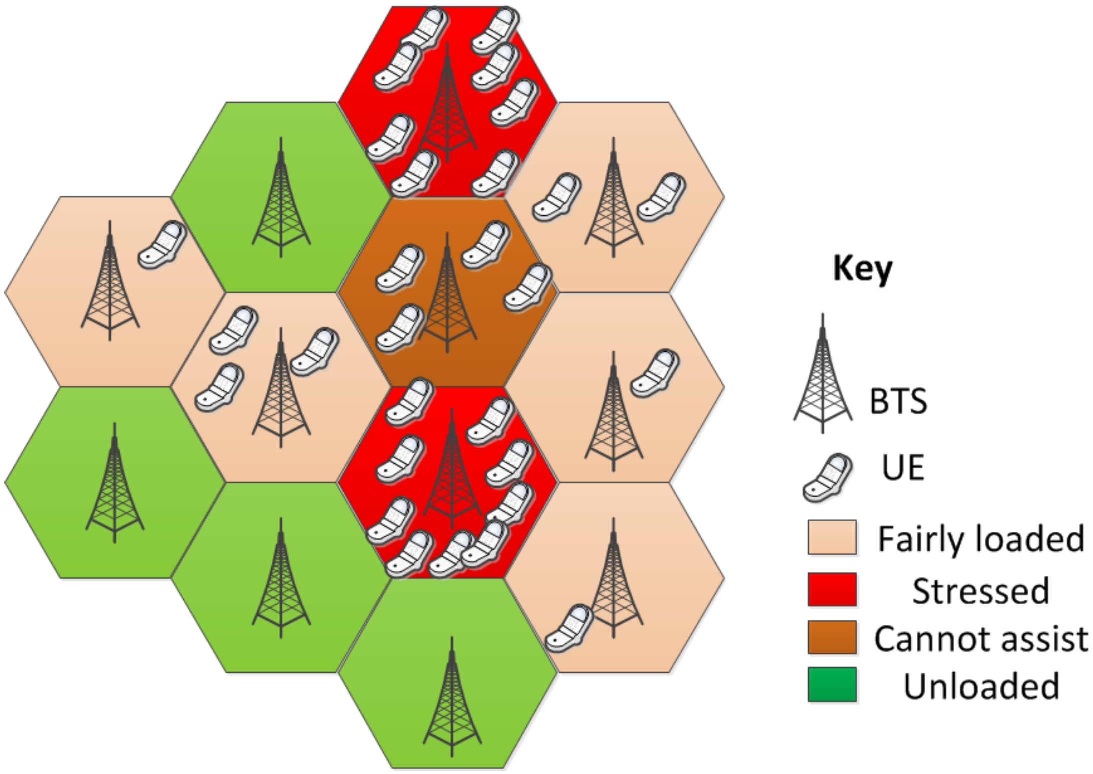

Figure 6.1 Choosing the right BTS to move

Algorithm must be deployed to correctly detect which of the neighbouring BTSs should move (with respect to distance) to assist a stressed network even before searching or applying a chosen optimization algorithm to compute the best (least) path.

6.3.6 Physical Layer Self-configuring antennas

One way of managing a network is by the use of radio frequency (RF) directional antennas; smart antennas. Idle BTSs can be designed to sense, understand and reconfigure its antenna direction towards the cell of large UE density for crowd and event managements; reconfigurable antennas [157-163]. This RF technique will be managed by the signal processing box or combined with the signal processing box.

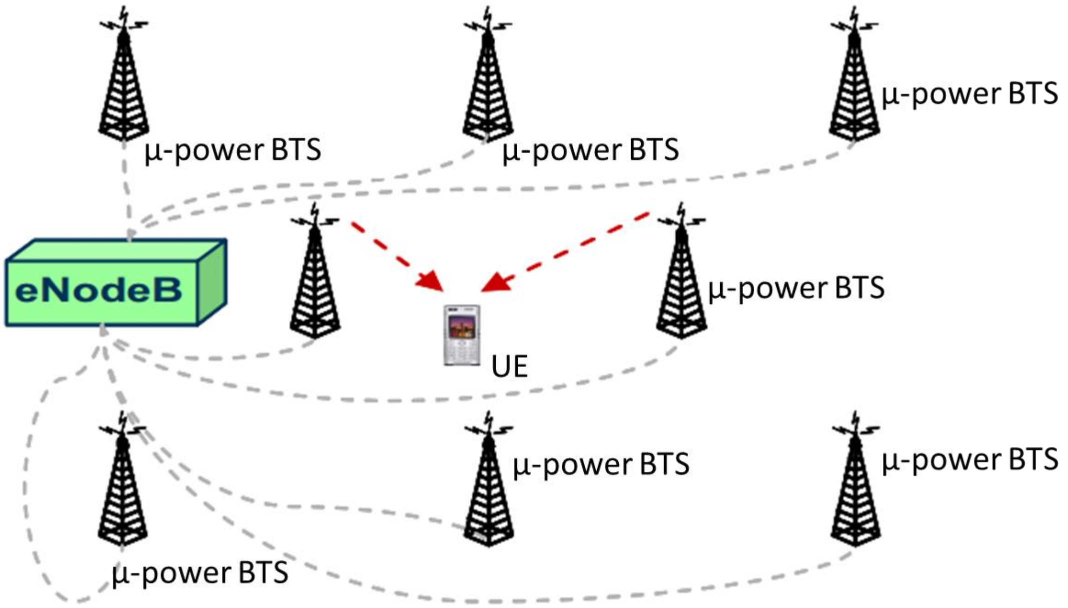

Figure 6.2 Coordinated multipoint transmission for micro-BTSs

6.3.7 Single Signal Processing Unit for many micro-power BTSs

Since the eNodeBs are the major signal processing boxes with several openly seen antennas, then the micro-power BTSs can be redesigned to communicate over a micro-power eNodeB box for cost-efficiency (see Fig 6-2) similar to the one described in Chapter 2 of this work. This follows from multipoint coordination [72, 99, 164-168] and would enable load balancing, higher throughput low percentage of packet loss rate and reduce latency. Define a unit coverage area, then many Femtocells can be deployed as a micro-powered BTSs over a single signal processing box eNodeBs serving many Femtocell-powered antennas nodes.

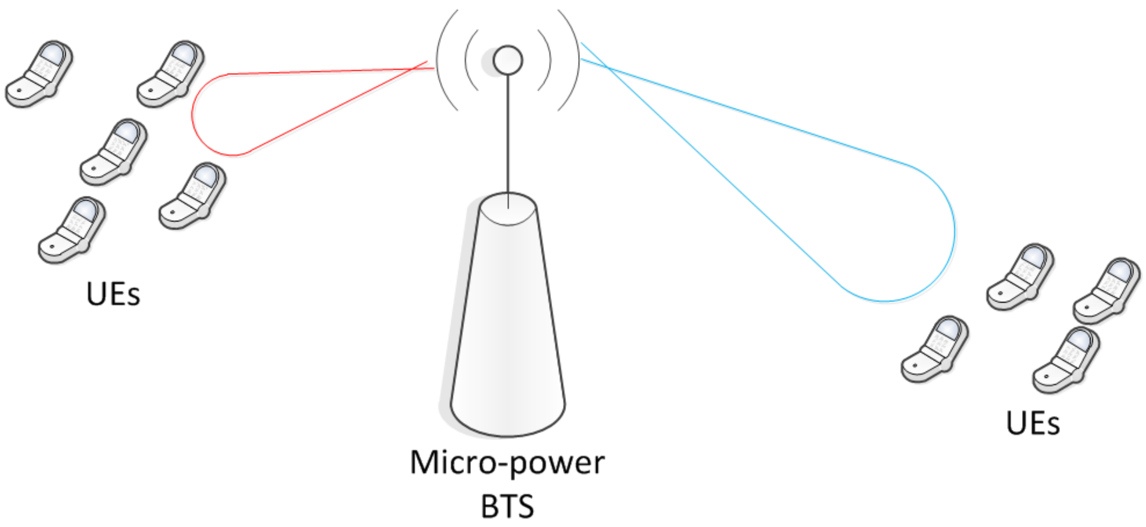

Figure 6.3 Micro-power BTS with beamforming over smart antenna

6.3.8 Beamforming

Instead of moving the entire BTS or considering an underutilized BTS nodes in the neighbourhood of a stressed cell, signal processing techniques can also be adopted to assist (the stressed BTSs) when the BTS cannot move. Suitable signal processing techniques that can help in this aspect include beamforming [169-176]. Beamforming involves electronically steering signal beams to a given direction using smart antennas as shown in Fig. 6-3. The technique in this case will deploy signal processing technique upon sensing neigbhouring cells undergoing overloading. The less-loaded or idle BTSs will steer signal beams coverage to help relieve the stressed neighbouring network.

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